Jonas Gunnarsson

Stockholm University
Sweden

- Professor in Marine Ecology and Ecotoxicology.
- Head of PhD education in Marine Ecotoxicology at DEEP (Department of Ecology, Environment and Plant Sciences).
- Head of the Swedish national benthic monitoring program in the Baltic Sea.

- Post Docs in: Newport, Oregon USA and then at UC Berkeley, USA.
- Leads a research group at SU with 3 PhD students, 1 post-doc, 1 research engineer.
- Principle investigator of several research projects on sediment remediation.

Thin-layer capping with reactive sorbents – a cost effective and environmentally sustainable alternative for remediation of polluted sediments

Examples from previous and ongoing research

Jonas Gunnarsson

INSURE conference , April 10. 2019

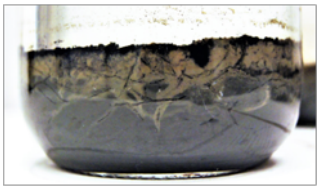
Why remediate sediments ?

- Most contaminants end up in the aquatic environment (limnic or marine systems) and **accumulate** in sediments.
- When contaminant emissions cease, the sediment turns from **a sink to a source** of previously accumulated contaminants.
- A recent report [1] shows that contaminated sediments occur in 19 of Sweden's 21 counties, with many sites being so polluted that they will need remediation to reach EU's Water Framework Directives.

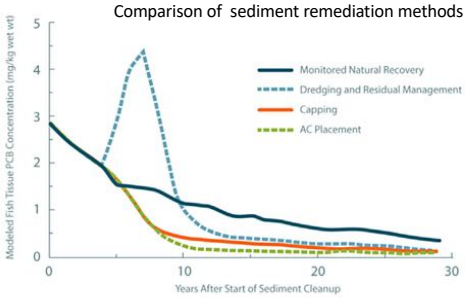
[1] **Jersak** J et al (2016) *In situ* capping of contaminated sediments, SGI 30-1E.

Sediment remediation

- Monitored natural recovery
- Dredging
- Capping
- Capping with active material (e.g. AC)



Comparison of sediment remediation methods



Patmont et al. IEAM 2014

Activated Carbon ?

- Often called "**activated charcoal** used for **detoxification** purposes in humans (e.g. after poisoning or drug overdoses).
- Activated carbon" is a form of carbon from e.g. anthracite or biomass (Coconut, Lignin), activated through pyrolysis (heating under low oxygen) which gives it **micropores** and a **very high surface area**.
- This large surface area makes it very efficient for **sorbing organic contaminants** (e.g. PCBs, PAHs, Dioxins) and also organo-metals (TBT, CH_3-Hg).

Activated carbon

- **CLASSIFIED BY PARTICLE SIZE**
  - *Powdered Activated Carbon* (PAC 15-250 µm) – **more efficient**
  - *Granular Activated Carbon* (GAC 200-5000 µm)

Mechanisms of Thin-Layer capping with active sorbents

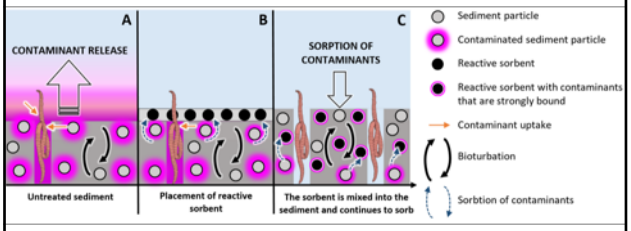
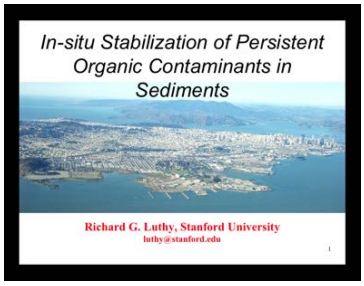
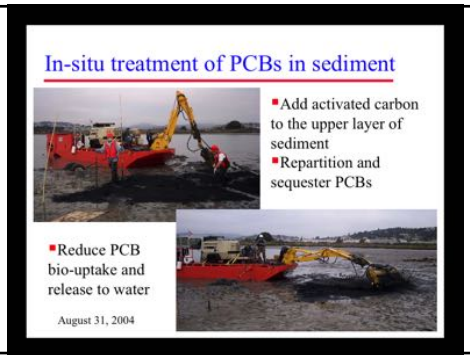
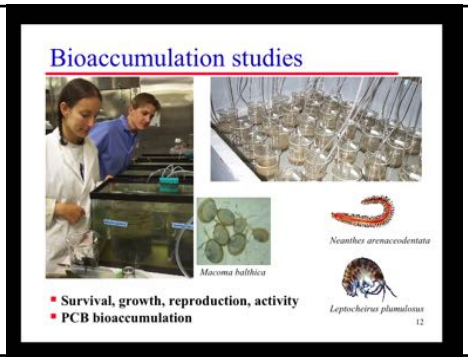


