PRACTICAL, ENVIRONMENTAL AND STRATEGICAL EXPERIENCES FROM TWO SPILLS IN 2011 OF CRUDE OIL AND CTO ALONG THE SWEDISH COASTLINE

Authors: Katrin Holmström (katrin.holmstrom@sweco.se), Charlotte Gyllenhammar (charlotte.gyllenhammar@sweco.se), Ingrid Håstad (Ingrid.hastad@sweco.se), Oscar Fogelberg (oscar.fogelberg@sweco.se), Niklas Törneman (niklas.torneman@sweco.se). The Oil Spill Advisory Service at Sweco. Address: Sweco Environment, Box 34044, SE-100 26 Stockholm, Sweden

ABSTRACT 300174:

In 2011, the Swedish coastline suffered two major oil spills. About 500 tonnes of bunker oil occurred in the marine waters of the west coast, in the waters of Skagerrak, on to the coastline of the Tjörn archipelago. The second spill, about 800 tonnes of CTO (crude tall oil) occurred from a land based tank farm on the east coast, into the Söderhamn archipelago in the brackish Baltic Sea. Both impacted areas exhibit a high ecological value and are frequently used for outdoor recreation. In Söderhamn, many private properties were impacted as opposed to Tjörn, where the archipelago is common land.

The affected coastal area at Tjörn comprise rocky beaches with varying degrees of cracks, bays, rock pools, etc. At Tjörn, remediation has been made through manual labor combined with experimental methods facilitating faster manual removal; such as mineral oil degreasers, coconut oil, rapeseed oil, and heating up the oil by means of a torch. Manual labor through scraping with various tools (e.g. spatulas, knives, cloths) has however been the main method. The remediation was difficult and dangerous due to the slippery rocks and tough weather conditions.

The shores of the Söderhamn Bay consist mainly of rocky beaches, large rocks as well as very small pebble stones. Since the oil also got into jetties, the entire clean-up process has been difficult and time consuming, also due to the cold weather conditions in the north. Remediation of the shores and stone coffins, inside the jetties, has been made through manual labor.

The impacts to the bird population were minimal in both incidents since most birds had migrated for the winter. At Tjörn, some short-term impact could be noted on indicator species like the Blue mussel. The incident happened during late fall, when the biological activity in marine organisms is low; hence low impact on the marine organism's active reproductive periods.

In Söderhamn, fatty acids, recin acids and sterols have been sampled in sediments, fish muscle, and mussels. Limited impact could be noted, however, established test methods are missing for CTO. Degradation time of the CTO was longer than expected.

Extensive and hardcore cleanup usually causes more damage to nature; removal of important microorganisms, increased soil erosion and diminishes the possibilities for the

vegetation recovery. It is cucial to start the communication process with public and property owners as early as possible to set expectations on how clean is clean.

INTRODUCTION:

In 2011, the Swedish coastline suffered two major oil spills of different character. The first spill of about 500 tonnes of bunker oil occurred in the marine waters of the west coast, in the waters of Skagerrak, on to the coastline of Tjörn. The second spill, about 800 tonnes of CTO (crude tall oil) occurred from a land based tank farm on the east coast, into the Söderhamn archipelago in the brackish Baltic Sea (Figure 1).

Figure 1: A map of Sweden and the areas (Tjörn and Söderhamn) being discussed in the paper

The Tjörn Incident

On 10 September 2011, a merchant ship collided with a fishing boat off the North coast of Jutland, off the Danish coast. As a result, the oil tank on the trade vessel was damaged. The coastline of Denmark was not hit by the oil, but on October 15, the Coast Guard's aviation unit discovered an oil belt at Tjörn (Sweden) which extended towards the archipelago. During the evening, locals reported on heavy oil in various locations along the coast. At the time, there was a strong westerly wind and oil was thrown several meters up on the rocks (Figure 2).

