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1.0 ABSTRACT

Hazardous Noxious Substances (HNS) can present a range of marine spill scenarios due to the many types transported in bulk and their varying fate and effects. In a review of HNS incidents Purnell, 2009, concluded that some increase in the number of HNS incidents may be expected. To better provide advice regarding monitoring and impact assessment during marine incidents and how this may be influenced by local conditions there is an urgent need to improve knowledge of the marine hazards/risks associated with some of the most hazardous chemicals transported. However the concern regarding HNS can often be greater due to the fact that they have a range of different physical and chemical behaviours. This range of potential behaviour also creates further uncertainty regarding what natural resources will be threatened when a spill occurs and so should be prioritised for action. Traffic volumes are particularly high in coastal regions of the North Atlantic, but developing countries account for the largest share of seaborne trade so potential exists for shipping incidents and chemical spills in other regions of the world. A series of toxicity and modelling studies was conducted to better understand the added influence during a spill of factors such as salinity and temperature (e.g. hypersaline high temperature conditions in the Arabian Gulf) upon the impact of high hazard/transport HNS. The affect of these factors upon HNS toxicity and of the resulting spill profile and therefore the likely overall environmental impact were evaluated and the results are discussed for several relevant HNS.

2.0 INTRODUCTION

Over the past four decades, world seaborne shipments grew at an annual average rate of 3 per cent, rising from 2.6 billion tons in 1970 to 8.4 billion tons in 2010 (United Nations Conference, 2013)

At 802 million tonnes, liquid bulk accounted for 46% of the total short sea shipping of goods to and from the EU-27 in 2011, followed by dry bulk at 348 million tonnes (20%). Roll on - roll off (Ro-Ro) units accounted for 234 million tonnes of goods in 2011 and containers a total of 231 million tonnes (both cargo types accounted for about 13 % of the total tonnages). The UK has the second largest share of the liquid bulk for 2011 with 138 million tonnes transported.

Developing countries account for the largest share of seaborne trade. The Arabian Gulf for example experiences the heaviest traffic of oil tankers compared to any other waterway, increasing the risks of oil or chemical spills. A potential oil or hazardous chemical spill in the Gulf region could lead to catastrophic consequences for desalinations plants (Namid et al., 2008) and other uses of the Gulf.

Hazardous and Noxious Substance (HNS) are defined as any substance other than oil, which if introduced into the marine environment is likely to create hazards to human health, to harm living resources and other marine life as well as to damage amenities and/or to interfere with other legitimate uses of the sea (IMO, 2000).

It is recognised that HNS transported at sea provide an extremely broad range of marine spill scenarios due to the 1000's of types transported in bulk through national and international waters and their widely varying fate and effects. As such, there is a need to improve our knowledge of the marine hazards/risks associated with the highest priority chemicals so as to provide better advice during marine incidents. In particular, there is a requirement to better understand how either regional or temporal changes in environmental conditions such as salinity and temperature can influence toxicity of certain compounds.

3.0 SELECTION OF HNS FOR MODELLING AND TOXICITY STUDIES

A European funded project monitoring the volume of chemicals transported in bulk or packaged form (HASREP, 2005) tackled the issue of transport volumes identifying the top 100 chemicals transported between major European ports. The 100 most transported chemicals from HASREP were subsequently used by Neuparth et al. (2011) as the basis for a more detailed consideration of the occurrence probability of HNS spills in European Atlantic waters and the severity of exposure associated with their physico-chemical properties and toxicity to marine organisms (Figure 1). Additionally Neuparth et al. (2011) conducted a screening analysis of the toxicological information available as well as the GESAMP assessments of persistence and bioaccumulation potential to enable a further prioritization of HNS that resulted in the identification of a subset of 24 HNS.

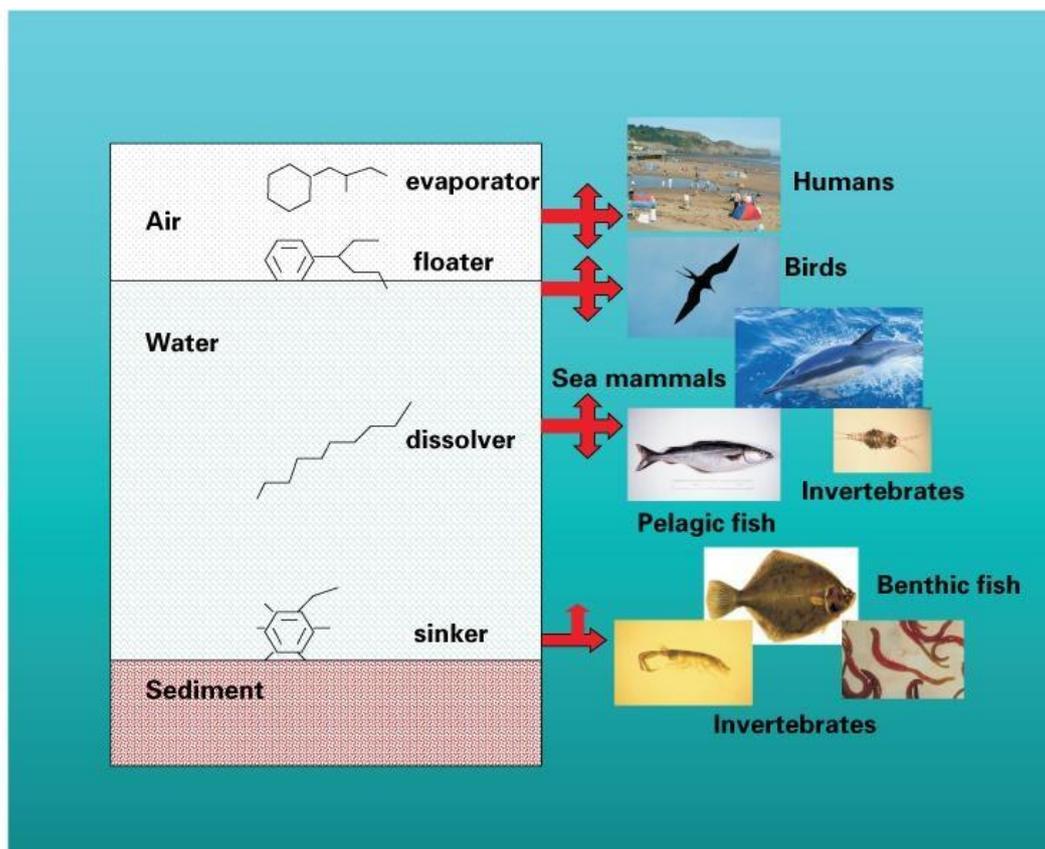


Figure 1 Behaviour categories for HNS and most likely groups at risk following a spill