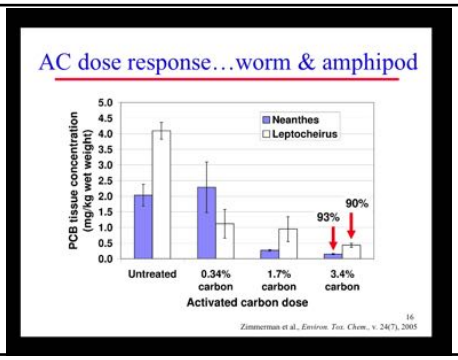
Illustration by Alexandra Poulsen, TUFFO Project CAPTIVE 2018-2021

First large field pilot test with thin-layer capping with AC in 2004









Remediation projects with AC capping in the world

So far no field projects in Sweden

Adapted from Patmont et al. 2014

Increased interest for **remediation *in situ*** with **active sorbents** in Sweden

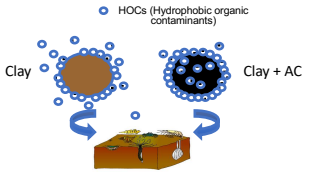
- Swedish entrepreneurs are in "the starting pit", but there is still lack of knowledge and acceptance for leaving contaminants in place.
- Recent SGI reports on capping, see **Jersak** J et al *In situ* capping of contaminated sediments, SGI 30-1E (2016) .
- See also "Åtgärsportalen": AC- baserad tunnskiktsövertäckning http://atgardsportalen.se/metoder/sediment/insitu-sediment/ac-baserad-tunnskiktsovertackning/ac-baserad-fordjupn

J.Gunnarsson: part of five previous and ongoing research projects on capping with AC as PI or co-PI:

- **THINC** (NIVA & SU)
- **OPTICAP** (NGI, NIVA, SU)
- **CARBOCAP** (SU, NIVA, UMU)
- **Baltic Cap** (SU, Baltic Sea Centre)
- **CAPTIVE** (SU, KTH, Elander teknik, Oskarshamn municipality)

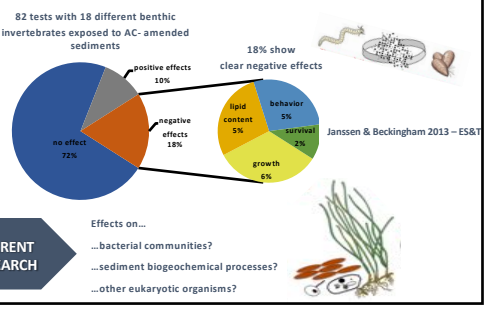
Collaboration with several leading researcher at NIVA, NGI, Umeå Univ, GU and SU, and environmental consultants and agencies.

Thin layer capping with AC



1) Effects of AC on contaminants: ca 70-90 % bioavailability reduction	2) Effects AC on benthic communities: ?

Adverse effects on benthic communities



CURRENT RESEARCH

Effects on…
…bacterial communities?
…sediment biogeochemical processes?
…other eukaryotic organisms?

