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BioBind - Airborne clean-up of oil pollution at sea with biogenic oil binders

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ABSTRACT 299157:

The success of oil spill response operations is mainly dependent on the response time and the weather and sea state conditions. That's where the research project “BioBind” is setting the focus: *To develop an oil spill response system fast to apply and sea state independent*. Within this project a network of eight different partners from universities, research institutes and medium sized companies work from summer 2011 to summer 2014. The paper provides an overview on the oil spill response research project “BioBind” and focuses on a large scale field experiment carried out in summer 2013 with the RV “E.M.Borgese” at the Baltic Sea.

INTRODUCTION:

Two factors mainly influence the effectiveness of an oil spill response operation. The response time is crucial for many oil properties, namely thickness, viscosity, weathering and of course spatial extension (ITOPF 2011, RAUTERBER & SPENGLER et al. 2009). The longer it takes for the responders to start their work, the more complicated and the more work intensive it will be.

Vice versa, if you fail to reach the spill in an appropriate span of time, the response operations will be nothing more than a show for the media to calm the parties concerned (PERRY & PANTON 2011). The second factor is the ability to recover oil from the water surface even under harsh sea state and weather conditions. Looking at the manuals of spill response equipment, the efficiency only decreases slowly with increasing wave height, but the reality shows a different picture. In fact, much spill response equipment suffers a massive loss of efficiency due to high sea state (FINGAS 2011, WORLD CATALOG 2013).

To solve this issue, the research project BioBind was launched. Its aim is to develop a fast oil spill response system with good performance even in high sea state conditions. Within this project a network of seven different partners from German universities, research institutes and medium sized companies cooperated from summer 2011 to summer 2014.

The BioBind system consists of the following components:

- Low-cost airborne analysis and monitoring of the oil spill and oil binders
- biogenic and biodegradable oil binders in combination with oil degrading microorganisms
- airborne deployment of oil binders
- seaborne recovery of oil binders with a netboom
- onshore recovery of oil binders with vacuum technology
- sea state forecast and drift modeling (Baltic Sea & North Sea)

To integrate all individual components into existing spill response conceptions and contingency plans, an oil spill management system has been developed. An environmental impact assessment of binders and residues of the microbiological oil degradation have been carried out by eco-toxicological analyses.

OIL SPILL RESPONSE SYSTEM BIOBIND

In the following section the components of the research project BioBind and the associated response system are briefly described. Figure 1 shows a schematic outline of the system and the way the individual components interact. (For more detailed information on single components, please contact the authors of this manuscript.)