For each of the 24 HNS identified there are associated behaviour categories (Bonn Agreement, 1994) that indicate if spilled at sea their tendency to evaporate, form a slick, and dissolve or to sink and



remain on the seabed. This behaviour determines to a large extent the potential to detrimentally affect marine wildlife and benthic habitats and which groups of organisms are likely to be most impacted. Of the 24 HNS identified half are likely to float and to partially dissolve or evaporate.

The list produced by Neuparth et al. (2011) highlighted the gaps in ecotoxicological data for many priority HNS with some chemicals having little data, or only data available for freshwater fauna and very little data available for algal taxa.

The European project ARCOPOLplus, which started in 2012, had the primary objective to improve maritime safety and Atlantic Regions' Coastal Pollution Response through technology transfer, training and innovation. One activity under this programme aimed to develop toxicological risk assessment of HNS by testing in the laboratory the hazard for marine life of selected HNS. The chemicals for further ecotoxicological work were chosen taking into consideration physicochemical properties and transport volume.

To consider the modifying influence of factors such as temperature and salinity upon the toxicity of selected priority HNS, based on the toxicity test data developed for a range of marine species within the Arcopolplus project, aniline was selected as the first HNS chemical to consider for assessment under modifying conditions for a study conducted on behalf of the International Tanker Owners Pollution Federation (ITOPF) and The Department of Environment Food and Rural Affairs (Defra).

Data for the top 100 European ports over years 2002 - 2004 showed aniline to be ranked 24/100 in terms of tonnage bulk handled (over 300,000 tonnes) for this period (HASREP, 2005). The ARCOPOLplus project also accounted for shipping incidents including the substances prioritised and aniline (in modest quantities) was involved in a spill in 1987 from the cargo vessel the Cason.

Aniline is an important intermediate in a wide range of industry sectors and imports for the Netherlands in 2012 for aniline and derivatives were just under 300,000 tonne (UN commodities trade). For countries such as China, exports of aniline were around 55,000 tonne (2012), India around 30,000 tonne. These figures have reduced considerably in the last five years with reduction in activity in various trade sectors but would be expected to increase with improving economic status of the different countries involved in trade and manufacture. The information available suggests that there is a reasonable level of trade in this chemical and other hazard property factors also support its consideration here.

Zinc sulphate is frequently used as a reference chemical in marine toxicity studies to confirm that an individual batch of test organisms are responding within an expected range to a given test compound i.e. that the test batch is in good 'health' before testing. Zinc compounds and zinc sulphate are also transported in bulk quantities e.g. typical bulk packaging for zinc sulphate includes up to 1000 kg sacs and zinc ores and concentrates are transported in bulk quantities (over 2 million tonnes imported into the EU 28 in 2013, UN commodities accessed 20/11/2014). Zinc concentrate is a Group A product which is listed in the International Maritime Solid Bulk Cargoes (IMSBC) Code under the schedule for "Mineral Concentrates". Several maritime incidents have also involved zinc concentrates/ores: In February 2000 there was a large explosion on the "Thor Emilie" which carried zinc skimmings described as oxide zinc ore/bulk concentrates. The explosion resulted from the formation of hydrogen gas from wet bulk materials. Also During the early hours of 29 June 2003, the coastal cargo vessel, Jambo, grounded and subsequently sank off the West coast of Scotland near Ullapool. The vessel was carrying a cargo of 3,300 tonnes of zinc concentrate at the time of grounding. Although there was potential for zinc release from both these incidents no pollution was reported to have occurred in either case. The following studies therefore also include the testing of zinc sulphate under modifying conditions both as a reference and as a relevant HNS.

4.0 DEVELOPMENT OF MODEL EXPOSURE PROFILES

4.1 Background

Different types of model are available for simulating chemical spills at sea to study their potential fate and effects during actual incidents, to help plan response in the case of future incidents and to identify gaps in emergency response capability. To consider the influence of various modifying factors upon chemical toxicity a preliminary modelling exercise was conducted around a selected spill scenario to inform the exposure concentrations and durations for subsequent laboratory toxicity tests. A modelling exercise was also carried out to assess the potential effect of temperature and salinity on predicted environmental concentrations of aniline. Modelling enabled prediction of chemical fate and also identified representative spill profiles that could be simulated in laboratory studies.

4.2 Method

To simulate chemical plumes the hydrodynamic transport model CHEMMAP (McCay et al., 2006) was used. This is a commercial chemical spill model developed by RPS/ASA and applied by Cefas and other organisations to inform the provision of advice in response to chemical spill incidents. The model implements a Lagrangian particle tracking technique that represents the chemical spill by an ensemble of particles (or spilletts) that follow the water flow and that are subject to wind movement, vertical and horizontal mixing and can move between chemical phases (e.g. from liquid or solid to dissolved forms). Concentrations are derived from the particle ensemble by an approximate procedure that associates a Gaussian spatial concentration distribution with each particle with the variance controlled by user supplied diffusivity rates. Chemical concentrations are calculated at each model time step by transferring the spillet concentration distribution onto a user specified 3D grid.

An existing near shore spill scenario (depth ~10m) with moderate ($\sim 0.3 \text{ ms}^{-1}$) tidal currents was used as a basis for the numerical experiment. This example is typical of areas on the South coast of England and as it is nearshore and at modest depth represents a potential worst case scenario as any chemical spill in this type of scenario is likely to track back and forth at a given location over a more prolonged period than would a spill further offshore. To provide as clear a biological response in laboratory studies as possible a relatively extreme (but plausible) marine spill scenario was modelled by assuming the release of 1000 tonnes of aniline over a 4 hour period. The release was assumed to be at the surface. Such a release might occur if a bulk chemical transporter suffered a large scale explosion or were involved in a collision with another vessel causing a large scale and rapid loss of a chemical into seawater. A similar scenario was modelled in McKay et al., (2006).