Figure 2: Remediated sites at Skaboholmen, Tjörn

The Tjörn archipelago consists of about 50 islands and islets with the character of bare rocks. Many islands are bird sanctuaries and within the municipality there are also inlets to Stigfjorden Bay which is a Natural conservation area. The affected coastal area comprise rocky beaches with varying degrees of cracks, bays, rock pools, etc. The rough surface of these rocks accumulates the oil to a higher extent compared to smoother rocks. In the area there are also seals. Rocky beaches exhibit a high ecological value, and are frequently used for outdoor recreation.

Figure 3: Oil contaminated shorelines, Tjörn

The Söderhamn Incident

On December 20 2011, crude tall oil (CTO) from land based tank farm close to the sea was released due to a tank rupture. The CTO was quickly moving on the surface of the sea along the coastline in Söderhamn's Bay, impacting a large coastal area (Figure 4). The mainland as well as many small islands was hit by the CTO. Since there are many private property owners in the archipelago, many were affected due to contaminated beaches and jetties (Figure 8). The shores consist of rocky beaches, large rocks and very small pebble stones, making the clean-up very difficult and time consuming. It is a brackish water archipelago with high ecological and recreational value. However, in the sediments, there are remains from previous activities such as discharges of waste water and dumping of waste from the pulp and paper industry.

Figure 4: CTO impacted shoreline

The paper will present and discuss practical, environmental and strategical experiences from the two different oil spills from the emergency phase as well as from the clean-up phase.

METHODS:

The Oil Spill Advisory Service at Sweco is a group of experts engaged in marine/fresh water environment issues with theoretical and technical skills to assess the environmental impact of oil and chemical incidents in marine and limnic environments. The service is financed by the Swedish Agency for Marine and Water Management, and provides assistance to rescue service, county administrative boards and municipal Environmental and Health Agencies in connection with oil and chemical spills. The service provides advice and assistance at impacted sites, and may also assist local authorities in planning of follow-up programmes of the short- and long-term environmental effects subsequent to an oil release.

The Service has practical experience in remedial work from previous oil incidents in Sweden (e.g. clean-up of the oil spills after the Fu Shan Hai-accident), and also on an international arena (e.g. EU observer at the Prestige accident, Spain, and Baltic Carrier accident, Denmark).

The Service at Sweco has followed the development at Söderhamn and Tjörn from the very beginning, and assisted with advice and support when requested. The Service has executed extensive inventory of the two impacted areas and also assisted in the development of follow-up programmes. The Service has also had extensive contacts with local, regional, and national authorities as well as private property owners on impacted sites.

BACKGROUND:

Mineral Oil Composition and Properties

The oil that reached the Tjörn coastline was a heavy fuel oil, of the type IF380, which is used as a marine fuel, see Table 1 for physicochemical data. The product is labelled R50/R53 and is toxic to aquatic organisms, which may cause long-term adverse effects in the aquatic environment. PNEC values for aquatic organisms range from 1-100 mg/L according to the safety data sheet.

In contact with water, the mineral oil may form a film on the surface of the water sheen. The sheen may physically harm aquatic organisms and reduce oxygen metabolism. The oil product, depending on conditions such as water temperature, either float, sink or form an emulsion when spilled out into the water.

CTO Composition and Properties

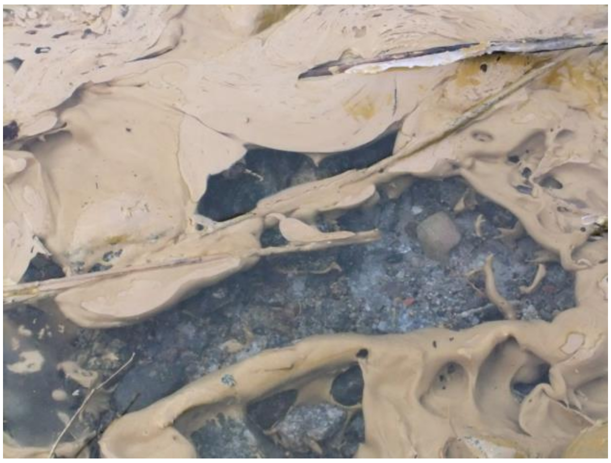

Figure 5: CTO in water

CTO is a byproduct formed when manufacturing kraft pulp (sulphate). Like mineral oil, CTO is a complex mixture of components; see Table 1 for physicochemical data. PNEC values for aquatic organisms range from 0,00011-0,2 mg/L for the different present components. Derived no effect limit (DNEL) for skin sensitization is set to 16.8 ug/cm^2 for high exposure workers, and 8.2 ug/cm^2 for low exposure such as the public.