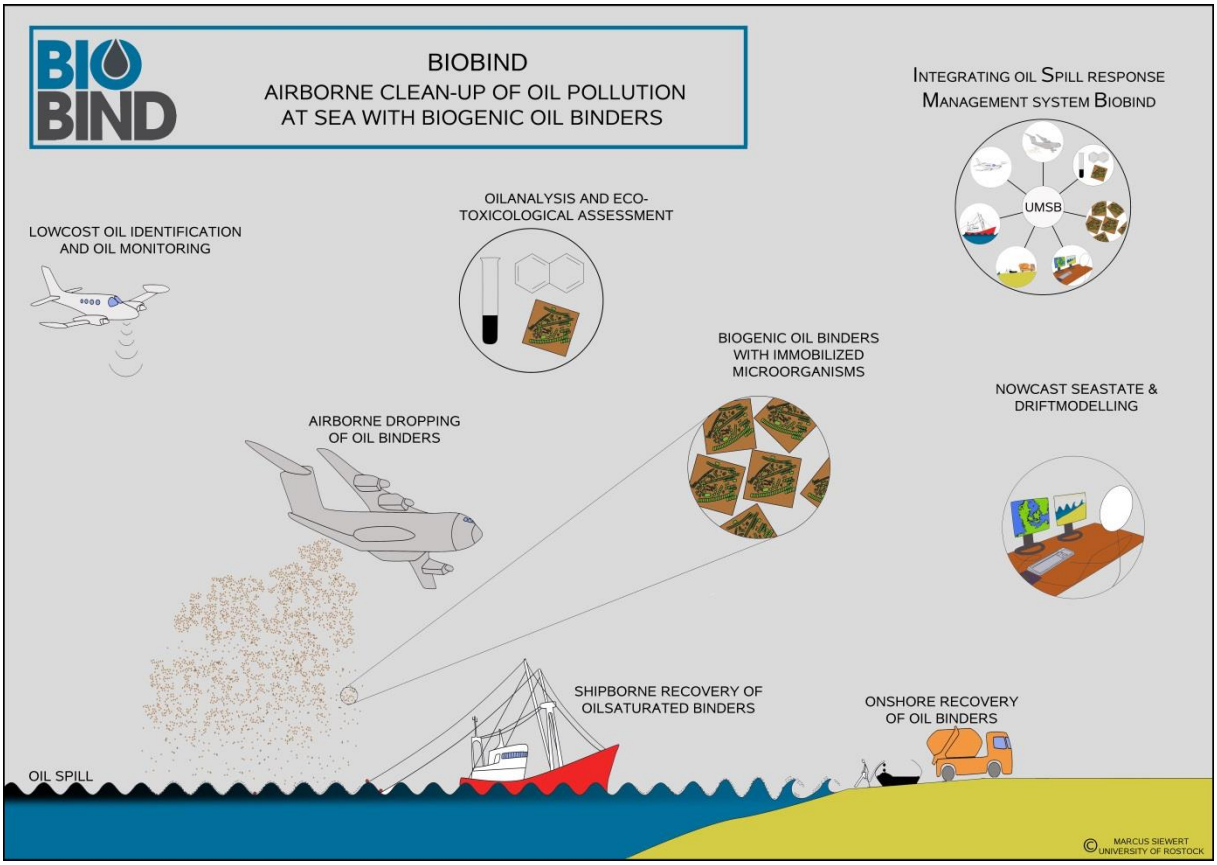

Figure 1: Schematic outline on the oil spill response research project BioBind and its individual components

Low-cost oil identification and oil monitoring

Information about the on-going drift of the oil and the binders is essential. This will be realised with a low cost spectrometer mounted to a small aircraft (e.g. Cessna 172) that analyses the reflected light of the water surface using a database of different oil concentrations at sea which has been created during the project, including many different sea state and weather conditions.

Due to the fixed lens mounted in the hull of the Cessna, the altitude influences the spatial extension of the analysis; the higher the Cessna is flying, the bigger the analyzed area per measurement. Thereby an aerial observation of the spill and its countermeasures is guaranteed, and the drift of the binders can be observed. Additionally, lab and field data on

the drifting behaviour of the binders were implemented in a numerical model to predict the drift. An online tool to assess the data, including charts for handheld GPS units, is available.

Biogenic oil binders with immobilized microorganisms

The oil binders are based on biogenic and biodegradable material (wood fibers). Thereby a small environmental impact and low production costs were achieved. Following different requirements from the project partners, an evolution process of two years lead to the final binder geometry of 5 cm x 5 cm x 0.4 cm. Extensive laboratory tests showed a stable oil recovery rate of ≈ 80 % with an oil-binding capacity about 600 kg/m³. Additional mesocosm trials confirmed these numbers. The floatability of saturated and non-saturated binders is at least 8 days, even under harsh sea state conditions.

To support the clean-up effect of the BioBind system, oil degrading microorganisms (MO) are applied to the binders. A variety (192) of different MOs were isolated from Baltic Sea water samples covering a wide range of salinity (2 psu – 16 psu) and mean annual temperatures. The oil degradation due to different MO was examined under fixed conditions (temperature, oil type, nutrient level etc.). Afterwards the most promising microorganisms were combined to a consortium for further investigation. In the case of an emergency the freeze-dried MOs will be reliquefied. The suspension can be sprayed on the binders while loading or during aerial deployment. Application on the water surface is also possible.