Example output from the scenario is shown in Figure 2. Input datasets for modelling were the Cefas tidal and bathymetric database containing tidal constituents at roughly a 2km resolution. No wind forcing was included. Vertical mixing was set to a relatively high value representing a well-mixed water column.

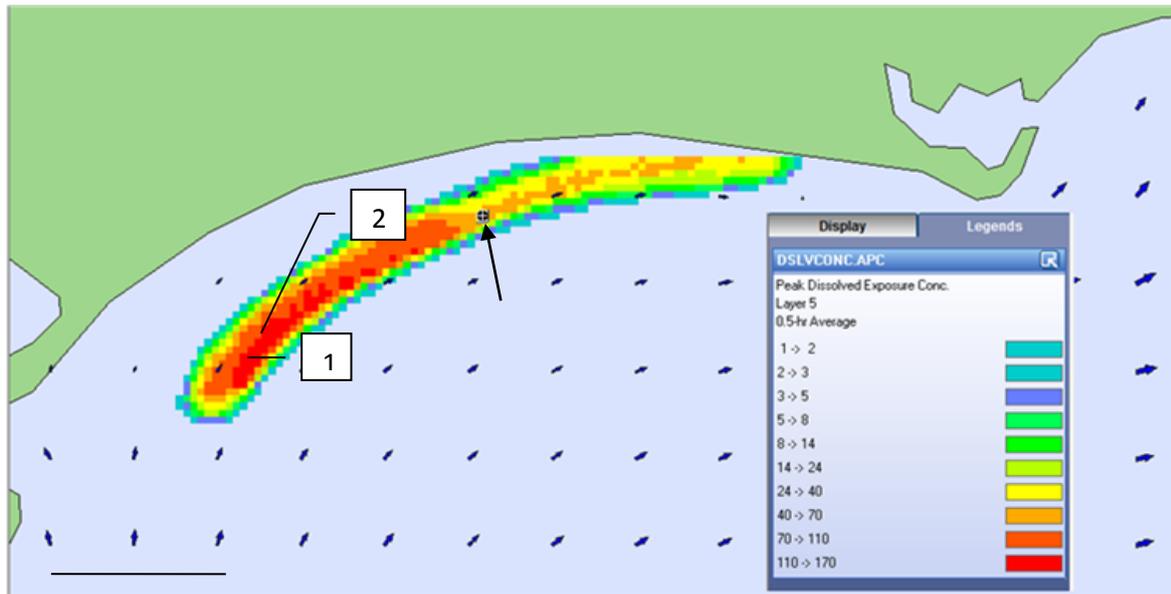


Figure 2 Spill scenario output. The arrow indicates the point of initial release and the line at lower right indicates scale of approximately 2 kilometres. Location 1 and 2 are points at which later profiles are located. The plot shows the maximum concentration (based on a ½ hour average) that each region of the seabed is exposed to during the whole of the simulated spill. For example for the region in yellow the concentration when it is averaged over half an hour was predicted to lie between 24-40 mg/l at some point during the spill and this was the maximum that occurred in these regions (the scale shows the average concentration in mg/l denoted by each colour).

Results from the model simulations are shown for 1) the amount of aniline that remains dissolved in the water column, has decayed, or has evaporated and also as 2) time series of seabed concentration at fixed locations representing possible exposure profiles for benthic organisms. Three simulations were carried out with water temperature set to 10°C, 20°C and 30°C respectively, all other parameters being identical. A fourth simulation was carried out with water temperature set at 30°C and salinity increased from a typical UK coastal value of 32 ppt to 40 ppt. The upper end of these simulations would correspond to conditions in parts of the Arabian Gulf for example.

4.3 Results

The predicted variation over the spill duration in the amount of aniline that remains dissolved in the water column, has degraded, or has evaporated is displayed in Figure 3 for the two extremes of the temperature considered. At 30°C around 33% of the aniline was predicted to evaporate after 25 hours compared to a predicted 18% evaporated for the 10°C simulation. Degradation also increased, from almost zero at 10°C to approximately 10% of the total discharge after 25 hours at 30°C. This lead to about 30% less dissolved aniline in the water column after 25 hours at 30°C compared to the 10°C simulation.

The effect of temperature on aniline concentration at the seabed at two chosen locations is shown in Figure 4 and Figure 5. At location 1 an increase in water temperature from 10°C to 30°C had quite a significant effect, especially for longer durations. The difference between the 10°C and 20°C concentration profiles however was quite small. At location 2 there was also a significant temperature effect (Figure 5) with an approximately 25% decrease in the localised peak concentrations predicted for the 30°C profile compared to that at 10°C.

The effect of increasing salinity from 32 to 40 ppt for the 30°C profile was a small increase in the evaporated proportion (presumably because at a higher water density more of the chemical remains at the water surface) (Figure 6). There is a correspondingly small effect on point concentrations at the seabed (Figure 7).

4.4 Discussion

The results for a single chemical (aniline) show temperature to have a moderate effect on near bed concentrations. However, note the model simulations only take account of the effect of temperature on chemical properties. Regions with high water temperatures arising from solar heating would generally be expected to exhibit water column stratification that would also significantly influence the fate of chemicals. For surface spills, stratification would inhibit the mixing to the seabed minimising benthic exposures and potentially allowing more chemical to evaporate as it is trapped in the surface layer. For benthic release the effect would be the opposite with material trapped below the thermocline. The model at present is not able to simulate this physical effect.

In the model simulations salinity was found to have a small effect on fate and concentration profile. In contrast to the situation with temperature the chemical processes in the model do not generally include salinity dependence and the effects seen in the simulations are due to the different physical behaviour of the dissolved chemical in different density water.

4.5 Conclusions

For aniline, the temperature change from 10°C to 30°C had a significant effect on overall fate of the chemical. The total evaporated fraction after 25 hours increased from just under 20% to over 30% at 10°C and 30°C respectively and degradation increased from near zero to about 10% of the total discharge. Concentrations at selected seabed locations showed a commensurate change.