CTO contains sitosteroler and neoarbital which may be considered vPvB, and hartsaldehydes which may be considered PBT. Sitosteroles are also potential endocrine disruptors. Phytoestogens from wood, like β-sitosterol and dehydroabietic acid are weakly estrogenic in some, but not all, cell tests (Mellanen 1996). Concern is due to previously reported effects in fish after exposure to pulp and paper mill effluents containing phytoestrogens.

The CTO does not seem to have the same tendency as the mineral oil to produce sheen when in contact with water (Figure 5).

Table 1: The table describes the different properties of the two oil types discussed in the paper

Physico chemical properties	**Unit**	**Crude Tall Oil**	**Crude Mineral Oil, IF380**
Reach registration number		01-211949486323-000	
EG-nr		931-433-1	
Classification		Xi; R43 Skin irritable 1; H317	R20; R38; R45; R48/21; R50/53; R63; R65
Physico chemical properties			
Apperarance		Dark brown to amber liquid	Black liquid
Odor		Sulfuric	Strong Petroleum Odor, Asphalt like
Melting point	°C (°K)	-3.15 (217)	
Boiling point	°C (°K)	346.85 (620)	180
Flash point	°C	212-185	> 60
Vapour pressure	Pa (25 °C)	22,7	
Density	Kg/m^3	959-969	955.5
Solubility in water	g/l (20°C, pH 4.6-5.5)	$7.35x10^2$	insoluble
Log Kow		4.9-7.7 (pH 2.0) 3.2-6.8 (pH 5-6)	<3
Self ignition	°C	276	>150 °C
Viscosity	cP (22 C	203-825	max 180 mm2/s (50 °C)

Environmental Effects

Our Swedish sea areas include the brackish Baltic Sea and the marine North Sea and are particularly sensitive to pollution. The climate is cold and the Baltic Sea is quite shallow and the water turnover is slow. The Baltic Sea is one of the largest brackish inland seas by area and occupies a basin formed by the glacial erosion process during the last few ice ages. The Baltic Sea is a Mediterranean sea located between Central and Northern Europe, from 53°N to 66°N latitude and from 10°E to 30°E longitude, confined by the Swedish part of the Scandinavian Peninsula, the mainland of Europe, and the Danish Islands. It drains into the sea of Kattegat through Øresund, the Great Belt and the Little Belt.

The Baltic Sea's salinity is much lower compared to ocean water (which averages 35‰), due to the abundant freshwater runoff from the surrounding land, combined with the shallow depth of the sea itself. The open surface waters of the central basin have a salinity of 6 to 8 ‰. At the semi-closed bays with major freshwater inflows, such as the head of the Finnish Gulf with Neva mouth and head of Bothnian Gulf with closed mouths of the rivers of Lule, Tornio and Kemi, the salinity is considerably lower.

The Baltic Sea has a difference in salinity due to the slow mixing with the upper waters, resulting in a salinity gradient from top to bottom; most of the salt water remains below 40 to 70 m deep. Below 40 to 70 m, the salinity increases to 10-15 ‰ in the open Baltic Sea, and greater near the Danish Straits.

The general sensitivity of the brackish Baltic Sea and the marine North Sea has been much debated. Some regard the Baltic Sea as more sensitive while others consider the North Sea as more vulnerable to pollution (Whitehouse, B. G.1984, Dorgelo, J 1973, Kinne, 0. 1964). The main claim for the Baltic being more sensitive is that organisms living near to the limit of their tolerance range (e.g. salinity) would be more susceptible to any additional stress. The contrary view is that since estuarine species have a wider tolerance to salinity, temperature and oxygen levels, this tolerance will pre-adapt the organisms to tolerate stress induced by a pollution incident. The field evidence for the latter argument would be that those species surviving in polluted marine areas are often the same as those found in estuaries.

