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REVIEW

Offshore oil and gas, and operational sheen occurrence: is there potential harm to marine birds?

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Abstract: Hydrocarbon discharges into the ocean, both regulated and accidental, occur from offshore drilling and production operations, and can result in oil sheen (≤3 μm thick) and slick (>3 μm thick) formation, potentially harming marine birds. Sheens may commonly occur around offshore oil and gas platforms in Atlantic Canada, however, there is little information on regularity of occurrence. Further, there are few direct studies on potential impacts of sheens, associated with offshore oil and gas operations, on marine birds. We reviewed potential sources and frequency of hydrocarbon accumulation on sea surfaces from offshore oil and gas operations in Atlantic Canada, and the likelihood of overlap with marine birds. We conducted a literature review on lethal and sub-lethal effects of low levels of oil contact and ingestion on marine birds, focusing on studies that describe measured dosages of oil. We extrapolated from these data on low-dose oil exposure to link possible effects to marine birds resulting from exposure to sheens. We found that sheens occur around production operations in Atlantic Canada at allowable levels of oil concentrations in produced water. Frequency and extent of occurrence cannot be estimated from current monitoring practices. While immediate lethal effects to seabirds likely are not common from external oiling of feathers from sheens, added stressors, such as cold weather, can result in external oiling from sheens having significant impact on seabird metabolic rate and can be ultimately lethal. Ingestion of small amounts of oil, doses that realistically could be expected from exposure to sheens, in some cases resulted in sub-lethal effects to adult seabirds, primarily affecting metabolic rate, sub-lethal health impacts, and reproductive output. Nestlings and eggs do not come in direct contact with sheens, yet these life stages are highly sensitive to oil, and transfer of oil from adults exposed to sheens likely is above tolerance levels at times. Negative effects to reproductive output from small doses of ingested oil could be causing undetected impacts on marine birds and marine bird populations. Lack of standardized monitoring of marine bird contact with sheens and potential harm makes assessments of magnitude and extent of impact problematic.

Key words: seabirds, offshore oil and gas, petroleum, oil sheens, produced water, operational discharges.

Résumé : Les décharges d'hydrocarbures dans l'océan, tant régulées qu'accidentelles, sont occasionnées par le forage en mer et les exploitations de production, et peuvent donner lieu à la formation d'une irisation d'hydrocarbures (≤3 μm d'épaisseur) et d'une nappe de pétrole (>3 μm d'épaisseur), nuisant potentiellement aux oiseaux de mer. Les irisations peuvent généralement se produire autour des plateformes de forage pétrolier et gazier extracôtiers au Canada atlantique ; cependant, il y a peu d'information au sujet de la régularité des cas. De plus, il existe peu d'études ciblées des conséquences potentielles des irisations liées aux exploitations extracôtières de pétrole et de gaz, sur les oiseaux de mer. Nous avons fait le point sur la fréquence et les sources possibles d'accumulation d'hydrocarbures sur les surfaces de la mer provenant des exploitations de pétrole et de gaz extracôtiers au Canada atlantique, et la probabilité qu'elle s'imbrique avec les oiseaux de mer. Nous avons passé la littérature en revue en ce qui a trait aux effets mortels et sublétaux sur les oiseaux de mer à la suite du contact et de l'ingestion de faibles niveaux de pétrole, en nous concentrant sur les études qui décrivent des dosages mesurés de pétrole. Nous avons extrapolé à partir de ces données sur l'exposition à de faibles niveaux de pétrole afin de faire le lien avec les effets possibles sur les oiseaux de mer à la suite de l'exposition à des irisations. Nous avons constaté que les irisations se trouvent autour des exploitations de production au Canada atlantique, et ce, à des niveaux permis de concentration de pétrole dans l'eau de production. Il n'est pas possible d'évaluer la fréquence et l'étendue des cas au moyen des pratiques de surveillance actuelles. Tandis que les effets mortels immédiats sur les oiseaux de mer ne sont probablement pas communs pour les cas de graissage externe des plumes par les irisations, des facteurs de stress supplémentaires tels que le temps froid peuvent causer un effet significatif du graissage externe des plumes sur le taux métabolique de l'oiseau de mer et peuvent être mortels à la fin. L'ingestion de petites quantités de pétrole, des doses auxquelles on pourrait s'attendre à la suite d'exposition à des irisations, a dans quelques cas eu des effets sublétaux sur les oiseaux de mer adultes, influant principalement sur le taux métabolique, les incidences sublétales sur la santé, et l'efficacité de la reproduction. Bien que les oisillons et les œufs n'entrent pas en contact direct avec les irisations, ces étapes de la vie sont fortement sensibles au pétrole, et le transfert de pétrole des adultes exposés aux irisations est probablement au-dessus du seuil de tolérance parfois. Les effets négatifs sur l'efficacité de la reproduction à la suite de petites doses de pétrole ingéré pourraient être en train de causer une incidence non détectée sur les oiseaux de mer et les populations d'oiseaux de mer. À cause du manque de surveillance normalisée du contact des oiseaux de mer avec les irisations et des dommages potentiels, l'évaluation de la grandeur et de l'ampleur de l'incidence est problématique. [Traduit par la Rédaction]

Mots-clés : oiseaux de mer, pétrole et gaz extracôtiers, pétrole, irisation d'hydrocarbures, eau produite, rejets d'exploitation.

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Introduction

It is well established that marine birds are negatively impacted by exposure to oil in the ocean (Alonso-Alvarez et al. 2007*b*; Burger 1993; Castege et al. 2007; Munilla et al. 2011). When seabirds contact oil, feathers lose their water-repellent properties, resulting in penetration of water and oil, loss of buoyancy, behavioural changes, impaired flight, and significant reduction in ability to thermoregulate; these effects are particularly lethal in colder climates and for diving birds (Burger 1993; Lambert et al. 1982; Levy 1980; McEwan and Koelink 1973). In addition, oil ingestion results in toxic effects to marine birds (Alonso-Alvarez et al. 2007*b*; Balseiro et al. 2005; Leighton 1991).

While all marine birds that come into contact with oil sheens and slicks are susceptible to harm, pelagic seabirds are some of the most vulnerable birds to marine oil contamination (Camphuysen 1998). Pelagic seabird life history is characterized by a long immature stage, high annual adult survivorship, and low reproductive output with typically one egg per clutch per year (Cairns 1992; Lack 1967). These characteristics make seabird populations sensitive to anthropogenic perturbations (Ford et al. 1982). Vulnerability to oiling is higher in birds that spend most of their time at the surface or diving (e.g., auks, seaducks, and divers) than those that forage on the wing (e.g., storm-petrels, albatrosses, and shearwaters), and highest for surface-dwelling seabirds that spend most of their lives at sea (Camphuysen 1998).

Most research on effects of oil on seabirds has focused on the impacts of larger catastrophic spills (e.g., Dunnet et al. 1982; Piatt et al. 1990). While much less is known about effects of chronic, low-level oily discharges, some evidence suggests these discharges may pose equal, if not a greater threat to marine birds than the less common, large discharges (Camphuysen and Heubeck 2001; Wiese and Robertson 2004). Operational discharges from maritime industrial activities, such as offshore oil and gas production, and shipping, are sources of chronic, low-level oil discharges. Hydrocarbon discharges from these industries typically are regulated in compliance with international protocols (e.g., International Convention for the Prevention of Pollution from Ships (MARPOL)). Environmentally safe levels of operational hydrocarbon discharges are determined though environmental impact assessments but may not fully take into account effects to many marine organisms.

In Canada, environmental impact assessments for offshore oil and gas operations have predicted no significant effects on marine birds (Husky Oil 2000; Mobile Oil 1985; Petro-Canada 1997); however, these conclusions appear to be based on a lack of data rather than data showing no effects to marine birds (Fraser et al. 2006). For the first time in this review we provide data, analysis, and discussion of sheen formation from operational discharges in Atlantic Canada. We then review the literature on effects of controlled doses of low levels of oil, externally and internally, on marine birds. From these data, we extrapolate to possible effects on marine birds from contact with low levels of oil.

Operational discharges of hydrocarbons from offshore oil operations

In Canada, allowable operational discharges of hydrocarbons can result in the formation of oil sheens. Sheens are defined as hydrocarbon concentrations on water surfaces that are less than or equal to 3 μm in thickness, as opposed to slicks, which are greater than 3 μm in thickness (ERIN Consulting Ltd. and OCL Services Ltd 2003). There are two main types of allowable, operational discharges from offshore oil and gas drilling and production operations: (*i*) produced water, (*ii*) oil- or synthetic-based drilling muds and cuttings. Hydrocarbons also can be released as a result of typical operating procedures that are not necessarily compliant with international protocols, such as storage displacement water, bilge and ballast water, deck drainage, produced sand, well treatment fluids, and accidental discharges and blowouts. However, in this review we focus on the operational discharges that occur at rates that are allowable in Canada.

Produced water accounts for the largest volume of waste discharged from offshore oil and gas operations (Neff 2002). Produced water is a mixture of formation water present in the ground and injection water used to raise pressures in oil recovery, mixed with the extracted hydrocarbons (Stephens et al. 2000). Generally, in the early stages of production, produced water volumes are small relative to the volume of hydrocarbons, but with time the volume of produced water increases to exceed hydrocarbon production. Produced water is released below the surface of the ocean but hydrocarbons can rise to the surface. In Canada, guidelines state that, 1.30 d volume weighted average oil-in-water (OIW) concentration does not exceed 30 mg/L (~ppm), and 2.24 h average OIW concentration, calculated at least twice a day, does not exceed 44 mg/L (Canada's Offshore Waste Treatment Guidelines 2010). Regulations for produced water in other countries are similar, generally between 30 and 42 ppm allowable OIW (Igunnu and Chen 2014).

Drilling muds are used to clean and condition drill holes, to lubricate drill bits, and to counterbalance pressure. Drilling muds can be oil-based, water-based, synthetic-based (SBM), or enhanced mineral oil-based muds. Canadian regulations state that SBM must contain polycyclic aromatic hydrocarbon concentrations of less than 10 ppm, be relatively non-toxic in marine environments, and be able to biodegrade aerobically, and that there should be no more than 6.9 g/100 g remaining oil on wet solids (Canada's Offshore Waste Treatment Guidelines 2010).