The effect of salinity was found to be small. However no direct effect of salinity on the model chemical constants is included in the model and the effects seen were simply due to the physical effect of salinity on the reactive density.

Possible effects of the stratification of the water column on chemical fate in a region of high temperature could not be simulated with the model used in this study but may also be influences upon fate and effects.

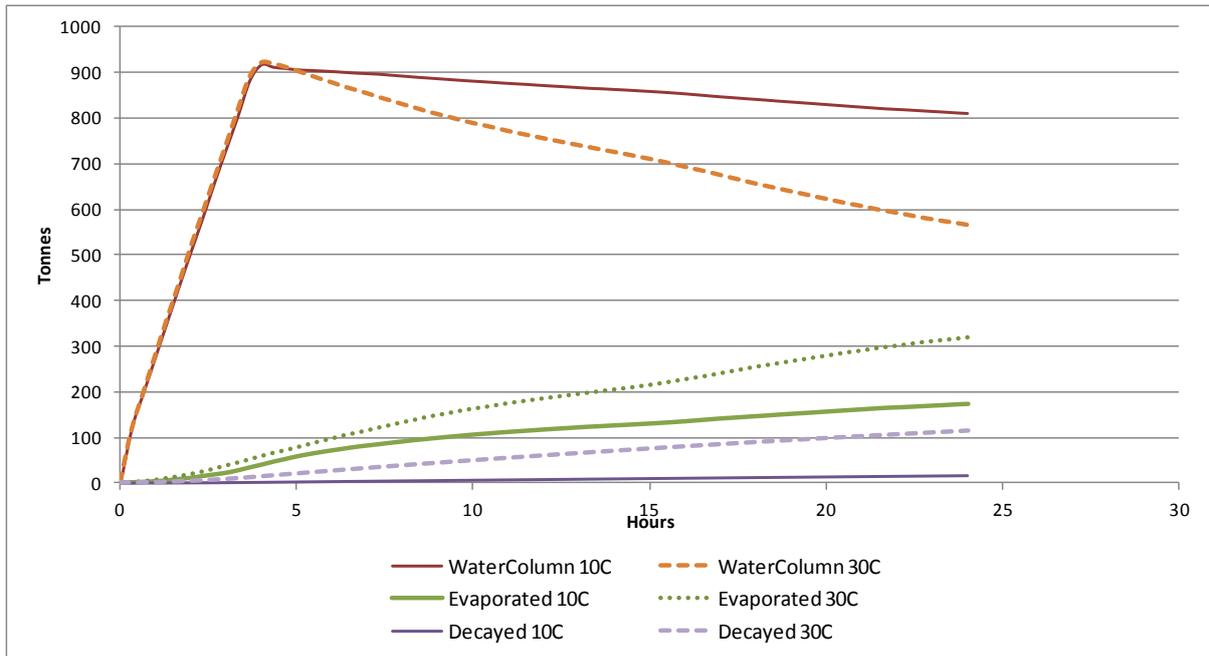


Figure 3 Water temperatures effect on the fate of aniline (10°C and 30°C).

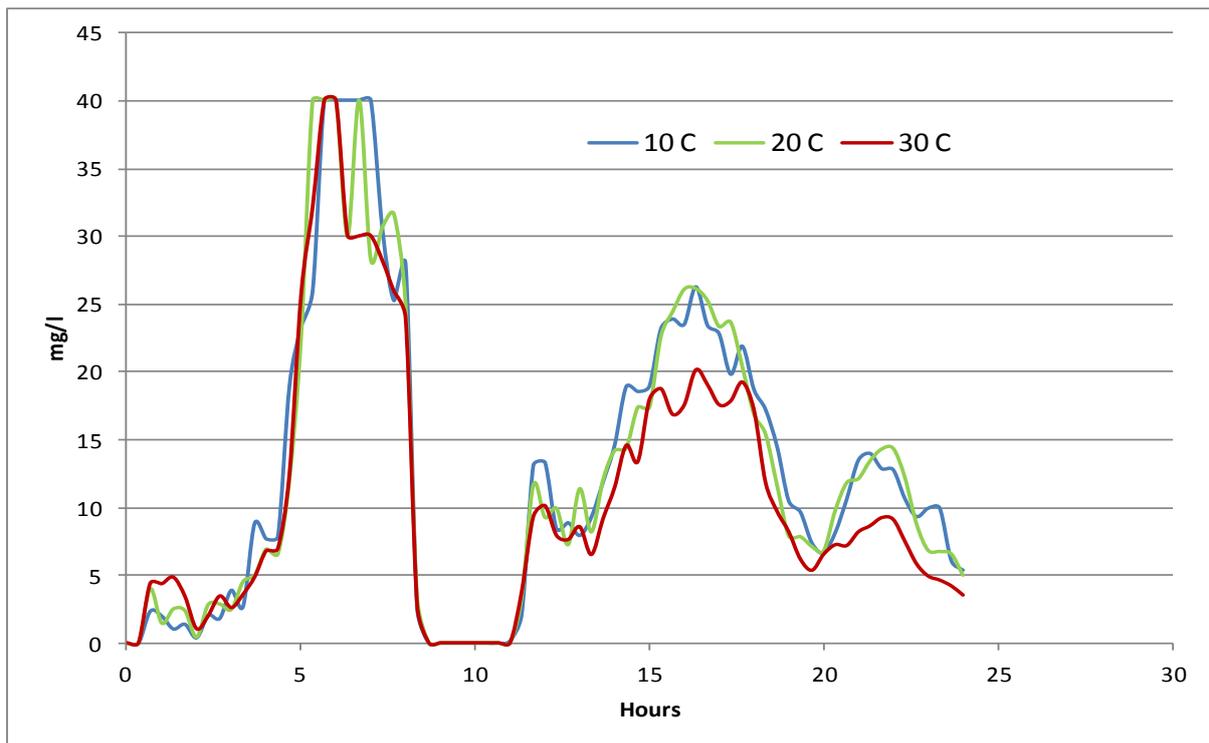


Figure 4 Location 1 (Figure 2) – temperature effect on near bed aniline concentrations.