Biological effects of AC amendment

- Adverse ecotoxicity response to AC in 1/5 of 82 tests.
- Effects: eg decrease in growth & lipid content, change in behavior and increased mortality.
- Depend on the organisms, AC type and granular size.
- Depends also on the type of experiment (i.e. short term lab studies / long term field studies).
- Depends on the type of statistical analyses & chosen endpoint (i.e. organism level / community level).

Take home message 1

- We need to better understand possible adverse biological effects from AC (or other active sorbents).
- We need to carefully weigh positive effects from contaminant reduction against negative side-effects on benthic organisms and possible perturbations of essential benthic ecosystem functions (e.g. mineralization of organic matter and nutrient cycling).

OPTICAP – CARBOCAP ca 3.5 M €

Scientific:

NIVA, Stockholm University, Umeå University, NGI

Funding:

Swedish Research Council FORMAS, HYDRO, Forskningsrådet The Norwegian Research council

Materials & technical:

Jacobi, INNVENTIA, AGDER MARINE, NOAH, SECORA, Hustadmarmor

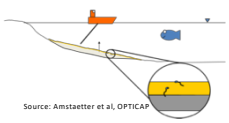
OPTICAP - Grenlandfjord (Norway)

Remediation of the Grenland fjord, Norway

- Dioxin contamination from a magnesium factory (1951-2002)
- Dioxins in sediment: up to 9 ng/g TEQ 300 times maximum tolerable conc.
- Natural attenuation requires several decades

Can we remediate using thin-layer capping (TLC)?

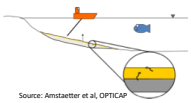
1. Technically feasible at 30 and 95 m depth?
2. Compare efficiency of capping materials
3. Measure sediment-to-water release fluxes of dioxins
4. Investigate secondary effects on benthic macrofauna communities



Source: Amstaetter et al, OPTICAP

Benthic macrofauna (>1mm) important actors in the sediment:

- Modify and re-work sediment by their activities: Bioturbation
  - Increase capping efficiency: Help facilitate contact between contaminants and the added sorbents
  - Increase release of contaminants
- Important for regeneration of nutrients

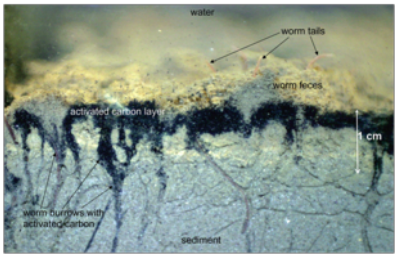


Source: Amstaetter et al, OPTICAP

Photo: NOAA-NCCOS

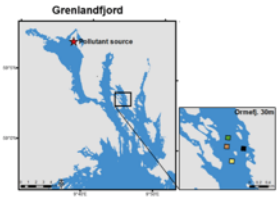
Caroline Raymond

Mixing of AC into sediment by bioturbation



Sun and Ghosh, EST 2007, 4774

Remediation of the Grenland fjord, Norway



Capping treatments:

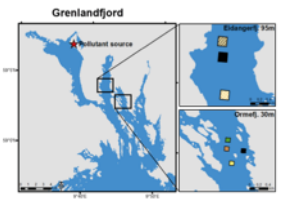
Ormefj. 30m (100x100)

Lime	Cap: 2.1 ± 1.2 cm
Clay	Cap: 3.7 ± 1.1 cm
AC+clay	Cap: 1.1 ± 0.6 cm
Ref	Cap: -

- Lime: Crushed limestone from Norwegian quarry (5 cm)
- Clay: Dredged marine glacial clay (TOC 1.8 %)
- AC: Active carbon from anthracite "BP2", fine 20 µm (Jacobi Carbons)

Caroline Raymond

Remediation of the Grenland fjord, Norway



Capping treatments:

Eidangerfj. 95m (200x200m)

AC+clay	Cap: 1.2 ± 0.3 cm
Ref - 80m	Cap: -
Ref - 95m	Cap: -

Ormefj. 30m (100x100)

Lime	Cap: 2.1 ± 1.2 cm
Clay	Cap: 3.7 ± 1.1 cm
AC+clay	Cap: 1.1 ± 0.6 cm
Ref	Cap: -