Airborne dropping of oil binders

To guarantee a fast spill response, the binders will be deployed by an airplane. For the research project this airplane was a modified single-engine agricultural plane of the type "Dromedar M-18" with a loading capacity of 1.5 m³. For practical applications this seems to be quite small, but to investigate the dropping behaviour and the fluid spray system at a reasonable price, the vessel size is appropriate. A highly accurate deployment is guaranteed by the spectral analyses, the resulting maps and experienced pilots.

Seaborne recovery

A combination of fishery nets and conventional oil containment booms led to a new kind of netboom. This netboom is designed to perform at high tow-velocities and high wave heights. Thereby the spreading of oil can be avoided even under harsh circumstances. The net will be carried in a standard container on a vessel that can handle this. It will be put out like any other normal boom and afterwards towed by two ships in a V-configuration. The netboom consists of three parts, two sides to route the binders and one detachable cod end to collect them. When the cod end is filled, it will be released from the first part and lifted to another ship (e.g. seagoing barge) and a new cod end will be attached. It is not necessary to remove the netboom to exchange the cod end.

Onshore recovery of Oil Binders

If a seaborne recovery of the binders is not possible, for example because of low water depths, an onshore recovery is also possible. Existing vacuum-technologies were combined with beach-going trailers to create a small recovery unit for independent coastal operation that can be pulled by any beach going vessel (e.g. quads, small tractors or off-road vehicles). The binders will be collected in replaceable big-bags, and the big-bags can be carried to temporary storage facilities at the coast, separate from the recovery process itself. Oiled binders will be brought to waste burning facilities for final thermal utilization.

Oil analysis and ecotoxicological assessment

Oil, especially crude oil, is a mixture of various single components which behave and react differently when it comes to evaporation, adsorption and biological degradation. To know these components, the used crude oil REB1 (Russian export blend 1) was fingerprinted. The binders (oil-saturated and non-saturated) and the biological degradation products were analysed, focusing on PAH, alkanes and emerging residues. No additional toxic components were detected. The official certification of the binders in Germany will probably be realised within the project time.

Integrating oil spill response management system

All individual components will be integrated in the VPS-system (German contingency planning system) including a statistical sea state analyses for the German Baltic Sea and North Sea and numerical models to forecast the sea state and the drifting path of the oil spill and the binders. To ensure the integration of the system BioBind into existing structures and contingency plans, the system was developed in close cooperation with the German Central Command for Maritime Emergencies (Havariekommando).

RESEARCH CRUISE 2013:

After numerous laboratory tests and several investigations in the field, all components of the system were brought together for an extensive field test during a research cruise in July 2013 in the Baltic Sea (see figure 2). The research cruise was carried out with the research vessel (r.v.) “Elisabeth Mann Borgese” (EMB) from the Baltic Sea Research Institute Warnemünde (IOW). It was built in 1987 as a navy vessel and converted to a multipurpose research vessel in 2011. The vessel and the most important technical features can be found in figure 1.

Length o.a.	*56.5 m*	*Beam*	*10.8 m*	*Draught*	*3.6 m*
Service Speed	*11 kts*	*Crew*	*11 people*	*Scientific staff*	*13 people*

Figure 2: The research vessel "Elisabeth Mann Borgese" from the Baltic Sea Research Institute Warnemünde (IOW) and some main technical features (source: IOW).

For the research cruise, an area in the "Mecklenburg Bight" in the German part of the Western Baltic Sea was chosen. Figure 3 shows the investigation area, six nautical miles off the German coast.