The effects of oil on various physiological functions of marine invertebrates are assumed to be related to concentration. At low concentrations, hydrocarbons affect oxygen consumption. Higher oil concentrations have been shown to increase respiration. Studies show that exposure to oil in combination with changes in salinity exerts more pronounced effects in the Baltic population than oil pollution in the North Sea. Organisms living in brackish water are in general more sensitive to pollution than their marine relatives. The higher sensitivity to pollutants in the Baltic Sea populations may be due to a number of factors such as changes in the characteristics of toxic substances (metals) with salinity, the higher relative ionic concentration of a given amount of poisonous substance in the low-saline Baltic Sea than in the North Sea, and direct interactions of toxicants with membrane permeability and osmoregulatory, which are already under strain at low salinities (Tedengren, M. et al 1998, Percy, J. A. 1977).

RESULTS/DISCUSSION:

Degradation

According to the safety data sheet, IF380 is not readily degradable, but does not contain persistent compounds. However, if left in large amounts on the impacted beaches, the oil will form into asphalt like structures, which prevents further degradation. Therefore, it is necessary to remediate the oil to a thin enough layer, in order to enhancing the natural degradation.

According to the safety data sheet, CTO should be readily biologically degradable. Initially, it was assumed that a majority of the CTO oil spill would degrade quickly. However, two years after the spill, oil not exposed to weathering by sun and wind (i.e. inside stone coffins and jetties, under rocks) remains nearly intact (Figure 6). An extensive long-term remediation action has been necessary in Söderhamn, contrary to initial expectations. However, CTO does not seem to produce asphalt-like structures, when left in thicker assemblies.

Figure 6: Opening of CTO impacted jetty, one year after the spill, the oil looks rather fresh

Remediation Methods

In both incidents cases, the Coast Guard initially tried to remove as much oil as possible from the water through pumps and oil skimmers. Also, remediation staff were using buckets, shovels etc. to remove oil from shallow areas. The oil that ended up on the beaches and shores were removed:

- In Söderhamn through manual labor; scraping with various tools (e.g. spatulas, knives, cloths)
- At Tjörn through manual labor combined with experimental methods facilitating faster manual removal; such as mineral oil degreasers, coconut oil, rapeseed oil, and heating up the oil by means of a torch.

Figure 7: Remediation of oil at Tjörn

Monitoring Program Tjörn

The Blue Mussel (*Mytilus Edulis*) is a common indicator organism when monitoring the environmental impact after oil spills. It remains stationary, and is commonly found along the entire Swedish coastline. The blue mussel is a well-studied organism in terms of uptake, accumulation and elimination of hydrocarbons. The mussel pumps and filters large amounts of sea water (approx. 3 l/h), and has a poorly developed detoxification system for many environmental contaminants, and accumulate dissolved as well as particle-bound pollutants within its tissues.

Blue mussels were collected from seven sites along the Tjörn coastline, in a gradient from impacted to non-impacted areas. Samples of sediment and fish (Eelpout, *Zoarces Viviparus*) were also collected.

High concentrations of polycyclic aromatic hydrocarbons (PAH) is an indicator of oil pollution in the marine environment. PAH is fat soluble, often stable and in some cases prone to bioaccumulation. Some PAH's are also classified as a carcinogenic. The analyses in the monitoring follow-up program showed elevated levels of PAH in blue mussels and surface sediment at 2 of 7 selected sites in the autumn of 2011. At these two sites, there was a large amount of oil accumulated and the oil was present in the water for a long time prior to removal. However, only three samples exceeded the current limit values for PAH (SFT 2007, EU 2013); Benzo (a) pyrene and benzo (b) fluoranthene in the mussel and pyrene and benzo (a) pyrene in the sediment; all highly toxic to aquatic organisms. Follow-up sampling of mussels and sediments were made in April 2012, indicating declining levels of previously elevated substances in mussels (below current guidelines). In sediment samples from one site, however, levels of pyrene and benzo (a) pyrene were still elevated. Some levels were even higher than in the first sampling campaign conducted in 2011 (Dimming, 2013).