- Lime: Crushed limestone from Norwegian quarry (5 cm)
- Clay: Dredged marine glacial clay (TOC 1.8 %)
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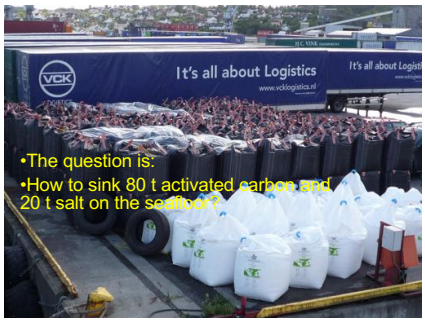
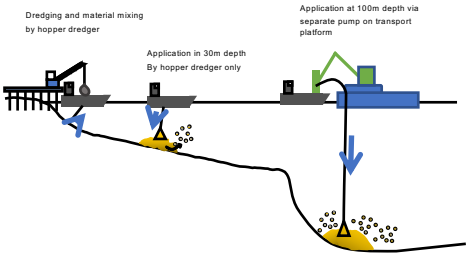
Caroline Raymond



Katja Amstaetter

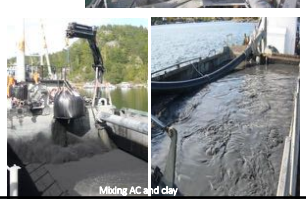
Material application



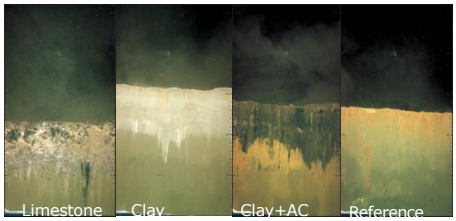
Katja Amstaetter

AC placement technique

Mixing of AC, clay, salt and sea water into a slurry on board

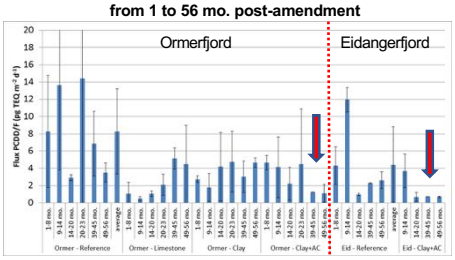


Sediment Profile Imaging



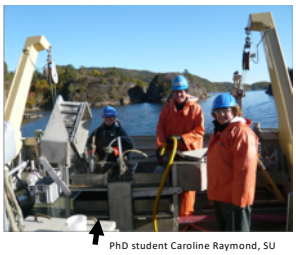
Gerard Cornelissen, Katja Amstaetter, Audun Hauge, Morten Schaanning, Bjørnar Beylich, Jonas S. Gunnarsson, Gijs D. Breedveld, Amy M.P. Oen, and Espen Eek. *Environ. Sci. Technol.*, 2012, 46, 12030-12037.

Dioxin/furan flux from sediment from 1 to 56 mo. post-amendment



AC more effective over time !

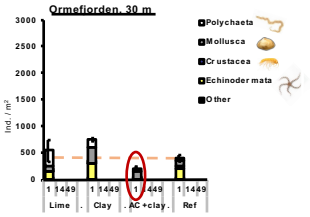
Effects of AC on benthic communities ?



PhD student Caroline Raymond, SU

a) Effects on species abundance

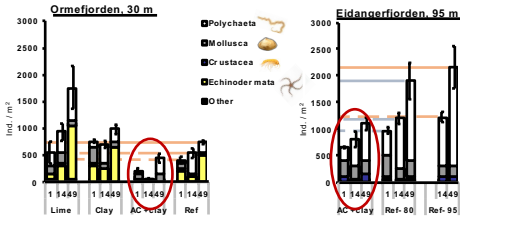
(nr of individuals of each species)



Caroline Raymond et al, in prog.