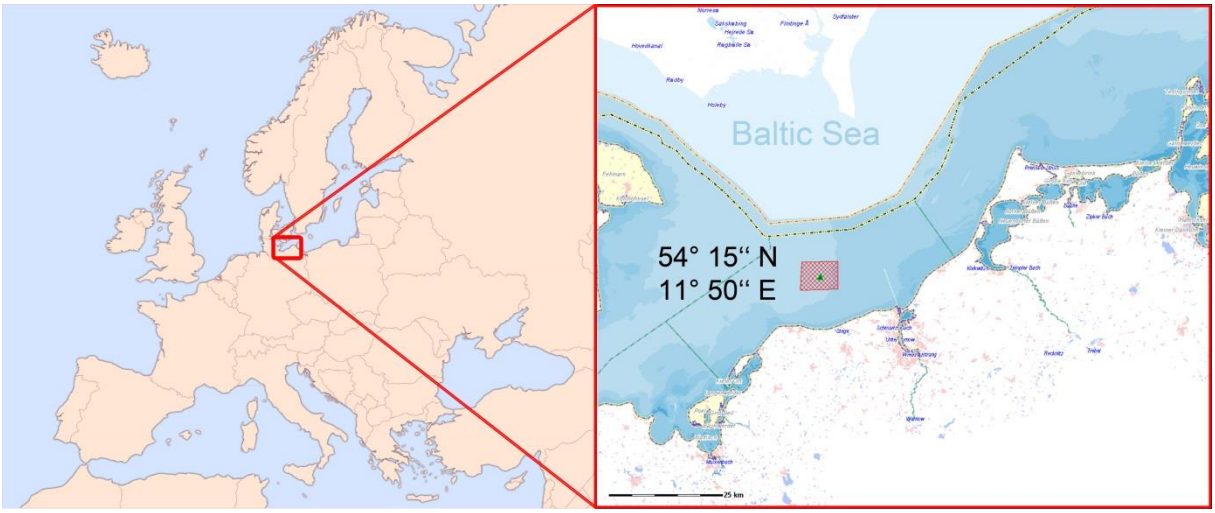

Figure 3: Western Europe (left) and a close up of the research area in the Western Baltic Sea (right)

During the research cruise in July 2013, two main topics were investigated:

- biological oil degradation ("mesocosm experiments")
- deployment and recovery of binders ("field experiments")

The meteorological and hydrodynamic conditions during this research cruise are summarized in Table 1.

Table 1: Meteorological and hydrodynamic conditions during the research cruise in July 2013

Date	*03.07.2013*	*04.07.2013*
Wind velocity	*4.3 m/s*	*4.4 m/s*
Wind direction	*130 °*	*280 °*
Significant wave height	*0.3 m*	*0.3 m*
Surface current velocity	*0.15 m/s*	*0.2 m/s*
Surface current direction	*260 °*	*90 °*
Air temperature	*20 °C*	*20 °C*
Water temperature	*16 °C*	*16 °C*

Mesocosm experiments

To analyze the impact of MO consortia on the oil degradation, eight mesocosm tanks were erected at the weather deck of the r.v. (see figure 4, left). Each tank was filled with 290 l of sea water, taken at the first day of the cruise, equipped with different combinations of crude oil, MO and oil binders. An overview on all combinations can be found in table 2.

Table 2: Combination of components for mesocosm experiments at different tanks

Tank No	1	2	3	4	5	6	7	8
Sea water	x	x	x	x	x	x	x	x
Oil		x	x			x	x	x
MO			x					x
Binders				x	x	x	x	x

Using two laboratories on board of the ship, a big number of samples were taken and further processed. For each tank the following parameters were either investigated on board of the ship, or probes were taken for later analyses after the cruise (see figure 4, right).

- oil adsorption of the binders
- oxygen and nutrient levels (phosphate & ammonia)
- conditioning of samples to determine alkanes and PAH in the water column
- preparations for gravimetric oil determination
- temperature, salinity and pH-value
- application of MOs to the Binders and MO growth
- fluorescence analysis of oil degradation

The interval between the measurements increased from a few minutes at the beginning of the experiment to several hours at the end of the experiment. To get as much data from this experimental setup as possible, the tanks were not emptied but taken from the ship after the cruise and carried to an outdoor location at the University of Rostock. The analyses mentioned above were carried on for several weeks. A detailed description of the mesocosm experiments and their results can be found in HÄHNEL et al. 2014 and UNBEHAUN et al. 2014.