The impacts to the bird population were minimal because most birds had migrated for the winter. Only approximately 20 birds were found dead in the area and a total of 40 oiled birds were reported and recovered at Tjörn (Dimming 2012).

The incident occurred during a time of year when the biological activity in marine organisms is low. The same spill in the spring or summer in this area would have most likely led to greater impacts in the marine environment, impacting the marine organism's active reproductive periods.

Monitoring program Söderhamn

In Söderhamn, blue mussel (*M. Edulis)*, fish (*Perca Fluviatilis*), and sediment were sampled at a number of sites. The selection of components to be analyzed was less straight forward compared to mineral oil, since little research has been done on environmental effects of CTO. Eventually, fatty acids, recin acids and sterols were chosen for sampling. A cell-based test for estrogenic potency was selected for evaluation of extracts from mussels, due to the potential endocrine impact of sitosterols. Anti-estrogenic actions were also evaluated with this test. The test measured the ability of compounds to bind to the estrogen receptor and activate a cell response.

Fatty acids, recin acids and sterols were measured in mussels from 20 sampling points. Fatty acids are natural in mussels, but the total concentration of fatty acids was elevated in one sample point close to the spill. It has been shown recins do accumulate in mussels, but recin acids were not detected. Highest concentrations of sterols found in mussels was in deeper water close to the origin of the spill. Concentration of sterols in mussels from shallow water close to the origin of the spill was similar to reference mussels.

Fatty acids, recin acids and sterols were measured in sediment from 12 sampling points. Chemical traces of the spill in sediment were found only at one site, which had elevated levels of recin acids. However, experience from field sampling in the Nordic Countries show that a site hit by a direct spill would be indicated by at least three times higher concentration of recin acids; why concentration cannot be considered extreme. Total concentration of fatty acids in sediments proved to be a poor indicator for acute spills; highest concentration of fatty acids was found in one reference point.

Fatty acids, recin acids and sterols were measured in 4 samples of fish muscle from 3 locations. Muscle was the preferred matrix over bile since focus was on human consumption of fish. Fatty acids are natural substances in fish, why their presence may not be due to the spill. Recin acids were not detected in the fish samples, while trace amount of sterols were found but not in any toxic relevant concentrations.

Regarding the tests on endocrine disruption, β-sitosterol and dehydroabietic acid were not shown to exhibit estrogenic effect in two different tested cell tests; however, extract from mussels did exhibit estrogenic effects - possibly an internal/natural estrogenic effect (Törneman 2013).

The Söderhamn area is historically influenced by pulp and paper industry including bleaching activities. The activities yield byproducts including both phytoestrogens and probably also chlorinated compounds as a result of bleaching, which can be a confounding factor regarding endocrine effects as well as elevated levels of certain substances.

The Benthic fauna community was also studied as a part of the Administrative County Boards consistent environmental monitoring program. The program showed similar status as previous years, and no effects on community density and diversity could be related to the CTO spill.

The impacts to the bird population were also in Söderhamn insignificant since most birds had migrated for the winter. Only around 15-20 birds has been found dead in the area.

Property owners and public opinion

The question of "how clean is clean" should be discussed in early stages of combatting oil spills, preferably before the clean-up has begun, in order to create a common understanding among all stakeholders as to what is considered "clean". This approach is to avoid the expectations of the local community that oil will disappear completely and that the environment will be returned to pre-spill condition. It is essential that stakeholders have a common understanding and acceptance that not all oil will be removed and that this will be discussed and communicated to the public, politicians, government agencies, and other pertinent stakeholders.

Nature's own ability to degrade oil has often been underestimated, in spite the fact that there is an efficient process of natural degradation. In recent years, from an ecological point of view, it has been found that it is often better to accept a certain amount of oil be left on the beach for natural degradation than to overexert the remedial works (Lindgren, C. 2005). This process requires more time why a conflict may occur between the public who believe that moving outdoors requires more harsh cleanup to get rid of the oil in a quicker manner.