Sheen formation in Atlantic Canada

Atlantic Canada is a globally significant area for seabirds, supporting over 40 million birds per year, including year-round residents and species that migrate to the region for breeding (Lock et al. 1994). The region is also a significant area for hydrocarbon reserves, with four active oil production operations (Hibernia, Terra Nova, White Rose, and North Amethyst) and a total production to date of over 1.5 billion barrels (C-NLOPB 2014–2015 annual report). Drilling and production operations are a significant source of low-level hydrocarbon discharges into the marine environments in Atlantic Canada through both regulated discharges and accidental spills (Burke et al. 2012; ERIN Consulting Ltd. and OCL Services Ltd 2003).

Whether oil sheens are a regular occurrence, or an infrequent result of high concentrations of oil discharge from offshore oil and gas operations, is not well-established (ERIN Consulting Ltd. and OCL Services Ltd 2003). Canadian offshore operations report average hydrocarbon concentrations of 20–40 mg/L in produced water, and that these levels can be associated with sheens (ERIN Consulting Ltd. and OCL Services Ltd 2003). In addition, effluent testing by industry to comply with guidelines may not adequately detect polar or lower weight hydrocarbons (C_4 to C_{30}), making actual hydrocarbon levels greater than reported levels (ERIN Consulting Ltd. and OCL Services Ltd 2003).

Sheens vary in appearance, to a certain extent corresponding to thickness (Table 1). It is important to note that sheens are a visual phenomenon and the perception of a sheen requires favourable environmental conditions. Estimation of oil volume based on sheen appearance is problematic because appearance and colour vary with available sunlight, sea surface state, light incidence, and the viewing angle of the observer (ERIN Consulting Ltd. and OCL Services Ltd 2003).

However, approximate estimation of thickness and volume based on appearance is an important tool for assessment of potential harm of produced water. Currently in Canada, government agencies and response corporations typically use the "thickness appearance rating code" (TAR code) developed by the Canadian Coast Guard and Environment Canada to characterize sheens

Table 1. Estimated oil sheen thickness and volume based on visual appearance using the "thickness appearance rating" (TAR) code, developed by the Canadian Coast Guard and Environment Canada.

Appearance	Thickness (μm)	Volume (L/km²)
Barely visible	0.04	50
Silver sheen	0.07	100
First colour trace	0.1	200
Bright colours	0.3	400
Dull colours	1	1200
Dark colours	3	3600

Note: TAR code is used as the standard reference for observation and quantification of oil on water (CAPP 2009).

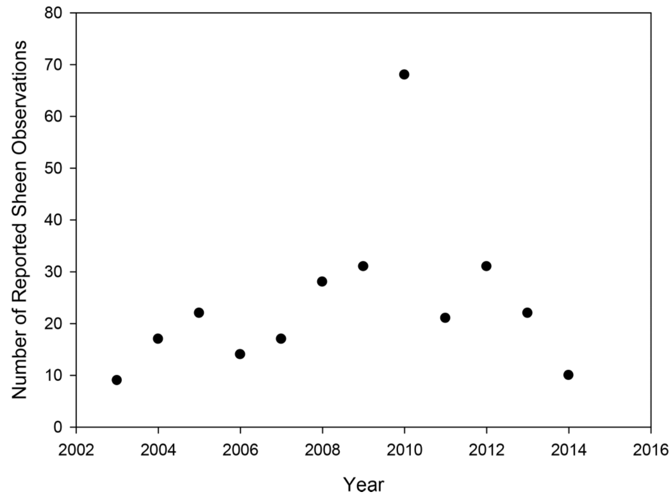
(CAPP 2009). Formation of sheens, in addition to being influenced by hydrocarbon concentration in the effluent, are influenced by hydrocarbon droplet size, water temperature differential between the effluent and sea, suspended solids in the effluent, type of hydrocarbon in the effluent, and weather – ocean surface conditions (ERIN Consulting Ltd. and OCL Services Ltd 2003). Oil sheens also can occur from natural processes releasing hydrocarbons into water.

Interviews with industry personnel from Canada's East Coast offshore operations, the Gulf of Mexico, and the North Sea were conducted by ERIN Consulting Ltd. and OCL Services Ltd (2003) to gauge frequency of sheen formation from produced water. They found that sheen occurrence responses varied widely by region. In Canada's east coast, occasional sheens were observed; in the Gulf of Mexico sheens were common in the 1990s but rare in the 5 years before the report; in the North Sea, sheens were a normal occurrence. Some informants suspected that sheens could form with hydrocarbon concentrations of less than 20 ppm. Respondents indicated that sheen observation was most likely with calm seas and on clear days (ERIN Consulting Ltd. and OCL Services Ltd 2003). Other respondents suggested that sheens may be very common around platforms off the east coast, and M. Fingas (Chief Science Officer, Spill Science, Edmonton, Alberta) is cited in the same report as saying sheens are "usually always present…visible under certain conditions".

Following the ERIN Consulting Ltd. and OCL Services Ltd. Report (2003), observations of sheen occurrence from production operations in Atlantic Canada have been reported from 2003 to present, and were supplied to us by the C-NLOPB (Table A1). According to C-NLOPB Environmental Protection Plan guidelines, sheen monitoring is recommended as a means of complying with Canada Oil and Gas Drilling and Production Regulations, Newfoundland Offshore Petroleum Drilling and Production Regulations (Government of Canada 2009). While specific protocols are not outlined in the Regulations, most operators direct platform and rig personnel to watch for sheens as part of their daily activities, investigate sources if sheens are observed, and report to the C-NLOPB within 24 h of the incident (D.G. Taylor, D.G. Taylor Inc. Pers. Comm., Nov. 2015). Because of the somewhat unspecific protocols, lack of standardization in effort, training, and possibly in reporting, the analyses and interpretation of these data are useful, yet limited.

We base our analyses on data that extend from 2003 to the end of 2014, and these data were collected from production operations only (not exploration). There were a total of 290 reported sheen sightings from produced water discharges over the 12 year observation period, making the reported number of sheens around production platforms in the Grand Banks approximately 24 per year. There was variation in the number of sheens reported per year but no obvious trend to increasing or decreasing sheen occurrence based on the information provided (Fig. 1).

Fig. 1. Number of oil sheens reported each year to the CNLOPB from produced water discharge, from three oil and gas production platforms in Atlantic Canada (Hibernia, Terra Nova, and White Rose). Observations for sheen occurrence are believed to occur continuously during daylight hours and reporting compliance is believed to be high.



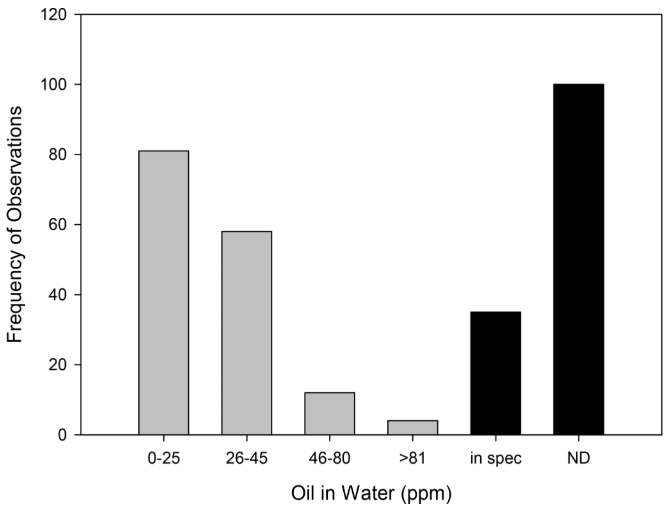
In 155 of the 290 reported sheen occurrences, there was one or more OIW concentration measure for produced water reported in conjunction with the occurrence. In some cases, a range of values was reported (e.g., OIW below 25 mg/L). If a range was given, rather than actual concentrations, we used the largest number in the range for our calculations. Using the maximum value potentially results in a greater value for OIW in association with sheen occurrence than if we had actual OIW values for our calculations. We consider this a conservative approach because we are exploring minimum threshold OIW values associated with sheen detections. In 135 of the 290 reported sheens from produced water, there was either no information on OIW, or it was reported that the OIW was "in spec" (within specified allowable limits); and therefore those 135 reported observations are not included in our calculated average of OIW during sheen occurrence.

The range of reported values during sheen occurrence was 4–137 mg/L with an average OIW of 29.8 mg/L and a median value of 28 mg/L (Fig. 2). The average and median OIW values during sheen sightings fall well within allowable limits, and therefore sheens may be a regular occurrence around platforms when oceanic conditions are favourable for formation (calm seas). This is supported by the distribution of sheen reports on a yearly basis, which shows that almost 50% of sheens are reported during the four months of May, June, July, and August when calm seas are most likely (Fig. 3). However, the skew of more observations of sheens in the summer months corresponds to longer daylight hours (see Fig. 3) and therefore greater potential observation time per day. Because observation durations per day and protocols were not made available to us, we do not adjust sheen occurrence by day length but note the potential for day length to skew observations.

Although we requested OIW measures independent of sheen occurrences, they were not provided to us, and for this reason, we cannot make inferences on relative contributions of OIW concentration versus oceanic conditions to sheen occurrence. Because sheens cannot be observed at night, and are less likely to be seen on overcast days, number of reported sheens, even with the most vigilant observation protocols, will be an underestimate of actual number of sheens.

Some data on sheen colour around platforms off the east coast of Canada are available and are presented in Table A1. The majority of sheens reported, for those that have a qualitative descrip-

Fig. 2. Frequency of reported sheens, from produced water discharge, from three production platforms in Atlantic Canada (Hibernia, Terra Nova, and White Rose) between 2003 and 2014.



tion, were characterized as blue-grey, silver, and silver with colour. These characterizations may describe sheens in the range of 0.07 to 1 μm in thickness (see Table 1). Thick sheens seem to be a rare occurrence based on the reported observations from the Canadian offshore operations (which frequently mention blue or colour sheens, but not specifically dark colour).

Based on these results, guidelines that reduce allowable amounts of OIW during summer months may help operators minimize sheen occurrence. However, these data also suggest that sheens can occur even at very low OIW concentrations, if conditions are favourable, and sheen occurrence may be unavoidable with current operating procedures and produced water discharge into the ocean.

Fate of hydrocarbons from offshore oil and gas operations

In addition to rates of sheen formation, it is important to know the spatial and temporal extent of hydrocarbon accumulation from offshore oil facilities. When produced waters are discharged they typically contain remnant particulate oil, dissolved oil, organic acids, phenols, metals, production chemicals, and radioactive material (Neff 2002).