Figure 4 Mesocosm tanks at the weather deck of the RV "E Mann Borgese" (left), Janne Hähnel analyzing oxygen levels in one of the laboratories on board of the ship.

Field experiments

The field experiments consisted of three parts:

- aerial deployment
- remote sensing
- seaborne recovery.

The aerial deployment was carried out by the Dromedar M18, carrying 1.5 m³ of binders in the hopper. It was emptied within three flyovers at an altitude of ~ 25 m (see figure 5) and thereby created a patch of 20 m x 100 m covering ~ 15 % of the water surface with binders. After the hopper was emptied, the plane flew back to the nearby airport (distance ~ 50 km) and was loaded again. Meanwhile, the drift of the binders was monitored and the pilot was informed about the updated coordinates for the second deployment; this procedure was carried out twice. The approaching of the plane, the aerial deployment, and achieved accuracy were very satisfying; only little improvements can be made in the field of communication and reloading the plane.

Figure 5: Aerial deployment of binders during the research cruise in summer 2013. The small workboat "Klaashahn" is waiting next to the deployment area. (Source: Dr. Safonova)

Remote sensing was carried out by a Cessna 172 equipped with a lens, connected to a low-cost spectrometer and a laptop. While flying over the area of interest, the spectrometer measured the reflected light of the water surface and compared the spectral data to the BioBind-database. Every measured point was GPS referenced, and thereby the spreading of the binders could be plotted to a chart. The Cessna 172 attended the whole experiment and flew over the area several times to measure the movement of the binders.

Additionally, aerial photos of the seaborne recovery were taken from the Cessna. With an accuracy of more than 70 %, the system could determine whether the Cessna was flying over natural sea water or over an area with applied binders. Furthermore it was recognized that the software used was not able to perform with sufficient speed. Due to this fact the analysis was changed from a cross-validation-principle to a neuronal-networking-system. The analysis is much quicker now and generates more satisfying results.

After several hours of binder drifting, the seaborne-recovery-process was initiated. The netboom was stored on the upper deck of the EMB on a 20’ flat container and launched astern at slow speed (v < 1 kts) by pulling it off the container. During the first try, it took 45 minutes to release the boom; in the third try it only took 6 minutes. After the netboom was completely launched, the main rope from one side of the system was handed over to the local fishing cutter “Prerow” (length 12 m, width 4 m, draught 2.5 m) which assisted the field experiments. Going at a velocity between 1.0 kts and 1.5 kts both vessels separated to a distance about 150 m to 200 m and started to approach the drifting binders. To reduce the relative velocity of the water particles and the netboom, it was tugged in the direction of wave propagation. Figure 6 shows an aerial photo of the RV EMB and the cutter “Prerow” towing the netboom.

Figure 6: RV „Elisabeth Mann Borgese (left) and cutter „Prerow“ towing the netboom at the Baltic Sea in July 2013. (Source: FSB-Airservice)

To verify numerical simulations of the drag forces, a dynamometer was included in the main rope at the larboard side of the system; simultaneously the behavior of the binders interacting with the netboom was recorded with a video camera from the workboat “Klaashahn” that was sailing directly next to the netboom. According to simulations, the drag forces increased during fast turns, at the same time local flow velocities at the skirt increased. In comparison to standard booms, the more permeable netboom could withstand higher local velocities without suffering a loss of binders due to drainage failure (figure 7, top), even though planing gets important at velocities above 1.5 kts. After several maneuvers the second main rope was returned to the EMB and the netboom was pulled to the deck by on-deck-

winches and cranes (figure 7, bottom) and the cod end was emptied. The recovery rate of dropped binder varied from 50 % on the first day to 80 % on the second day.