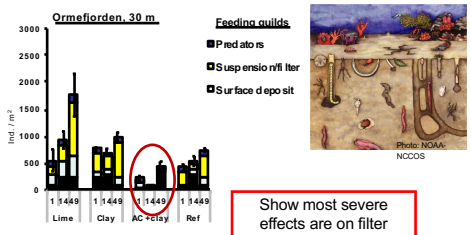
a) Effects on species abundance

(nr of individuals of each species)



Caroline Raymond et al, in prog.

b) Effects based on functional traits

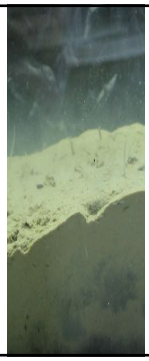


Show most severe effects are on filter feeders & deposit feeders

Effects on benthic organisms

- **Lime**: Initial but short lasting effects.
- **Clay**: Possible positive effects.
- **AC+clay** (30m): Severe effects already after 1 month. After 14 months, further deterioration. Start of recolonization can be seen after 49 months: small opportunist recruits.
- **AC+clay** (95m): Less severe initial effects compared to 30m, but still persistent effects after 49 months.

Caroline Raymond



Take home message 2

Further research is needed on:

- **The cause of the observed ecotoxicity**
- **Possible effects on the ecosystem** (i.e. regeneration of nutrients)
- **Time needed for recovery**
- **Differences in toxicity between different types of AC (PAC & GAC)**

Start of the TUFFO project **CAPTIVE** :

*"Thin-layer **cap**ping with reac**tive** sorbents – a cost-effective and environmentally sustainable alternative to dredging of polluted sediment"* (6 M SEK)

J. Gunnarsson (SU), G. Renman (KTH), P. Elander (Elander Teknik)

In cooperation with:

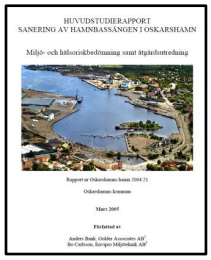
- The Oskarshamn municipality
- The Oskarsham remediation steering group
- Local entrepreneurs
- Local stakeholders

Copper refinery
- Mainly **Cu, Zn, Pb, Co, As, Fe**
- **Dioxins** and furans (PCDD/F)

Battery factory (Saft Nife AB)
- Mainly **Ni, Cd**

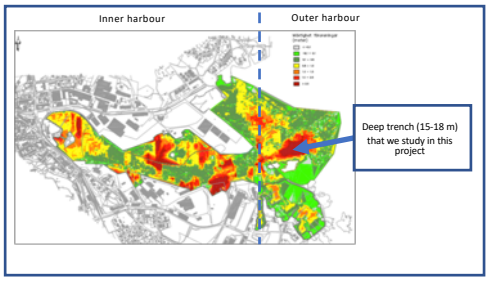
Oskarshamn municipality
- Untreated municipal wastewater until 1970

Small boats harbour
- Mainly **TBT**

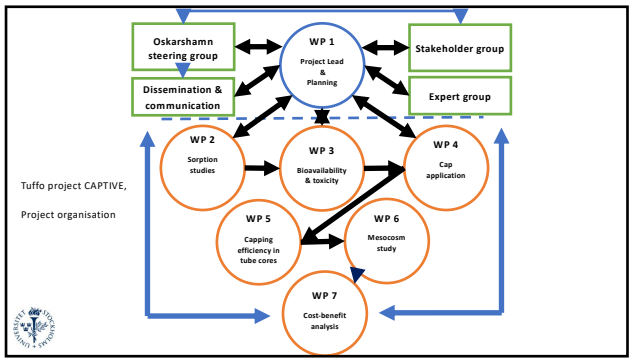


Bank A, Carlsson B (2005) Huvudrapport: Sanering av hamnbassängen i Oskarshamn. Miljö- och hälsoriskbedömning samt åtgärdsutredning.