Environmental assessments for some offshore operations in Atlantic Canada acknowledge that subsurface discharges may rise to the surface, but that rapid dilution and evaporation takes place (Husky Oil 2000; Mobile Oil 1985; Petro-Canada 1997). ERIN Consulting Ltd and OCL Services Ltd (2003) reported that at one micrometre thickness sheens may persist for up to 24 h whereas at 0.1 μm, sheens disappear within 20 to 60 min. In the North Sea, where sheens occur frequently, they have been observed stretching up to one kilometre or more from platforms depending on wind and currents. Sheens often begin as small areas a few metres in diameter and spread into thin trails a few hundred metres long, disappearing within an hour (ERIN Consulting Ltd and OCL Services Ltd 2003).

Impacts of oil on aquatic birds

Environmental assessments of offshore drilling operations in Atlantic Canada have concluded that potential effects to seabirds from regulated discharges are "negligible" or "non-significant" (Husky Oil 2000; Mobile Oil 1985; Petro-Canada 1997). Fraser et al. (2006) and Burke et al. (2012) question this assertion and point out that no evidence is provided to support the no-effects conclusions. Fraser et al. (2006) refuted the negligible impact conclusions using a model of sheen formation and risk to auks. They predicted 3.6–100% mortality of the auk population in a 1 km² area around a platform, resulting in an assessment of low to high impact of offshore oil operations. They stress that lack of access to data on frequency of sheen formation from offshore oil operations in the Grand Banks severely impairs attempts to accurately assess risk to marine birds (Fraser and Ellis 2009; Fraser et al. 2006).

Oil pollution has the potential to impact seabirds through external oiling of plumage, toxic effects due to ingestion of oil, and by contaminating or killing their nutritional sources (Jenssen 1994). Short-term and long-term studies of large marine oil spills show negative impacts to marine bird survival (Burger 1993; Goldsworthy et al. 2000; Munilla et al. 2011), physiological impairment (Alonso-Alvarez et al. 2007*a*; Balseiro et al. 2005; Leighton et al. 1983), disruption to reproductive output, and long-term population declines (Barros et al. 2014; Golet et al. 2002; Irons et al. 2000; Lance et al. 2001). Yet, there is little direct data on the impact of chronic, low-level oil pollution and sheens on marine birds. We therefore summarize effects of low levels of hydrocarbons on marine birds from controlled dose studies (Table A2). We then use these data to make inferences on possible effects of sheens from offshore operations on marine birds in general and within the Atlantic region context.

External oiling

Feather microstructure

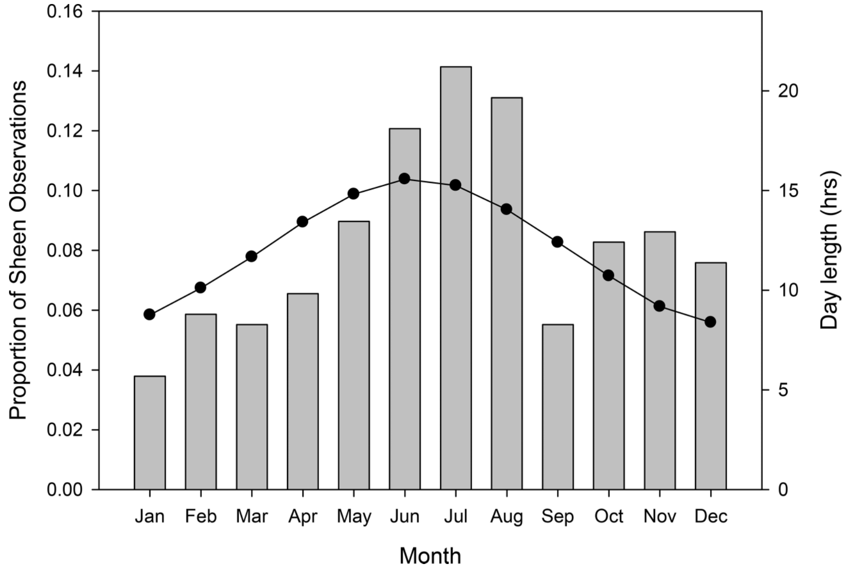
In addition to flight, feathers are important for both insulation and buoyancy on water. Feather microstructure, made up of barbs and barbules, creates an interwoven mesh structure that traps air under water, and results in a waterproof barrier (Stephenson 1997), but still allows for breathability out of the water. It is this microstructure and the oleophilic nature of the structure and feather material that result in the water repellency of feathers (Rijke 1970). In water birds, the structure within and between feathers is adapted to the specific (high) surface tension of unpolluted water (Swennen 1978). Oil adheres to bird feathers causing a reduction in water repellent properties by collapsing the interlocking structure of barbs, barbules, and hooks (Hartung 1967; Jenssen 1994; Jenssen and Ekker 1988). In addition to disrupting the feather microstructure, oil and other materials lower the surface tension of water resulting in feathers being less able to resist penetration (Stephenson 1997; Stephenson and Andrews 1997; Swennen 1978). A compromise of feather integrity can result in water penetrating plumage and displacing the layer of insulating air, which may result in loss of buoyancy, hypothermia, and death.

There are few studies specifically examining the effects of oiling on microstructure of feathers and water and oil penetration. Hartung (1967) was the first to observe and report on feather structural changes caused by oil. Hartung examined oiled and unoiled mallard (*Anas platyrhynchos*) feathers and observed severe matting and a "deranged" appearance in the barbules of oiled feathers. A study on cleaning feathers following immersion in various oils noted that feather microstructure returned to a preoiling state after magnetic cleansing (Orbell et al. 1999). More recently, significant feather microstructure disruption and oil and water uptake were shown for seabird feathers exposed to sheens of petroleum and fish oil (Morandin and O'Hara 2014; O'Hara and Morandin 2010). Because these studies were on single feathers, it is not possible to scale up to effects of sheens on whole birds; however, it was evident that thin sheens significantly disrupt feather structure, and their water-repellent and insulative properties. If the oil and water were to penetrate more than the outer feathers, effects on birds could be severe.

Metabolic rate

Because oil on feathers can result in water penetration, one of the major effects of external oiling is elevated metabolic rate.

Fig. 3. Proportion of oil sheens observed off of production platforms in Atlantic Canada, attributed to, or suspected to be from, oil in produced water, separated by month, over a 12 year period, from 2003 to 2014. Day length is the interval, in hours, from sunrise to sunset at the middle of each month for latitude 46.75°N.



Portier and Raffy (1934) were the first to publish findings on the effects of oil on bird thermoregulation. They found that after external oiling, exposure to low air temperatures or immersion in water resulted in a lowering of body temperature and concluded that oiled seabirds are particularly susceptible to hypothermia because rate of heat loss can exceed heat production capacity.

Hartung (1967) found a doubling of metabolic rate in mallard ducks after experimentally oiling plumage with 15 g of oil at –10 °C compared to control birds, and a similar response in black ducks (*Anas rubripes*). Hartung described a dose-dependent response of metabolic rate to oiling with 5–50 g of various oil types. Lambert et al. (1982) exposed mallard adults to a simulated 50 μm thick crude oil slick under laboratory conditions for 1 h and then measured metabolic rate in a –12 °C chamber. They found a significant increase in metabolic rate of birds after exposure to the oil slick compared to control birds. Exposed birds were observed shivering and microscopic feather inspection revealed that barbules of oiled feathers were matted into clumps leading the authors to conclude that disruption of the smooth, organized structure of feathers caused water to penetrate the plumage. Jenssen and Ekker (1991) found that metabolic heat production of common eiders (*Somateria mollissima*) resting in 5.5 °C water for 3 h after external application of 10–70 mL of crude oil increased over time and with dose, and that there was no change in metabolic rate at the low dose of 2.5 mL. Eiders are a large, well-insulated northern bird and any impacts of oiling found in eiders likely would be as bad or worse in other smaller, or less insulated seabirds (Robertson et al. 2014). Adelie Penguins (*Pygoscelis adeliae*) with residual vegetable oil on their plumage had metabolic rates 50% higher than control birds, and the authors hypothesized that exposure to oil could lead to mass losses of penguins (Culik et al. 1991). Butler et al. (1986) dosed birds externally with 1.0 mL of crude oil and found no change in metabolic rate; however, birds were maintained in relatively warm temperatures during the experiment and were not exposed to water. Disruption of water repellence of feathers has greater implications for heat loss and thus metabolic compensation for birds that are on water or wetted after oiling as opposed to oiled birds in dry conditions (see Jenssen 1994). Even with undisturbed, water-repellent feathers, seabirds floating on water surfaces in medium and high latitudes require an increased metabolic rate to maintain body temperature and further stress from cold water penetration can result in death (Stephenson 1997).

Behavioural effects

Drying out on land after water penetration of contour feathers could aid in thermoregulation, reducing heat loss to water, which has a higher specific heat capacity than air. The immediate response of some oiled and wetted birds is to seek land; however, this poses additional problems, such as reduced time for foraging and breeding, and increased risk of predation (Stephenson 1997). Pelagic seabirds forage solely in the marine environment and thus drying out on land may result in starvation (Hartung 1967; Jenssen 1994).

Burger and Tsipoura (1998) applied fresh and weathered oil to the belly feathers of sanderlings (*Calidris alba*) simulating 20% plumage oiling. Oiled birds spent less time resting and more time bathing and preening, resulting in increased spread of oil on feathers and less time feeding. The amount of oil evident on feathers steadily decreased over 2 weeks, but was never completely eliminated. Similarly, Burger (1997) found that time spent preening was increased and time spent feeding was decreased proportionally to amount of oil on semipalmated plovers (*Charadrius semipalmatus*). Burger speculated that the decrease in time allocated to foraging could prove fatal or reduce reproductive output in birds that are already time-stressed.

Conversely, Camphuysen (2011), examining lesser black-backed gulls (*Larus fuscus*) following oil spills, found that most oiled birds were clean within a week and bred successfully, without human intervention. Camphuysen noted that oiled birds usually were absent from the colony for a few days following the oiling event, but then displayed normal behaviour following their return, and concluded that due to effective preening behaviour, and their access to land for food and cleaning (unlike pelagic seabird species), long-term survival and reproduction of these gulls may not be significantly impacted by smaller quantities of oil resulting from exposure to chronic oil pollution. Perhaps this is not surprising, as Camphuysen noted that gulls as a group (Larids) are ranked relatively low among marine birds in terms of Oil Vulnerability Index (Camphuysen 1998; King and Sanger 1979) because they roost on land. However, the study only directly examined a couple of birds' breeding success and was further hindered in that many gulls from both oiled and unoiled categories gave up breeding during the oil event year. As well, Camphuysen (2011) did not collect toxicological data from oiled individuals (see subsection entitled Internal Toxicity).