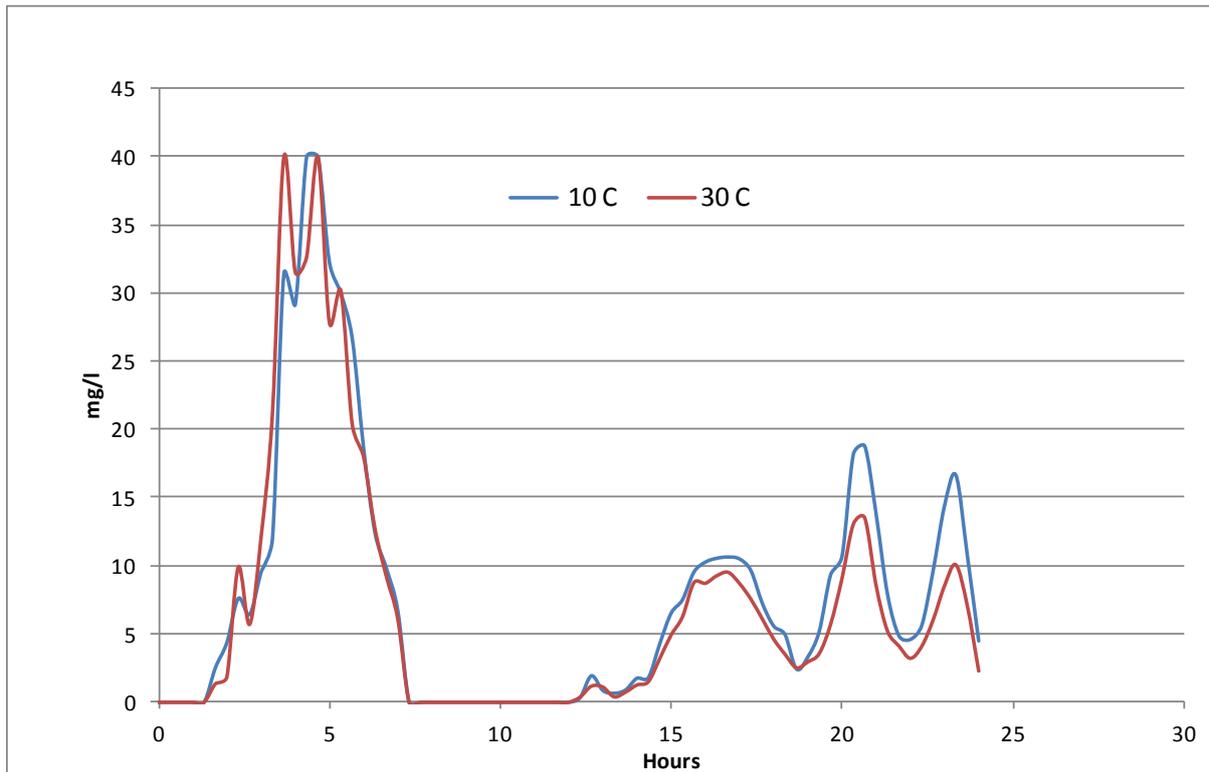


Figure 5 Location 2 (Figure 2) – temperature effect on near bed aniline concentrations.

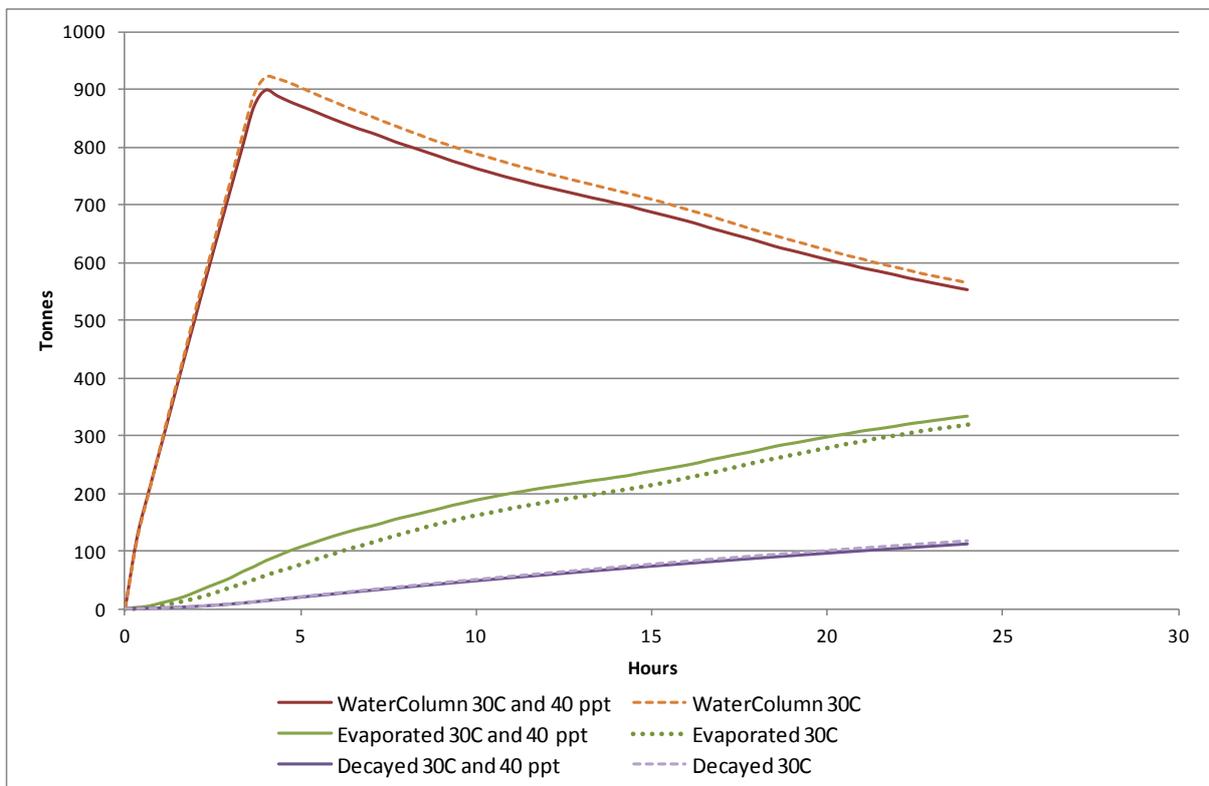


Figure 6 Water density influence on fate of aniline (32 ppt and 40 ppt).