Current sediment remediation in Oskarshamn

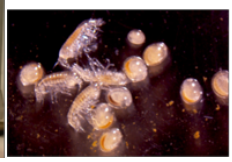


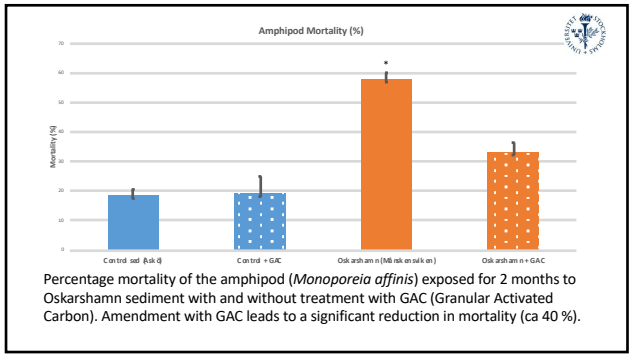
The Oskarshamn harbour. Areas marked in dark red contain the highest amount of contaminated sediments from previous industrial emissions. The inner harbour has now been dredged. In the CAPTIVE project we will evaluate how the outer deep trench could be remediated with thin-layer capping with reactive sorbents.



Early results: Toxicity tests with Oskarshamn sediment capped with AC

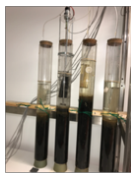
Acute and chronic (Reproduction tests) with Baltic Sea amphipods *Monoporeia affinis* exposed to sediment from Oskarshamn with and without AC.



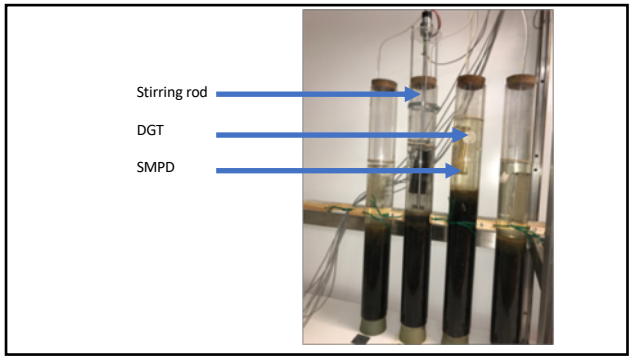


Percentage mortality of the amphipod (*Monoporeia affinis*) exposed for 2 months to Oskarshamn sediment with and without treatment with GAC (Granular Activated Carbon). Amendment with GAC leads to a significant reduction in mortality (ca 40 %).

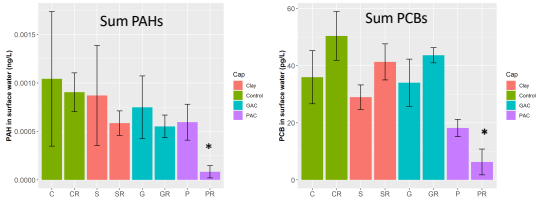
Effects of AC capping and resuspension on contaminant release from Oskarshamn sediment



Intact sediment tube cores collected from Oskarshamn, exposed for >100 d to capping with GAC or PAC , with and without mechanical resuspension. Release of PCBs and PAHs and metals measured in passive samplers (SPMDs and DGTs).



Effects of AC amendment and resuspension on dissolved PAHs and PCBs in overlying water



C: Control (no capping); S: Cap with sediment only: G: Cap GAC; P: Cap with PAC
R: Resuspended (i.e. with mechanical stirrer).

Promising early results:

- First results show that we can decrease the release of dissolved organic contaminants from Oskarshamn sediment after treatment with PAC.
- The effects of PAC are stronger after resuspension, probably due its mixing effect, thus increasing the contact between AC and contaminants.
- Capping with GAC was less efficient than PAC.
- Capping with fine GAC decreased the contaminant toxicity to amphipods and caused no negative side-effects.

Ongoing research

- Sorption tests and Bioassays to **identify suitable AC sorbents** (Test of various particle sizes from PAC to GAC).
- Test of **composite reactive sorbents**, i.e. mixing of AC with calacareous-silicate material (Polonite) that can also retain some metals and Phosphate.
- Test of **application techniques** (sedimentation column).
- Validation using **mesocosm experiments** (boxcores)
- Risk assessment and **cost-benefit analyses**: *i.e. how can we apply TLC with reactive sorbents to the outer Oskarshamn harbour ?*
- **Welcome to to collborate with us** ☺.

Thank you !