Preening can result in eventual, effective removal of oil from plumage for some birds, primarily those with access to land and warmer climates; however, behavioural changes during the cleaning time and toxic effects from ingestion pose serious threats to survival and reproduction for many marine bird species. Yet, another study found that preening resulted in greater effects than oil left alone on the feathers because preening resulted in oil being spread around and into feathers, enhancing metabolic heat loss (Jenssen and Ekker 1991).

Internal toxicity

It is well known that large-volume oil spills cause toxicological effects to marine birds, often resulting in death from acute toxicity or multiple sub-lethal effects (Balseiro et al. 2005; Briggs et al. 1997, 1996; Burger and Tsipoura 1998; Esler et al. 2000; Goldsworthy et al. 2000; Golet et al. 2002; Golightly et al. 2002; Irons et al. 2000; Khan and Ryan 1991; Parsons and Underhill 2005; Stubblefield et al. 1995*b*; Wiens et al. 2001). Ingestion of oil, from preening oiled feathers, drinking water with oil, or from oiled food sources, negatively impacts reproductive ability (Butler et al. 1988; Cavanaugh and Holmes 1987), disrupts hepatic function (Gorsline and Holmes 1981, 1982; Gorsline et al. 1981), osmoregulatory function (Holmes et al. 1978), increases metabolic rate (Butler et al. 1986), causes anemia (Balseiro et al. 2005; Leighton et al. 1983; Newman et al. 1999), and oxidative damage to red blood cells (Couillard and Leighton 1993; Newman et al. 1999). Reproductive disruptions include increased embryo mortality, decreased hatchling success, and decreased chick growth (Butler et al. 1988). Whether ingestion of low doses (i.e., dosage levels expected from exposure to oil sheens) results in toxic effects to marine birds has not been well-studied. In the following sections, we review studies that use controlled, relatively low doses of oil on adult and juvenile seabirds, and seabird eggs.

Toxicity of oil to adult aquatic birds

There are relatively few controlled-dose studies on direct toxic effects of low levels of oil to adult marine birds. An early study showed that acute oral LD_{50} values for several petroleum-derived products on waterfowl range from 7 to 20 mL/kg (Hartung and Hunt 1966). Some of the toxic effects common to all the industrial oils they tested were lipid pneumonia, gastrointestinal irritation, fatty changes in the liver, and adrenal cortical hyperplasia. They found that toxicity of oils was greatly enhanced when birds were stressed by crowded conditions and cold temperatures, lowering LD_{50} values to 1–4 mL/kg. Translating these results to seabirds, for a common murre (*Uria aalge*) weighing 1 kg for example, as little as 1 mL of ingested oil could result in death in cold climates.

Other studies have focused on testing effects of lower levels of oil ingestion. While not testing toxicity per se, Butler et al. (1986) internally dosed adult Leach's storm-petrels (*Oceanodroma leucorhoa*) with 0.1 mL of Purdue Bay Crude Oil (PBCO) and found a 25% increase in metabolic rate over control birds 24 h after dosing. They speculated that some of the metabolic increases seen from external oiling in other studies may be due to ingestion from preening. A recent study on yellow-legged gulls (*Larus michahellis*) breeding pairs internally dosed with only 0.04 mL of Prestige oil for 7 days showed significant, negative effects (Alonso-Alvarez et al. 2007*b*). Most notably, they found significant decreases in blood glucose and phosphorus, higher levels of two aminotransferases, and a significant decrease in blood calcium in female birds.

Similar to the increased effects of external oiling when exposed to multiple stressors, internal toxicity can be more severe and evident at lower doses when birds experience even minor cold stress. Holmes et al. (1978, 1979) fed ducks 3–6 mL of crude and fuel oil over 100 days. Bird death was minimal over the first half of the experiment while temperatures were maintained at 27 °C, but when temperatures were lowered to 3 °C, mortality in all of the oil-treated groups increased to 60%–90%. Birds in control groups also experienced an increase in mortality when under cold stress, but death did not occur as quickly or in as high numbers as in the oiled groups. The authors concluded that consumption of oil is problematic when there are multiple, additive physiological stressors.

Negative effects on reproduction have been shown to occur at relatively low levels of oil ingestion (e.g., Butler et al. 1988; Fowler et al. 1995; Miller et al. 1980; Peakall et al. 1982; Trivelpiece et al. 1984). Reproduction could be impacted by transfer of oil from adults to eggs, nestlings (discussed in following sections), or direct sub-lethal effects to adults that result in impaired ability to produce healthy eggs or provision offspring. Cavanaugh and Holmes (1987) fed female mallard ducks 3 mL/100 g dry food (no estimate was provided of actual amount of oil ingested per bird) each day for 50 days. They found significant decreases in reproductive hormones and significant delays in egg laying in the group fed oil. They hypothesized that such sub-lethal effects could seriously threaten survival of seabird populations, which characteristically have low annual recruitment of fledglings. Similarly, a series of studies using low doses of oil (2.5 mL/kg with ranges of actual doses from 0.02 to 0.3 mL per adult) found a 40% decrease in hatching success of Leach's storm-petrels, a decrease in chick survival up to 50% when a single member of a breeding pair was intubated, significantly lower weight gain of chicks with oiled parents, and damage to adult nasal and adrenal glands (Miller et al. 1980; Trivelpiece et al. 1984). The authors hypothesized that the decreased hatching success, chick growth, and chick survival likely were due to temporary desertion of the burrow and (or) impaired ability of oil-treated adults to provide for their young.

Despite evidence that even small amounts of ingested oil can impact adult metabolic rate, health, and reproductive output, there are other low- and high-dose studies that show no negative impacts on adults. In a study on oxidative damage to red blood cells in adult rhinoceros auklets (*Cerorhinca monocerata*) exposed to PBCO, low dose birds received 2.5 mL/kg body weight of oil for five consecutive days (Newman et al. 1999). There were no negative effects on any of the tested blood parameters. Stubblefield et al. (1995*a*) assessed acute and sub-acute toxicity of weathered Exxon Valdez crude oil (WEVC) on mallard ducks. In the acute tests, ducks were fed 5 g/kg body weight WEVC and observed for 14 d. They concluded that acute oral LD_{50} exceeded 5 g/kg and they observed no treatment-related toxicity during the study or in post-mortem examination. They hypothesized that weathered oil may be less toxic than unweathered oil. In addition, Alonso-Alvarez et al. (2007*b*), in the study described earlier on yellow-legged gulls, showed that the low dose of 0.04 mL of oil over 4 days showed no immediate effects on reproductive output. A study on the reproductive impacts of ingested oil in Cassin's auklets (*Ptychoramphus aleuticus*) found no effect of doses less than 0.6 g (~0.7 mL) of oil but did see a reduction in the number of eggs laid for birds in the 1 g dose group (Ainley et al. 1981). Cassin's auklets are about 3–4 times the weight of Leach's storm-petrels, which may in part account for the lack of effect on reproduction.

Toxicity to chicks and embryos

Chicks

Lab and field studies have shown that even small levels of oil ingested by chicks can impact nestling growth, metabolism, endocrine balance, and liver function (e.g., Butler and Lukasiewicz 1979; Lee et al. 1985; Peakall et al. 1980; 1982). Tests of effects of ingestion of PBCO and Hibernia crude oil were conducted on nestling herring gulls (*Larus argentatus*) (Lee et al. 1985). Birds received 4 mL/kg or 10 mL/kg (approximately 1.8 mL/bird and 4.6 mL/bird respectively) of PBCO or 10 mL/kg of Hibernia crude oil for six consecutive days. Hepatic cytochrome P-450 was increased fourfold, along with increases in other hepatic and renal mixed function oxidase activities, suggesting that ingestion of toxins induced a metabolic response to enhance elimination of toxic chemicals. In another study on herring gull nestlings receiving 10 mL/kg (approximately 4.6 mL/bird) of PBCO for 5 days, severe hemolytic anemia was evident (Leighton et al. 1983).

Miller et al. (1980), using lower doses than in the preceding studies, fed nestling herring gulls 1 mL of PBCO and examined changes in mass for 4days, comparing birds to a control group that were sham dosed. All birds were deprived of food during the experiment. The dosed birds lost mass at twice the rate of control birds and the authors hypothesized that oil dosing caused an increase in metabolic rate. Using even smaller doses, Peakall et al. (1980) fed nestling black guillemots (*Cepphus grille*) with 0.1–0.5 mL of weathered South Louisiana Crude Oil and detected a transient rise in plasma sodium, a decrease in growth rate, and hypertrophy of adrenal glands.

Prichard et al. (1997) fed pigeon guillemot (*Cepphus columba*) nestlings 0.05 and 0.2 mL of weathered PBCO twice, at 20 and 25 days post-hatching and examined blood for protein biomarkers related to health. They found only a weak treatment effect on blood proteins and no effect on sodium levels, liver enzymes, or bird growth or body mass and concluded that the doses used were not large enough to cause a negative impact. They also speculated that because weathered crude oil is less toxic than unweathered oil as a result of loss of low molecular weight aliphatics and aromatic fractions by evaporation and dissolution (Stubblefield et al. 1995*a*), their use of weathered crude oil may have resulted in minimal detectable impact.

While data indicate that nestlings may be more susceptible to acute effects from ingestion of low levels of oil, seabird nestlings would not be directly exposed to hydrocarbons from offshore drilling and production operations. However, transfer of oil to nestlings likely could occur through external contact with fouled plumage of adults (Albers 1980), transfer from adults to eggs (King and Lefever 1979), or through ingestion of contaminated food (Alonso-Alvarez et al. 2007*a*).

Embryos

There is some evidence that oil on eggs may negatively impact developing embryos, even at very low dose levels (Couillard and Leighton 1989, 1990, 1991; Hoffman and Albers 1984; King and Lefever 1979). While embryos were exposed externally in experiments, through transfer or application of oil to eggs, we include the discussion of embryo impacts in the internal toxicity section of this report because the primary impact is thought to be through toxicity. Couillard and Leighton (1989, 1990, 1991), in a series of studies on the effects of various oils on chicken (*Gallus gallus domesticus*) embryos, found that eggs externally dosed with 2.6–20 μL of various types of crude oil suffered subcutaneous edema, liver necrosis, dilation of the heart, renal tube mineralization, and enlargement of the spleen. When eggs were exposed to 5 μL of PBCO at 8–8.5 d old, there was 100% mortality. Exposure at 9 d old with12 μL of PBCO resulted in 32% embryo mortality, indicating that embryos may be particularly sensitive at certain developmental stages. Conversely, Stubblefield et al. (1995*b*) found no negative impacts on hatchling survival or growth after application of WEVC to 1/6–1/3 of mallard eggs. They concluded that their results may differ from similar studies that found negative impacts of crude oil on eggs because of the use of less toxic weathered oil in their study, as opposed to unweathered oil. Hoffman and Albers (1984) estimated LD_{50} levels of various types of crude and refined petroleum for mallard embryos. They found that many of the petroleum products were embryotoxic and had LD_{50} of 0.3–5 μL/egg.