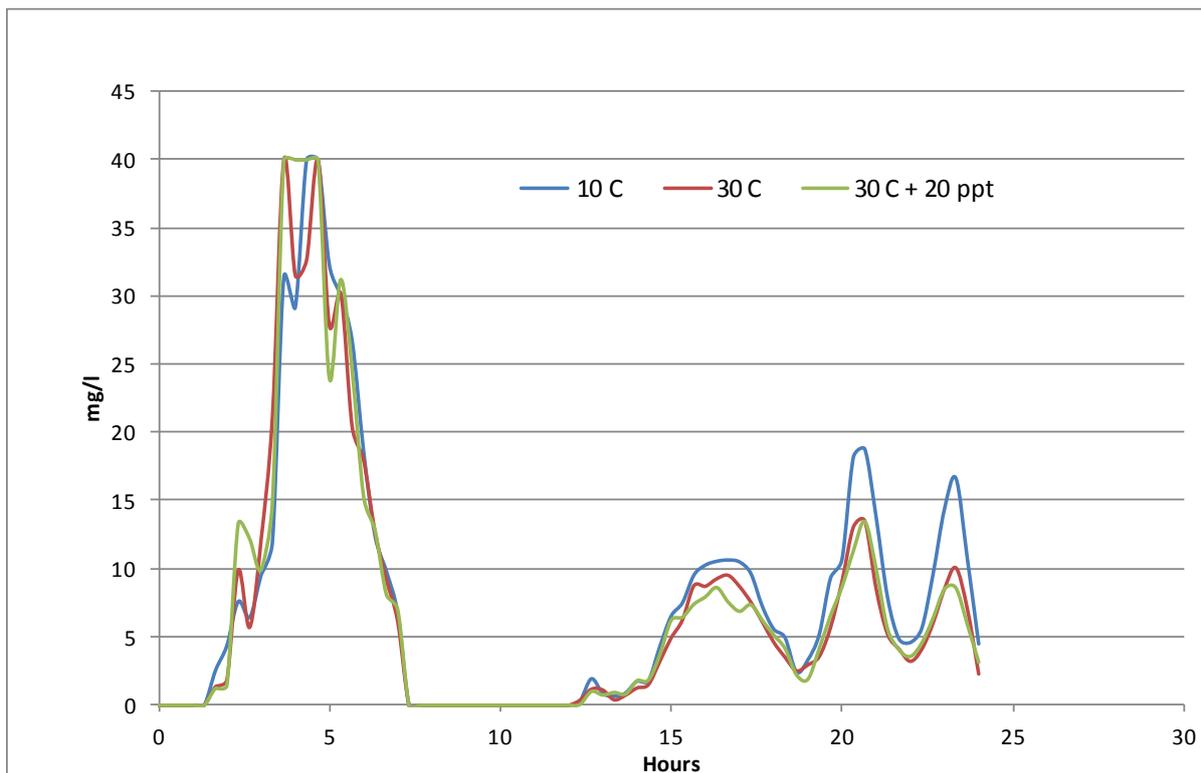


Figure 7 Location 2 (Figure 2) - temperature and salinity effect.

5.0 TOXICITY TEST METHODS

Constant exposures and time based exposures were performed at different temperatures and salinities. Toxicity results were then compared to evaluate the effect of these variables on the toxicity of different HNS.

5.1 Sampling and analysis of test chemical

Aniline solutions were prepared in filtered seawater for each of the salinities tested. Subsamples of this primary stock were used to make the definitive test dilution series. Samples of the stock solutions were analysed to determine the concentrations of aniline. Aniline test solutions were analysed by Gas Chromatography Mass Spectrometry (GCMS). This method has an assured detection limit of $2 \mu\text{g l}^{-1}$.

For zinc a 1 g l^{-1} primary stock was prepared in reverse osmosis water and kept at $4 \pm 2 \text{ }^\circ\text{C}$ in the dark. Dilution series were then prepared from this on the day of each test.

5.2 Test conditions

Natural sand-filtered seawater was used for the toxicity tests and was subsequently filtered through a $0.2 \mu\text{m}$ filter and then sterilised using a UV filter to eliminate pathogens and parasites. Salinity was adjusted using TropicMarine synthetic salts (TropicMarine®, Wartenberg, Germany) to obtain 30, 35 and 40 ± 1 ppt salinity. Tests were carried out at 20 and $30 \pm 2 \text{ }^\circ\text{C}$ at the Cefas laboratory in Lowestoft.

5.3 Test species selection

The copepod *Tisbe battagliai* was chosen as the test species because of its sensitivity, ecological relevance and because of its use in previous projects. Copepods are small crustaceans that are frequently dominant secondary producers in marine zooplankton (Hart, 1990) and are accordingly important to the marine foodweb. Copepods belonging to the genus *Tisbe* are particularly useful for risk assessment because of their relatively small size, short lifecycle and the ease of continuous culture (Hutchinson *et al.*, 1999a and b). *Tisbe* are also epibenthic organisms, which are most likely to be affected by the spill profiles being modelled as part of this project.

The *Tisbe* used for the toxicity studies were obtained from Guernsey Sea Farm and used within 2 weeks of delivery date. *Tisbe* were acclimatised at the test salinities for at least a week before the beginning of the test.

Corophium volutator is an amphipod crustacean which is an abundant species in intertidal ecosystems. Organisms were purchased from Fisheries Enhance (3 St Colme Road, Dalgety Bay, Dunfermline, Fife, KY11 9LH). Once at the laboratory, animals were released and allowed to burrow in 30 l aquarium containing reference sediment. As for *Tisbe*, they were acclimatised at the different salinities for a week prior the beginning of the test.