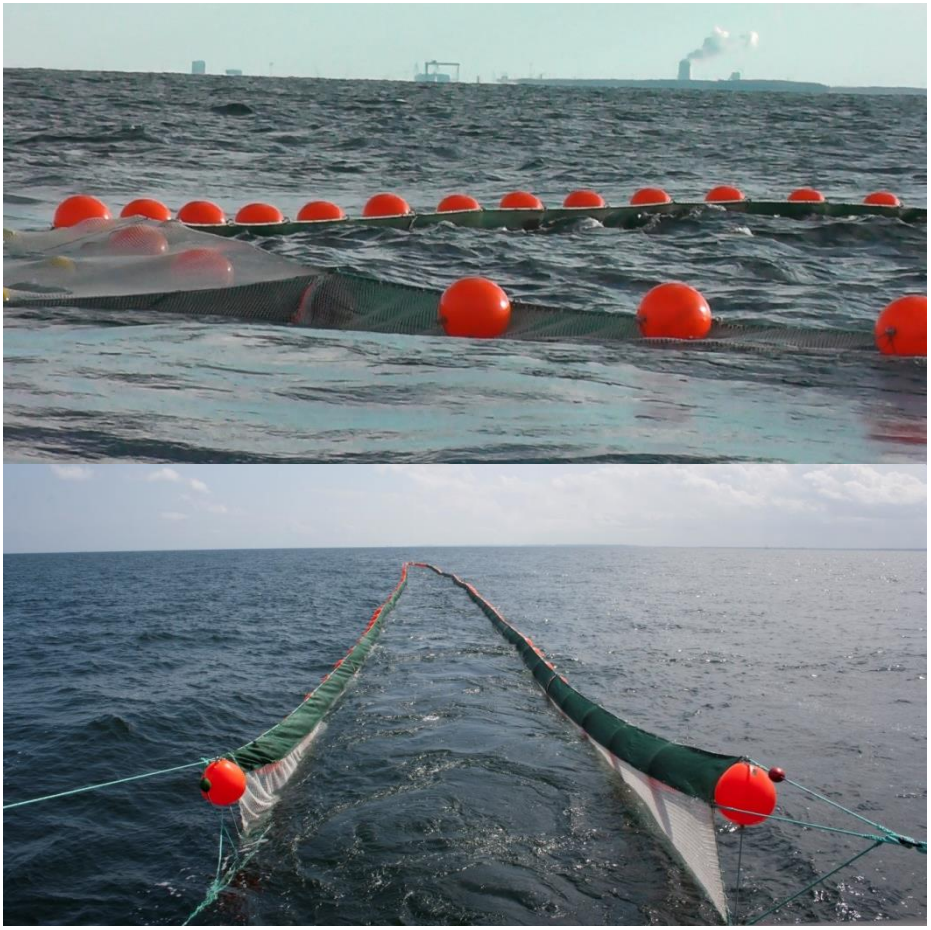

Figure 7: End of the tugged netboom with open codend to take up binders (top), "closed" netboom lifted out of the water astern of the EMB after returning the mainline of the second wing back to the EMB (bottom).

CONCLUSION:

The airborne oil spill response system BioBind was tested in the field during an extensive research cruise in summer 2013 in the Western Baltic Sea. The general functionality was proven in several test runs with different boundary conditions. All individual components performed satisfyingly, but combing them to an enclosed spill response system still requires some improvement especially in:

- communication between planes (monitoring & deployment) and tug boats
- loading of binders
- positioning of tug boats to optimize the net geometry
- planing behavior of the netboom

The spill response management system will guarantee a smoothly integration of all individual components into one functioning system. Two more cruises will be carried out in the research project to test the modified equipment and to ensure a real improvement process.

ACKNOWLEDGEMENTS:

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