Laughing gulls (*Leucophaeus atricilla*) dosed with 2.5 mL of oil to the breast feathers transferred oil to eggs, resulting in 41% embryo mortality compared to 2% for controls (King and Lefever 1979). They speculated that the cause of mortality was from egg smothering and (or) toxicity of the oil, rather than behavioural changes in the incubating adults. Albers (1980) exposed breeding mallards to water with 100 or 5 mL of PBCO per square metre of water surface area and observed breeding behaviour, hatching success, and duckling survival. The oil thicknesses that the birds were exposed to correspond to oil films 0.1 and 0.005 mm thick for the high and low treatments, respectively. The 0.005 mm treatment is only slightly thicker than a sheen (which are up to 0.003 mm thick). Albers found that there was oil transfer from adults to eggs in both treatments, in a dose-dependent fashion. Hatching successes (proportion of eggs hatched) were 96%, 80%, and 47% in the control, low, and high treatment groups, respectively. Survival rate of hatchlings and incubation behaviour of adults did not appear to differ among treatments. Albers concluded that subacutely oiled birds continue to incubate their eggs normally, but that transfer of oil to eggs could have devastating effects on embryos and hatchability.

Extrapolation to effects of oil sheens

Most studies on marine birds and oil have examined the effects of contact with large oily discharges that are not typical of produced water or SBM discharges, which typically cause thinner layers of oil of 3 μm or less in thickness (sheens). A light silver sheen, possibly the thinnest sheen that can be visually observed, and likely only on a clear day with calm water, is approximately 0.04 μm thick and has a hydrocarbon volume of about 0.04 mL/m^2 of sea surface. Thicker sheens that show trace colours are 0.1 μm, and bright to dark colour sheens are approximately 0.3–3 μm thick with a corresponding volume of 0.3–3 mL/m^2. How much oil a bird would pick up from a sheen is, of course, a critical question when assessing impacts. Lambert et al. (1982) observed that mallard ducks in a swim tank 50 cm × 52 cm × 30 cm with a 50 μm thick oil slick picked up almost all of the oil from the surface within a few minutes. The lipophilic (or hydrophobic) nature of the materials that make up feathers (keratin coated with waxes and esters) (Stephenson and Andrews 1997) likely cause them to readily adhere to oil. Birds swimming in sheens therefore could pick up an appreciable proportion of the surface oil that they contact directly. While the lipophilic nature of feathers could cause a "wicking" effect (i.e., oil moving in behind oil drawn up the feathers) causing greater oil absorption than would be estimated by direct contact, we keep our estimates conservative and do not factor in additional oil uptake from this potential wicking effect.

While studies point to "minute" amounts and "small spots" of oil causing significant impact and death, none quantified exact amounts meant by those qualitative descriptions. We hypothesize that those qualitative descriptions likely are equivalent to 1 mL of oil or less. There is definitive evidence of impacts of external and internal impacts of approximately 5 mL of oil ingested or on plumage. We therefore provide context for oil transfer of 1 and 5 mL when birds are exposed to sheens. For a bird to pick up 1 mL of oil from a trace colour sheen (~0.1 μm thick), it would need to swim through the equivalent of about 10 m^2 of sheen and pick up all of the oil from the area. A bird swimming through a colour sheen (~1–3 μm thick) could come in contact with 1 mL of oil in 0.3–1 m^2 of surface, making it likely that these thicker sheens could result in significant oil transfer. For a bird to pick up 5 mL of oil from a trace colour sheen (~0.1 um thick), it would have to swim through the equivalent of approximately 50 m^2 of sheen and pick up all of the oil from the area; not a likely scenario. Yet, a bird swimming through a colour sheen (~1–3 μm thick) could come in contact with up to 5 mL of oil less than 2 m^2 of surface, making it plausible that, at the least, 5 mL of oil could be picked up by a bird swimming in a colour sheen. In the next subsection, in the context of the literature discussed (Table A2), we assess whether oil from sheens could result in harm to marine birds.

External oiling

Effects on thermoregulation are proportional to the amount of oil to which birds are exposed and the extent of coverage on plumage, with only a small spot of oil, 5 mL, and 10 mL shown to significantly increase metabolic rate (Hartung 1967; Jenssen 1994; McEwan and Koelink 1973). Studies have reported that even "minute" oiling of plumage can be fatal to birds when combined with stresses imposed by severe environmental conditions (Hartung 1967; Levy 1980; McEwan and Koelink 1973). This is supported by our studies, which show disruption of feather microstructure, and oil and water uptake when feathers are exposed to thin sheens of petroleum and fish oil (Morandin and O'Hara 2014; O'Hara and Morandin 2010). In addition, beached bird surveys commonly find dead birds with only small spots of oil on their plumage. Researchers believe that these small amounts of oil (possibly equivalent to about 1 mL of oil) when found on beached birds, particularly when it is heavy oil, result in wetting and hypothermia, and are the primary cause of death (Francis Wiese, Pers. Comm., July, 2016).

Internal

It is unlikely that exposure to oil sheens resulting from discharges of hydrocarbons within regulated amounts would cause acute toxic effects to adult seabirds. However, a number of studies have found sub-lethal effects and reproductive effects on adult birds, when as little as 0.02–3 mL of oil was ingested, singly or over a number of days. The primary route of internal exposure for birds exposed to sheens is from preening oiled feathers (although ingestion can also occur from "drinking" oiled water and eating oiled food).

Studies show that birds will preen from 50% to "most" and "all" of the oil from their feathers over a few days (Birkhead et al. 1973; Camphuysen 2011; Hartung 1963, 1964; Stubblefield et al. 1995*a*). Using the conservative estimate of 50% of oil on plumage preened and ingested, a bird fouled with 0.04 mL of oil on its plumage could experience sub-lethal toxic effects described in previous sections. Because a sheen can have up to 3 mL of oil per square metre, it is plausible that a seabird swimming in a sheen could pick up at least 0.04–2 mL of oil on its feathers. It is reasonable to propose then, that some sub-lethal toxic effects are experienced by adult seabirds from sheen exposure. It is important to emphasize that some studies on adult birds (reported in previous sections and in Table A2) found no effects of low levels of oil ingestion on factors they tested. Possible explanations for differences between study findings are the use of weathered versus unweathered oil, species, and (or) size of bird tested, and responses tested. Therefore, sub-lethal effects of sheens on adult seabirds is expected to vary based on factors, such as age of oil that a bird contacts (weathered or unweathered), bird species and size, and feeding mode.

Nestlings are more susceptible to acute toxicity from low levels of oil ingestion than adult birds, showing consistent, negative effects with ingestion levels as low as 0.1 mL. Nestlings, however, do not come in direct contact with sheens, and transfer rates to nestlings from oiled adults have not been quantified. It is plausible that adults exposed to oil sheens could transfer small amounts of oil to nestlings at sufficient dosages to cause toxic effects, based on the low nestling toxicity threshold.

Like nestlings, eggs will not come in direct contact with sheens; however, embryos are susceptible to even minute amounts of oil. King and Lefever (1979) showed that 2.5 mL of oil applied to incubating laughing gulls resulted in 41% embryo mortality (compared to 2% in controls); it therefore follows that birds exposed to thicker sheens could pick up oil at levels that cause significant embryo mortality. Albers (1980) found transfer of oil to eggs from adults that were oiled from slicks that were only slightly thicker than sheens. There was decreased hatching success of eggs compared to control eggs, making it one of the few studies to show a direct causal link between oil sheens and decreases in reproductive output. With an LD_{50} for mallard embryos of 0.3–5 μL a bird would need to pick up only 0.1 mL of oil and transfer about 5% to an egg in order for the egg to be dosed with 5 μL of oil. While species will differ in their susceptibility to oil, these findings make it plausible that some amount of embryo mortality is occurring from seabird exposure to sheens. However, it should be noted that exposure of adults (and consequently, nestlings and eggs) to oil discharged in the production areas in the Atlantic is unlikely during breeding because most Atlantic species do not travel during foraging trips as far as oil platforms, which lie approximately 300 km offshore. Leach's storm-petrel are an exception as birds breeding in Nova Scotia have been shown to fly thousands of kilometres in single foraging trips during the breeding season (Pollet et al. 2014).

Population effects

Studies of marine bird populations following major oil spills indicate that there are both short- and long-term negative impacts on populations (Esler et al. 2000, 2002; Golet et al. 2002; Irons et al. 2000; Lance et al. 2001; Votier et al. 2005). Population effects following oil exposure will vary based on many factors including whether the species are pelagic or not (Lock et al. 1994; Votier et al. 2005), and feeding mode, such as diving (Irons et al. 2000) or surface feeding birds (Butler et al. 1988). Further, it is reasonable to expect vulnerability to vary within species with life history stages and annual cycles. For example, immature birds may be less capable of preening and recovering feather function than older, more experienced birds. Birds may also be more susceptible to effects of external oiling during moult, particularly if they experience periods of flightlessness (Stone et al. 1995).

Some of the most vulnerable birds to oil spills in Canada (chronic and acute) are alcids, with murres often making up the largest proportion of dead individuals found after spills (Irons et al. 2000; Robertson et al. 2006; Wiese and Ryan 2003). Models estimating recovery time of pelagic bird populations following large or chronic discharges are hampered by the inadequacy of data to form the basis for these models; however, there is some suggestion that even very small decreases in fecundity or adult survivorship cause large increases in recovery time, especially for those species with already low reproductive rates and adult recruitment (Ford et al. 1982). In addition, chronic, low-level pollution could result in changes in survivorship and fecundity that make populations more susceptible to large-scale perturbations (Ford et al. 1982). It has been proposed that chronic discharges may be more detrimental to seabird population stability than periodic major discharges (Burger 1992; Wiese and Ryan 2003) and it has been shown that timing and location of oil is a better determinant of seabird mortality, and population effects, than volume of oil (Burger 1993). Further, Wiese et al. (2004) showed how multiple anthropogenic stressors can lead to cumulative effects when mortality rates attributable to these stressors are additive as opposed to compensatory.