5.4 *Tisbe battagliai* toxicity tests

Standard toxicity tests

Standard 48 hour exposure studies were conducted with juvenile copepods (6 ± 2 days old) exposed to aniline. The nominal concentrations chosen were 0, 0.3, 1, 3, 10 and 30 mg l⁻¹. Observations of mortality and number of alive and dead juveniles were made at 24 and 48 hours. Water qualities were recorded at the beginning and at the end of each test. A parallel zinc reference test was carried out to ensure the batch of organisms tested were of similar sensitivity to previous batches.

Time-based studies

Time based studies were performed to compare the lethal concentrations (LC₅₀) with the lethal times (LT₅₀). They were carried out for zinc at 20°C for the three salinities (30, 35, 40 ppt). The nominal concentrations chosen for zinc were 0, 0.1, 0.3, 1, 3, 10 and 30 mg l⁻¹. Observations of mortality and number of alive and dead juveniles were made after 1, 2, 3, 4, 6, 8, 24, 32 and 48 hours. Water qualities were measured at the beginning and the end of the experiment.

5.5 *Corophium volutator* toxicity tests

Water only toxicity tests were performed for aniline using *Corophium volutator* as test organism. Although *Corophium* is normally present in burrows in the sediment this approach was adopted initially to avoid the potential influence of the presence of sediment upon the test chemical. A short spill profile time of 48 hours was adopted so as to compare with that used for *Tisbe*. Organisms were tested in water only (same procedure used for standard reference test). Aniline nominal concentrations used for the test were 0, 0.1, 1, 10, 100 and 1000 mg l⁻¹.

5.6 Statistical analysis

All statistical analyses for lethal times and lethal concentrations were performed in CETIS v1.8.0 (Tidepool Scientific, USA). When appropriate, survival effects were analysed using linear (Probit model) regression if possible. When not possible, linear interpolation or Trimmed Spearman-Kärber method was used. Analyses were performed using the measured concentrations of the chemicals in both the *Tisbe* tests and those for *Corophium*.

The Bartlett Homogeneity of Variance test and the Shapiro–Wilks Normality test respectively within the CETIS package were used to confirm whether the dataset met the assumptions required for a normal distribution and as a consequence identified appropriate tests of significance between the response of treatment groups and the control.

5.7 Results

Test chemicals

Test concentrations were not renewed over the 48 hour exposure period. Aniline concentration declined over this period particularly at concentrations below 1mg l^{-1} therefore the effect concentrations are derived on the basis of measured concentrations. Zinc sulphate was more stable in the test solutions and therefore nominal concentrations are used to derive LC_{50} data.

Tisbe battagliai toxicity tests

All the tests at the same temperature were run in parallel using the same batch of animals and stocks so that the comparison of the results would be easier. Chemistry of samples was always analysed for confirmation of the initial stock solutions that were then used for the preparation of the dilution series.

Standard toxicity tests

Standard toxicity tests were performed with *Tisbe battagliai* exposed to aniline and zinc sulphate. Toxicity at three different salinities (30, 35 and 40 ppt) was compared.

Toxicity data for *Tisbe* exposed to aniline at different salinities are shown in Figure 8. The lowest LC_{50} was found in *Tisbe* exposed to aniline at 20°C and 35 ppt salinity which was 8.14 (5.86 - 12.06) mg l^{-1} aniline.

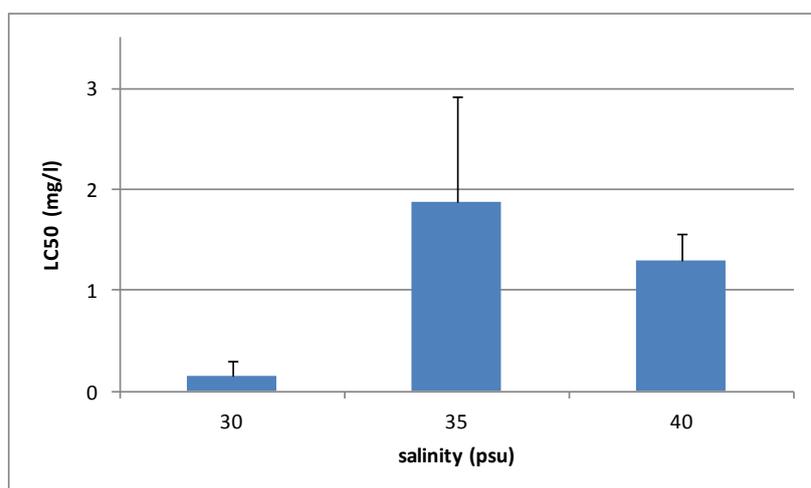


Figure 8 LC_{50} s (mg l^{-1}) calculated for the different concentrations tested of aniline at three different salinities at 20°C during a 48 hours constant exposure of *Tisbe battagliai*. Error bars show upper 95% confidence limits.

Figure 9 show LC_{50} s obtained for *Tisbe* exposed to zinc sulphate for the three different salinities tested in the experiments. The lowest LC_{50} was found in *Tisbe* exposed to zinc at 30 ppt salinity. The biggest differences were found between those exposed at 35 ppt and 40 ppt.

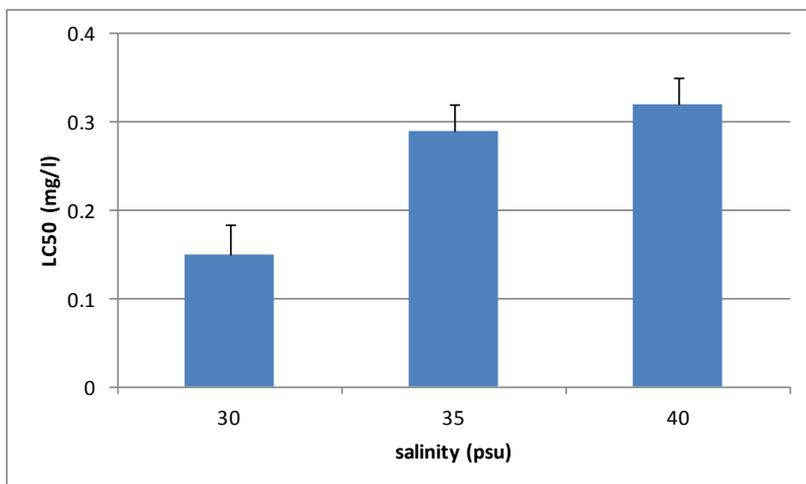


Figure 9 LC₅₀s (mg l⁻¹) calculated for the different concentrations tested of zinc sulphate at three different salinities at 20°C for *Tisbe battagliai* during 48 hours constant exposures. Error bars show upper and lower 95% confidence limits.