Observations from the case studies indicate that extensive decontamination does not usually increase the recovery rate on the oil contaminated beaches. Therefore, we do not recommend cleaning up to level as “clinically clean”. An overly harsh cleanup causes in general more damage to nature, removal of important microorganisms, increased soil erosion and increases the difficulty for the vegetation to recover clean-up efforts. If the oil on the beaches is degraded into less harmful components, the hydrocarbon may in fact act as food source for beach living organisms.

Figure 8: CTO impacted jetty (left), and remaining oil on sea bed (right)

CONCLUSIONS:

- The time of year of both incidents lowered the impacts on birds and marine organisms.
- The immediate and long-term effects after an oil spill are difficult to monitor in the natural environment.
- Degradation time of CTO was longer than predicted, which resulted in the need for extensive remediation, contrary to initial expectations.
- Early communication with the public, political decision makers, property owners and other relevant stakeholders to set expectations on how and when clean is clean is crucial in order to avoid overexerting clean-up.
- New regulation may be required for CTO tanks. Since CTO is not considered as flammable, there is no need for containment, except if the tank is located close to a drinking water supply.

REFERENCES:

Capuzzo, J. M., Lancaster, B. A. (1981). Physiological effects of South Louisiana crude oil on larvae of the American lobster (Homarus americanus). In: Vernberg, F J.. Calabrese, A., Thurberg, F. P., Vernberg, W B. (eds.) Biological monitoring of marine pollutants. Academic Press, New York, p. 405423

Dimming, A. 2013. Oljepåslaget på Tjörn 2011. Uppföljande undersökning av oljeförorening i marin miljö 2011-2012. The County Administrative Board of Västra Götaland. Report 2012:64 (in Swedish)

Dorgelo, J (1973). Comparative ecophysiology of Gammarids (Crustacea: Amphipoda) from marine, brackish and freshwater habitats exposed to the influence of salinity-temperature combnations. 111. Oxygen uptake. Netherl. J. Sea Res. 7 253-266

Edwards, R. R. C. (1978). Effects of water-soluble oil fractions on metabolism growth and carbon budget of the shrimp Crangon crangon. Mar Biol. 46- 259-265

European Union. 2013. Directive 2013/39/EU of the European parliament and of the council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy. Official Journal of the European Union, 24.8.2013.

Kinne, 0. (1964). The effects of temperature and salinity on marine and brackish water animals. 11. Salinity and temperature. Salinity combinations. Oceanogr mar. Biol. A. Rev. 2: 281-339

Lindblad, C., Kautsky, N., Kautsky, U. (1986). An in situ method for bioassay studies of functional response of littoral communities to pollutants. Ophelia 4 (Suppl.): 159-165

Lindgren, C. and J. Fejes 2005. “How clean is clean” - A proposed method for determining endpoints and evaluating results of oil spill clean up operations. Paper. International Oil Spill Conference, Miami, Florida

Linden. 0. 1976. Effects of oil on the amphipod Gammarus oceanicus. Environ. Pollut. 10: 239-250

Mellanen et al. 1996. Wood-Derived Estrogens: Studies in Vitro with Breast Cancer Cell Lines and in Vivo in Trout. TOXICOLOGY AND APPLIED PHARMACOLOGY 136, 381–388.

Percy, J. A. (1977). Effects of dispersed crude oil upon the respiratory metabolism of an arctic marine amphipod, Onisirnus (Bolkrsimus) affinis. In: Wolfe, D. A. (ed.) Fate and effects of petroleum hydrocarbons in marine organisms and ecosystems. Pergamon Press, New York, p. 192-200

SFT Statens forurensningstilsyn. 2007. Veileder för klassifisering av miljøgifter i vann og sediment. Revidering av klassifisering av metaller og organiske miljogifter i vann og sedimenter TA-2229/2007.

Tedengren, M., Arnér, M. and N. Kautsky, 1998. Ecophysiology and stress response of marine and brackish water Gammarus species (Crustacea, Amphipoda) to changes in salinity and exposure to cadmium and diesel-oil. Marine Ecology. Vol 47: 107-116.

Törneman et. al .2013. Follow-up program Söderhamn. *In manus*

Whitehouse, B. G. (1984). The effects of temperature and salinity on the aqueous solubility of polynuclear aromatic hydrocarbons. Mar. Chem. 14: 319-332