***Corophium volutator* toxicity tests**

Lethal concentrations 50% (LC₅₀s) were also calculated for toxicity tests of *Corophium* exposed to different concentrations of aniline at 15°C and in different salinities. *Corophium* showed a decrease in sensitivity with the increase in salinity. In fact, the 48 hour LC₅₀s ranged from 275 (91-421.1) mg l⁻¹ aniline in 30 ppt salinity to 308.9 (110-649.4) mg l⁻¹ aniline in 35 ppt salinity. The highest LC₅₀ was found for those organisms exposed to aniline in 40 ppt salinity in which the LC₅₀ was 341.7 (262.4-437.3) mg l⁻¹ aniline.

5.8 Overall Discussion

The European project ARCOPOLplus recently identified 23 HNS as having a high likelihood of being present in maritime transport incidents suggesting these be the focus of efforts to fill data gaps. This study therefore focused on aniline. Zinc sulphate was also considered in the study as well as a standard/control. Few acute aquatic toxicity data for aniline are available in the literature with data for some freshwater species reported by Kühn *et al.* (1989) and Russom (1993) and data for two marine species, a shrimp and a clam, reported by McCleese and Zitko (1979). Acute toxicity data for *Tisbe battagliai* and other species were obtained during the ARCOPOLplus project.

In this study chemical models have been used to predict the dispersion and fate of aniline during a standard spill scenario. The behaviour of a similar spill (i.e. same quantity, release rate and Location) with different environmental conditions (i.e. salinity and temperature) was then compared. The dispersion profiles of aniline did not show significant differences when parameters such as salinity and temperature were modified to be representative of the types of change that might be

associated with proximity to estuarine inputs, differences in season or in respect to different geographic regions.

This preliminary study focused on standard and time-based toxicity tests to evaluate the effect of temperature and salinity for different HNS as these data can be better employed to interpret the effect of different spill profiles upon the ultimate impact of a spill.

Data on the effect of temperature and salinity on the toxicity of zinc are available in the literature. A recent study published by Park et al. (2014), evaluated the effect of salinity on acute toxicity of copper and zinc on the copepod *Tigriopus japonicas*. Their results showed how the toxicity decreases with an increase of salinity due to a decrease in dissolved ions in solution. Their study evaluated salinities ranging between 5 and 35 ppt. The biggest differences in terms of dissolved ions and toxicity were found between the lower salinities. In this study the concentration of dissolved zinc in solution stayed constant at the different salinities. The LC₅₀s though, ranged from 0.15 mg l⁻¹ zinc at 30 ppt to 0.29 mg l⁻¹ zinc at 35 ppt and 0.32 mg l⁻¹ zinc at 40 ppt. Other authors have shown comparable results for cadmium toxicity to another crustacean species, the whiteleg shrimp *Litopenaeus vannamei* (Ardiansyah et al., 2012).

No data in the literature could be sourced for marine species for the effect of salinity on toxicity of aniline. Our results indicate that aniline is more toxic at low (30 ppt) relative to at intermediate salinity (35 ppt) and high (40ppt) salinity. Toxicity data obtained for *Corophium volutator* exposed to aniline followed a more delineated trend. In this case, the sensitivity decreased consistently with the increase of the salinity even if this species showed an overall lower sensitivity to the compound (LC₅₀s greater than 250 mg l⁻¹).

Temperature is considered one of the most important factors influencing toxicity of chemicals (Heugens et al., 2001) and data generally show enhanced toxicity as temperature increases. Preliminary studies that we have conducted on *Tisbe* exposed to zinc and aniline at higher temperature (30°C) indicate greater sensitivity of this species compared with results observed at lower temperatures (20°C). These results agree with some of the data available in literature. Heugens et al. (2003) showed an increase in sensitivity of *Daphnia* to cadmium due to an increased uptake rate. Similar results were shown for the copepod *Tigriopus japonicas* exposed to copper and the antifoulant chemical tributyltin (Kwok and Leung, 2005). Unfortunately toxicity data for chemicals in combination with temperature for a range of marine species are rather limited but a review conducted by Zhou et al., 2014 that focuses on metal toxicity indicates that for some marine species chemical toxicity may be lowest at some optimum temperature and increase either side of this value. The review conducted by Zhou et al., indicated that the main trend for species sensitivity distributions for the metals zinc, chromium and cadmium was that a several times (1-3 times) increase in sensitivity occurred over an approximate 15°C temperature increase.

These preliminary data also indicate that in regions of higher salinity HNS chemicals may be several times less toxic (1-5 in these studies) at salinity of 35 – 40 ppt compared to at lower salinities. Previous investigation of the effects of salinity upon chemical behaviour supports these findings indicating that neutral chemicals at or near saturation in river water must volatilise, rise to the surface in the form of a slick, or, more important for larger molecules, sorb to suspended particles as salinity increases (Turner, 2003).

Based on the chemical modelling data a 10°C increase in temperature may result in a 10 - 25% decrease in the exposure concentration but this is very situation specific and will be highly influenced by the state of the sea and the depth of release in the water column.

In general terms chemical spills in coastal areas are likely to represent the most risk because of the threat to humans, the operation of coastal industries and various wildlife species in areas of shallower water. The potential for lower salinity and higher temperature in these same areas is therefore likely to increase the susceptibility of exposed organisms. In areas where both high salinity and high temperature combine

In conclusion, these data form part of an initial assessment of the effects of salinity and partially temperature on chemical spill toxicity. Higher salinity appears to decrease the toxicity of the selected HNS (i.e. zinc, and aniline). Preliminary studies on temperature increase also led to an increase in the toxicity of both zinc and aniline at all the salinities tested. Investigations are underway to further characterise the influence of temperature and salinity on the toxicity of other compounds and to other species. Time-based studies will also be used in future tests together with modelled profile assessments to further improve our understanding of the extent of impact of HNS under different environmental conditions.

5.9 Acknowledgements

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