Understanding how seabirds interact with offshore oil and gas operations can also be important for estimating potential impacts from operational discharges of hydrocarbons. It is known that some seabird species are attracted to offshore drilling and production structures, potentially exacerbating any impact that hydrocarbon discharges from offshore operations could have (Burke et al. 2012; Fifield et al. 2009; Ronconi et al. 2015). Tasker et al. (1986) estimated that seabirds were approximately seven times more dense within 500 m of platforms than in locations further from platforms. Similarly, Baird (1990) estimated bird density increases of six to seven fold in locations after commencement of drilling and production operations. In Atlantic Canada, Wiese et al. (2001) estimated that seabird concentrations near offshore oil platforms in the Grand Banks were 19–38 times higher than in transect locations more remote to platforms. However, Hurley (2000) showed no evidence of avoidance or attraction to Nova Scotia platforms.

It has been noted that a lack of monitoring and data on seabird distributions at sea, and co-occurrence with offshore drilling operations hinder risk assessment (Burke et al. 2012; Hedd et al. 2011). Despite regular standardized seabird monitoring that has been conducted from offshore oil and gas platforms in the North East Grand Banks since 1997, a number of challenges were identified by Baillie et al. (2005) that precluded useful analyses (e.g., study design, observer training, and data management). Although some of these challenges have been addressed, there remain issues with protocol compliance, data management, and species identification that all could be addressed potentially with sufficient training (Fifield et al. 2009).

Seabird populations are at risk from any mortality because of their slow intrinsic population growth rates, particularly if they are already stressed from other factors. The consensus of data show that sheen-level hydrocarbon exposure can harm individual birds through external exposure and internal sub-lethal toxicity; any added mortality due to sheens, however minor, should be considered as part of the cumulative effects on these species. Effects of sheens on seabird populations are only speculative at this point and specific research is critical before possible implications for population level impacts can be identified, understood, and managed.

Conclusion

Sheens regularly occur around offshore drilling and production operations under Canada's current regulatory limits on hydrocarbon discharges. Because operational discharge regulations in other parts of the world are similar to Canadian regulations, frequency of sheen occurrence from oil and gas operations, and threat to seabirds, likely is similar in other locations with significant seabird populations. Pelagic seabirds are found in areas where current offshore operations are located and some species are attracted to offshore drilling and production structures, making it probable that there is regular contact between marine birds and sheens around platforms. Contact with sheens can cause damage to feather microstructure and may result in reduced buoyancy, and (or) water penetration and increased metabolism. Depending on other stressors, such as cold weather, disruption of feather microstructure from sheens could cause death from hypothermia or starvation. In addition to metabolic disruption, low levels of external oiling could alter behaviour resulting in more time preening and less time feeding and tending nests. Thus, low levels of external oiling could have more significant impacts during the breeding season. Conversely, internal acute toxic effects are unlikely from exposure to sheens around offshore oil and gas operations. Yet, sub-lethal effects are likely; impacting health and reproduction either through a number of mechanisms including inadequate provisioning of the nestlings, altered incubation behaviour, and (or) transfer of oil from adults to eggs and nestlings. Sheens from offshore oil and gas platforms therefore are a probable contributor to the cumulative effects of anthropogenic stressors on marine birds.

We have not focused on large accidental discharges from drilling and production operations that exceed regulatory limits. These events occur occasionally, yet regularly, at drilling and production platforms. Depending on factors such as magnitude of the discharge, climatic conditions, local bird populations, and time of year, these events likely cause impacts to seabird individuals, reproduction, and populations.

Pelagic seabird populations may be detrimentally affected because of the life-history characteristics that make them particularly vulnerable to increased adult mortality or decreased reproductive output; subtle impacts from contact with sheens around offshore drilling and production operations. However, whether these likely impacts to individuals have long-term effects on populations is speculative at this point due to (i) lack of data on incidence of seabird oiling around platforms; (*ii*) more consistent monitoring, reporting, and transparency of the likelihood, persistence, fate, and thickness of sheens resulting from discharges associated with produced water and drilling muds; (*iii*) controlled studies that directly quantify effects of sheens on seabirds; and (*iv*) long-term effects on pelagic seabird abundance in Atlantic Canada.

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Appendix A

Tables A1 and A2 appear on the following pages.

Table A1. Sheen occurrence around offshore oil and gas production platforms in the Canada-Newfoundland and Labrador offshore area.

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2003	7	27	SBM on cuttings	NA	NA	NA
2003	7	29	SBM on cuttings	Winds 26 kn WS, swh 1.1 m, visibility 15 nm	Oil from cuttings pile rising to surface	Sheen approximately 50 m by 150 m.
2003	9	25	Produced water discharge	Winds 5 kn SW, swh 2.3 m, visibility 10 nm	Produced water discharge	Grey sheen approximately 50 m × 150 m and progressively became dull as it extended out. PW OIW at 07:00 was 67 mg/L, at 10:00 was 31 mg/L, at 14:00 was 34 mg/L.
2003	10	16	Produced water discharge	Winds 20 kn SE, swh 2.4 m, visibility 15 nm	Produced water discharge	Grey finger-like sheen approximately 30 m by 40 m, that became progressively dull as it extended outward.
2003	10	18	Produced water discharge	Winds 7 kn W, swh 2.2 m, visibility 15 nm	Produced water discharge	NA
2003	10	26	Produced water discharge	Winds 7 kn NW; swh 3 m visibility 15 nm	Produced water discharge	Blue–grey finger 50 m wide by 100 m became progressively duller as it extended outward. PW OIW at 06:15 was 61 mg/L.
2003	11	8	Not determined	Winds 9kn SEE, swh 2.5 m visibility 15 nm	Not determined	Blue–grey finger approx. 50 m × 300 m, which became progressively dull as it extended outward. PW OIW at 6:20 was 40 mg/L.
2003	11	17	Produced water discharge	Winds 14 kn WSW, swh 3.5 m, visibility 15 nm	Produced water discharge	Blue–grey finger approx. 100 m by 100 m, which became progressively dull as it extended outward. PW OIW at 12:00 was 39 mg/L.
2003	11	19	Produced water discharge	Winds 9 kn NW, swh 3.5 m, visibility 15 nm	Produced water discharge	A blue–grey finger approximately 100 m by 500 m, which became progressively dull as it extended outward. PW OIW at 07:00 was 46.5 mg/L.
2003	11	24	Produced water discharge	Winds 34 kn EN, swh 2.2 m, visibility 3/4 nm	Produced water discharge	Blue–grey sheen approximately 100 m by 150 m and became progressively dull as it extended outward.
2003	11	26	SBM on cuttings	—	Discharge of cuttings with low synthetic oil on cuttings resulting in the synthetic base oil appearing on the surface	A substance was sighted in the water which had a hydrocarbon appearance to it.
2003	12	6	Produced water discharge	Winds light and variable NWN	Produced water discharge	A blue–grey sheen approximately 100 m by 100 m and progressively dull as it extended outward. PW OIW at 07:30 was 112 mg/L.
2003	12	9	Produced water discharge	Winds 18 kn SW, swh 4.5, visibility 6 nm	Produced water discharge	A blue–grey sheen approximately 100 m by 150 m. The discharge became progressively dull as it extended outward. PW OIW at 07:30 was 137 mg/L.
2003	12	17	SBM on Cuttings	Unknown	Discharge of cuttings with low synthetic oil on cuttings resulting in the synthetic base oil appearing on the surface	A substance was sighted in the water which had a hydrocarbon appearance to it.
2004	1	19	Produced water discharge	Winds 9 kn NNW; swh 2 m; vivibility 8 nm	Possibly from produced water discharge	A bluish-grey sheen intermittently covering an area about 150 m by 400 m with approx. 15% coverage. PW OIW at 06:00 14.8 mg/L.
2004	4	2	Not determined	Winds 19 kn NNW, swh 2.3 m visibility 10 nm	None identified	A blue–grey sheen about 50 by 150 m that became progressively dull with distance. PW OIW was 25 mg/L at 06:00.
2004	4	9	SBM on Cuttings	Winds 25 kn SES; swh 1.2 m; visibility 15 nm	Oil from cuttings pile rising to surface	A blue–grey sheen 150 m by 20 m.
2004	4	30	Suspect Produced Water Discharge	Winds 25 kn NE; swh 2.2 m; visibility 1 nm	Suspect produced water discharge	A blue–grey sheen about 30 m by 500 m.
2004	5	3	NA	Winds 15 kn ES; swh 2.5 m; visibility 0.25 nm	NA	A blue–grey sheen about 200 m by 500 m. PW OIW at 08:00 was 28.1 mg/L.
2004	5	19	SBM on Cuttings	NA	Cuttings	A substance was sighted on the ocean.
2004	5	27	Not determined	Winds 10 kn ENE, swh 2.7 m, visibility 10 nm	Not determined	A blue–gray sheen 200 m by 100 m. PW OIW at 18:00 was 25 mg/L.

Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2004	6	14	Not determined	Winds 0 kn variable; swh 1.5 m; visibility 10 nm	Not determined	A blue–grey sheen, 100 m × 75 m.
2004	7	1	SBM on Cuttings	NA	NA	Discharge of residual SBM and sediment from cleaning of pits.
2004	7	1	Not determined	Winds 9 kn S, swh 1.0 m, visibility 0 nm	Not determined	A blue–grey sheen 75 m by 200 m. PW OIW content at 14:00 was 39 mg/L.
2004	7	13	Not determined	winds 7 kn NW, swh 2.0 m, visibility 15 nm	Not determined	A blue–grey sheen 50 m × 500 m.
2004	8	12	Suspected Produced water discharge	Winds NW, 12 kn, swh 1.5 m, visibility 15 nm	Seas "very calm"	Blue–grey sheen estimated at 100 m × 300 m, PW OIW at 07:00 was 42 mg/L; at 10:00 was 33 mg/L; at 14:40 was 33 mg/L; at 17:00 was 56.2 mg/L.
2004	8	26	Suspected Produced water discharge	Winds 35 kn NE; swh 2.1; visibility 5 nm	Possible produced water discharge	A blue–grey sheen, 100 m × 500 m. PW OIW at 14:00 was 44.8 mg/L.
2004	10	1	Produced water discharge	Winds 28 kn SEE; swh 1.5 m visibility o nm	Possible produced water discharge	A blue–grey sheen 75 m by 100 m was reported on the south side of the installation. Oil content of the discharged produced water at 06:30 was 85 mg/L. The sheen has been attributed to the produced water discharged.
2004	10	16	Produced water discharge	NA	Oil in water content of produced water exceeded daily limit, am sample 107.7 mg/L pm sample 53.6 mg/L	A silvery sheen approx. 30 m by 20 m. Dissipating with wave action.
2004	10	17	Suspected produced water discharge	Winds 8 kn NE; swh 1.8 nm, visibility 10 nm	Possible produced water discharge	A blue–grey sheen, about 50 m by 200 m.
2004	11	3	Suspected produced water discharge	Winds 32 kn E by N; swh 4.0; visibility 4.0 m; visibility 5/8 nm	Possible produced water discharge	A blue–grey sheen. The estimated total size of the sheen was 70 by 200 m. PW OIW at 07:00 was 31.7 mg/L.
2004	11	9	Produced water discharge	Winds light and variable; swh 2.1 m, visibility 3/8 to 2 nm	Startup mode following EPA/ESD	A blue–grey sheen approx. 200 by 500 m. PW OIW at 06:30 was 41 mg/L.
2004	11	26	Produced water discharge	NA	NA	Associated with past spill.
2004	11	27–28	Produced water discharge	NA	NA	Sheen approx. 30 × 350 m. associated with past spill.
2004	11	28	Fire Pump operations	NA	NA	Incident of sheen observed.
2004	12	10	Produced water discharge	Winds 6 kn S; seas 1 m; visibility 15 nm	Very calm conditions, little dispersion of produced water plume when surfaced	A blue–grey sheen approx. 100 m by 400 m. PW OIW at 06:30 was 26 mg/L; at 15:00 was 31 mg/L.
2004	12	16	Produced water discharge	Winds 21 kn ENE; seas 2.6 m; visibility 8 nm	High OIW concentrations in PW discharge	A blue–grey sheen approx. 170 m × 700 m. PW OIW at 07:00 was 22.5 mg/L; at 09:30 was 101 mg/L.
2004	12	22	Produced water discharge	Winds 25 kn at 250 T; swh 5.2 m; visibility 10 nm	NA	A sheen, bluish-gray, with light patches of dull brown, was observed approx. 100 × 600 m. PW OIW 21 mg/L.
2004	12	26	Produced water discharge	Winds N at 17 kn; swh 2.5 m; visibility 15 nm	NA	A blue–gray sheen 1.5 m × 25 m. PW OIW at 06:30 was 28 mg/L; at 15:00 was 38 mg/L.
2004	12	29	Suspected produced water discharge	Winds W 24 kn; swh 4.8 m; visibility 15 nm	NA	Bluish-grey sheen about 25 m × 200 m. PW OIW at 07:00 was 25 mg/L.
2004	12	29	Suspected produced water discharge	Winds W 33 kn; swh 3.8 m; visibility 15 nm	Produced water discharge	Bluish-grey sheen, intermittently covering area of 10 m × 50 m. PW OIW was 4 mg/L.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2005	2	1	Suspected produced water discharge	0830 obs were WS 14 kn from 350°; swh 4.3 m; MCS 7.2; visibility 15 nm	Possible produced water discharge	Surveillance flight reported 0.5 mile by 100 ft sheen. Operator subsequently reported as 0.75 nm × 100 ft. PW OIW at 08:40 was 41.6 mg/L.
2005	2	2	Produced water discharge	WS 10 kn from 010°; swh 1.8 m; visibility 15 nm	Produced water discharge	Blue–gray sheen approx. 30 m × 100 m fading to small individual patches. Seas calm. PW OIW was 53.6 mg/L.
2005	2	3	Produced water discharge	WS 10 kn from 050°; swh 1.5 m; visibility 15 nm	Suspected produced water discharge	"Transparent" sheen observed about 30 m wide by 100 m long. Seas very calm and low winds. PW OIW at 06:30 was 22 mg/L; at 11:30 was 19 mg/L.
2005	2	4	Suspected produced water discharge	WS 40 kn from E; swh 1.6 m; visibility 1/8 nm	Suspected produced water discharge	Sheen with discontinuous blue–gray patches and spots of light brown observed. Extended to the south in fractured 20 m wide form to about 150 m. Sea surface was calm. PW OIW at 05:45 was 25.2 mg/L; at 10:35 was 26.1 mg/L; at 16:00 was 40.9 mg/L; at 17:45 was 37.5 mg/L.
2005	2	7	Produced water discharge	Winds 27 kn 070°; swh 3.2 m; visibility 8 nm	Produced water discharge	Surveillance flight reported 0.5 nm long, 50 foot wide sheen. PW OIW at 08:30 was 29.3 mg/L; at 10:15 was 27.7 mg/L; at 14:45 was 34.5 mg/L.
2005	2	7	Produced water discharge	Seas calm	Produced water discharge	Sheen of discontinuous blue–gray patches observed, 1–2 m wide finger-shaped patches extending to approx. 150 m. PW OIW at 10:15 was 27.7 mg/L; at 14:45 was 34.5 mg/L.
2005	2	8	Produced water discharge	Winds 13 kn 040°; swh 1.5 m; visibility0.5 nm in fog	Produced water discharge	Non-continuous blue–gray patches of sheen about 30 m by 100 m long. Seas calm in vicinity. PW OIW at 06:50 was 44 mg/L; at 11:30 was 46 mg/L; at 14:00 was 28.3.
2005	2	23	Suspected produced water discharge	Winds 30 kn 070°; swh 2 m	Suspected Produced water discharge	Blue–gray sheen approx. 100 m × 350 m, in fingers. PW OIW at 06:30 was 26.9 mg/L.
2005	3	25	Produced water discharge	Winds 29 kn 110°; swh 1.5 m; visibility 15 nm	Produced water discharge	Light silvery sheen about 100 m long. PW OIW at 17:30 was 39 mg/L.
2005	3	26	Produced water discharge	Winds 17 kn 070°; swh 0.7 m; visibility 15 nm	Produced water discharge	Surveillance flight observed slick/sheen about 2.7 km × 100 m in discontinuous patches. PW OIW at 06:30 was 74.3 mg/L; at 09:00 was 22 mg/L.
2005	3	29	Produced water discharge	Winds 10 kn 170°; swh 0.5 m; visibility 15 nm	Produced water discharge	Light silvery sheen observed 100 m wide and extended to south. PW OIW at 16:30 was 24.9 mg/L.
2005	4	3	Produced water discharge	Winds 18 kn 100°T; swh 1.5 m; visibility 15 nm	Produced water discharge	Silvery sheen observed about 40 m × 60 m extending to south. PW OIW at 07:10 was 41.3 mg/L; at 17:10 was 35.9 mg/L.
2005	4	4	Produced water discharge	Winds17 kn SE, swh 1 m visibility 15 nm	PW discharge	A sheen about 100 m by 500 m. Appeared as finger-like patches, along zones of convergence were non-continuous small dull brown patches ringed in blue grey prior to dispersing. PW OIW at 15:30 was 73.8 mg/L; at 17:25 was 28.5 mg/L.
2005	4	17	Residual from spill	Winds 18 kn NE; swh 2.7 m; air temp 2 °C; visibility 5 nm	Residual from spill	Weathered crude.
2005	6	2	Produced water discharge	Winds 8 kn E; swh 0.8 m visibility 8 nm	Produced water discharge	A light slivery sheen 30–50 m wide extending in a southerly direction. PW OIW at 06:10 was 21.2 mg/L.
2005	6	13	Produced water discharge	Winds 11 knkn N; swh 2.1 m, visibility 7 miles	Produced water discharge	Transparent sheen extending to south beyond 300 m. Sea conditions calm. PW OIW at 06:50 was 26.5 mg/L.
2005	6	17	Produced water discharge	Winds 7 kn from 260°; SWH 1.3 m; visibility 15 nm	Produced water discharge	Non-continuous blue–gray sheen observed extending to south in fingers 1–2 m wide. Seas calm. PW OIW at 07:00 was 51 mg/L; at 10:00 was 42 mg/L.
2005	6	19	Produced water discharge	Winds 19 kn from 080°; swh 1 m; visibility 7 nm	Produced water discharge	Non-continuous blue-gray sheen observed extending south in fingers 1–2 m wide. Seas calm. PW OIW at 07:00 was 34.8 mg/L; at 17:00 was 38.5 mg/L.

Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2005	7	9	Produced water discharge	NA	Produced water discharge	Slivery sheen 150 m × 5 m.
2005	7	14	Produced water discharge	Winds 27 kn 220°; swh 1.0 m; visibility 0 nm	Produced water discharge	A blue–grey sheen extending about 100 m in a southerly direction.
2005	7	17	Residual from spill	Winds 24 kn WSW; swh 1.0 m; air temp 11.3 °C; visibility 1.5 nm	Residual from spill	Slick estimated to be 50 m by 4 m, contains a lot of marine growth.
2005	7	23	Produced water discharge	Winds 3 kn EN; swh 0.5 m; visibility 0 nm	Produced water discharge	A sheen consisting of non-continuous patches was observed extending south in 1 to 2 m wide fractured finger shapes.
2005	7	23	Residual from spill	Winds 15 kn SW; swh 1.4 m; visibility 1/8 nm in fog	Residual from spill	Installation reported sheen 2 m × 150 m.
2005	7	26	Residual from spill	NA	Residual from spill	Sheen 2 m × 150 m.
2005	7	29	Residual from spill	NA	Residual from spill	Two slicks showing bright bands of color about 15 m × 15 m with a tail about 2 M × 400 m.
2005	7	31	Residual from spill	Winds 4 kn; swh 1.3 m air temp 15 °C visibility 15 nm	Residual from spill	A silvery sheen about 20 m × 150 m. Seas were calm.
2005	8	3	Residual from spill	NA	Residual from spill	Residual crude.
2005	8	6	Residual from spill	Winds 25 kn, swh 2.5 m, air temp 16 °C, visibility 0 nm	Residual from spill	Silvery sheen with 10% darker colors 20 m × 20 m.
2005	8	7	Residual from spill	NA	Residual from spill	Sheen covered an approximate are of 4000 m^2. Weathered crude.
2005	8	8	Residual from spill	NA	Residual from spill	A sheen.
2005	8	9	Residual from spill	NA	Residual from spill	A sheen about 2400 m^2.
2005	8	17	Residual from spill	Winds 28 kn ESE	Residual from spill	A sheen. Likely weathered crude.
2005	8	18	Residual from spill	NA	Residual from spill	A sheen.
2005	8	22	Residual from spill	NA	Residual from spill	A sheen 1 m × 200 m attributed to residual from spill.
2005	8	24	Residual from spill	NA	Residual from spill	A silvery grey sheen covering about 3000 m^2 attributed to residual from spill.
2005	8	30	Residual from spill	NA	Residual from spill	Rosebuds silvery with bright coloured centres.
2005	8	30	Residual from spill	NA	Residual from spill	Sheen.
2005	8	31	Residual from spill	NA	Residual from spill	Rose buds small in size and silvery grey in appearance forming small dispersed sheens which were being dissipated.
2005	9	8	Residual from spill	NA	Residual from spill	Sheen.
2005	9	9	Residual from spill	NA	Residual from spill	Sheen attributed to residual from spill.
2005	9	13	Residual from spill	NA	Residual from spill	Sheen attributed to residual from spill.
2005	9	18	Produced water discharge	Winds 3 kn SE; swh 0.5 m; visibility 6 nm	Produced water discharge	A sheen consisting of non-continuous blue/grey patches to form small fingers.
2005	9	19	Residual from spill	NA	Residual from spill	Sheen attributed to residual from spill.
2005	9	23	Residual from spill	NA	Residual from spill	Sheen rose budding attributed to residual from spill.
2005	9	25	Residual from spill	NA	Residual from spill	Sheen rose budding attributed to residual from spill. Dissipating very quickly due to heavy seas.
2005	10	1	Residual from spill	NA	Residual from spill	Sheen.
2005	10	7	Residual from spill	Winds 15 to 17 kn; swh 3.1 m visibility 15 nm	Residual from spill	Sheen estimate covering 1200 m.
2005	10	9	Residual from spill	Winds 15 to 17 kn; swh 3.1 m visibility 15 nm	Residual from spill	Sheen covered 1000 m by 400 m; 30% sheen 60% silvery and 40% bright bands of color.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2005	10	30	Residual from spill	Winds 15 to 17 kn; swh 3.1 m visibility 15 nm	Residual from spill	Sheen attributed to residual oil.
2005	11	3	Residual from spill	Winds 15 to 17 kn; swh 3.1 m visibility 15 nm	Residual from spill	Sheen reported attributed to residual oil.
2005	12	2	Produced water discharge	Winds 19 kn ES; swh 0.7 m visibility 15 nm	Produced water discharge	A light slivery sheen 20–30 m wide extending in a southerly direction in narrow finger-like formations. PW OIW at 07:00 was 26 mg/L.
2005	12	13	Residual from spill	Winds SE 32 kn kn; swh 2.9 m visibility 0 nm	Residual from spill	Believed to be residual oil.
2005	12	26	NA	NA	NA	No further details.
2006	1	4	Residual from spill	NA	Residual from spill	Silvery sheen about 30 m by 10 m.
2006	2	5	Process area centrifuge	Winds 7 kn NNW; swh 0.7 m; visibility 15 knm	Oil water interface detection malfunctioned	A light silvery sheen, 20 m × 30 m extending in a southerly direction, calm conditions.
2006	2	7	NA	Winds 20 kn SW; swh 2.8 m; visibility 1/8 nm	Sample taken	A light silvery sheen about 20 m × 30 m extending in a northwesterly direction in long narrow finger-like formations. PW OIW was 24.5 mg/L.
2006	2	8	Residual from spill	NA	Residual from spill	A sheen 50 × 4 m.
2006	2	24	Residual from spill	NA	Residual from spill	Attributed to residual oil.
2006	3	13	NA	Winds 20 kn NWW; swh 3.4 m; visibility 15 nm	NA	A light silvery sheen about 30 m × 60 m in a southerly direction. PW OIW was 10.5 mg/L.
2006	3	16	OIW analyzer discharge hose	NA	NA	NA
2006	3	17	Produced water discharge	Wind 17 kn, 240°, swh 2 m, visibility 15 nm	Produced water discharge	A light silvery sheen measuring 40 m × 60 m and extending to southeast.
2006	4	21	Residual from spill	NA	Residual from spill	Attributed to residual oil.
2006	4	27	Residual from spill	NA	Residual from spill	Sheen observed about 30 m × 20 m, 95% barely visible 5% silvery sheen.
2006	4	28	Residual from spill	NA	Residual from spill	Attributed to residual oil.
2006	5	6	Residual from spill	Wind 5 kn SSE; swh 2 m air tem 9 °C; visibility 1/8 nm	Residual from spill	Sheen about 120 m × 5 m; 40% silvery, 40% trace color and 20% bright bands.
2006	5	7	Residual from spill	Winds 21 kn ESE; swh 1.9 m; sea temp –4.9 °C; air temp –8.8 °C; visibility 1 1/2 nm on mist	Residual from spill	Sliver sheen 100' × 3' volume estimate 0.00225.
2006	5	9	Suspected produced water discharge	Winds 25 kn ESE; swh 1.5 m visibility 5 nm light rain and mist	Possibly produced water discharge	A light slivery sheen.
2006	5	16	Suspected produced water discharge	Winds 8 kn NE; swh 0.9 m visibility 0 nm light rain and mist	Possibly produced water discharge	Sheen consisting of broken silvery and grey patches about 10 m × 20 m. Calm seas.
2006	5	18	Residual from spill	—	Residual from spill	Sheen 100 m × 2 m attributed to residual oil.
2006	5	18	Suspected produced water discharge	Winds 4 kn SE by E; swh 1.1 m visibility 0 nm light rain and mist.	Possibly produced water discharge	A sheen patches of silver, grey and occasional tan spots was observed approximately 10–20 m.
2006	7	4	Suspected grey/blackwater discharge	Wind 20 kn 240°, swh 1.8 m, temp 12 °C	Possibly grey or blackwater related	A film/sheen was observed. Very light sheen, fingered, no colours. Analyses determined likely not petroleum.
2006	8	18	Suspected produced water discharge	NA	Possibly produced water discharge	Slight sheen. The seas were calm. The cause was not known at that time; it may be from the produced water or separators.
2006	9	1	Produced water discharge	Wind 40 kn NE; swh 3.0 m; visibility 2.5 nm	Possibly produced water discharge	A produced water blue–grey sheen, about 50 m × 300 m, was reported. PW OIW at 06:30 was 31.1 mg/L.

Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2006	9	2	Produced water discharge	Winds 20 kn NE; swh 2.0 m; visibility 1.5 nm	Possibly produced water discharge	A produced water blue–grey sheen, about 50 m × 300 m, was reported. PW OIW at 06:30 was 37.2 mg/L.
2006	9	3	Cuttings	NA	Possibly sheen from cuttings discharge	Sheen estimated 0.137 L likely a result of a buildup of SBM cuttings in the overboard discharge line.
2006	10	15	Suspected produced water discharge	Winds 30 kn ESE; swh 2.3 m; visibility 100 m	Suspected produced water discharge	A sheen about 40 m wide consisting of multiple streamers of silvery grey and blue and dull colors. The sheen appears to have originated from the produced water outlet. Sheen lasted for 10–12 minutes.
2006	10	21	Suspected produced water discharge	Winds 8 kn E N; swh 1.8 m; visibility 15 nm	Suspected produced water discharge	A sheen consisting of broken blue grey colored patched/ fingers. The sheen was about 100 m × 800 m. Due to calm condition some of the oil remained adjacent to form brown patches 20 m × 5 m. PW OIW was 31 ppm.
2006	10	28	Suspected produced water discharge	Winds 31 kn SSE, swh 2.5 m; visibility 10 km	Suspected produced water discharge	A sheen 2–3 m in width consisting of light silvery streaks interspersed with occasional rainbow was observed moving in a westerly direction beyond 300 m.
2006	11	7	Suspected produced water discharge	Winds 2 kn, WSW, swh 0.7 m visibility 15 nm	Suspected produced water discharge	A sheen about 3515 by 200 m 50% coverage. Difficult to tell sheen from what appeared to be thermal plume. Conditions very clam with 0.5 m waves at the time of the report and low winds. PW OIW was 21 ppm.
2006	11	9	Suspected produced water discharge	Winds 5 kn SE; swh 0.6 m; visibility 8 km	Suspected produced water discharge	A sheen consisting of small silvery patches interspersed with occasions rainbow colors was observed moving in a westerly direction and accumulating to form a wider sheen beyond 300 m. PW OIW at 06:00 was 33.6 ppm.
2006	11	26	Suspected produced water discharge	Winds 17 kn NW; swh 4.1 m; visibility 15 km	Suspected produced water discharge	A sheen consisting of small silvery patches interspersed with occassional rainbow colors was observed moving in a westerly direction.
2006	12	13	Suspected produced water discharge	Winds 4.5 kn NW by W, swh 4.5 m; visibility 15 nm	Suspected produced water discharge	Sheen 3 m in width consisting of small silvery patches interspersed with occasional rainbow colors was observed moving in a easterly direction beyond 300 m. Produced water at 13:00 was 51.4 ppm.
2007	2	11	Suspected produced water discharge	Winds 13 kn WSW	Suspected produced water discharge	A sheen consisting of silvery patches interposed with rainbow colors was observed moving in a westerly direction. PW OIW morning sample 25.8 mg/L; at 11:03 was 28.4 mg/L.
2007	4	1	Suspected produced water discharge	Winds 45 kn NNW, swh 2 m, visibility 2 nm	Suspected produced water discharge	A light silvery sheen measuring approximately 20–20 m wide and extended off in a southeasterly direction in narrow fingerlike formations.
2007	4	3	Suspected produced water discharge	Winds 50 kn N, swh 4 m. visibility 8 nm	Possibly produced water discharge	A slivery sheen measuring approximately 10–20 m wide and extended in a southerly direction in narrow finger-like formations. PW OIW 31 mg/L.
2007	5	18	Suspected produced water discharge	Winds 12 kn SW; swh 2.0 m; visibility 5 nm	Possibly produced water discharge	A sheen consisting of silvery finger-like projections 15 to 20 m wide was observed moving in a SW direction. PW OIW at 14:00 32 mg/L.
2007	6	10	Suspected produced water discharge	Winds 16 kn SW; swh 1.0; visibility 0 nm	Possibly produced water discharge	A sheen consisting of slivery finger-like projections approx. 10–15 m wide was observed moving in a southwest direction. Over board OIW at 18:00 was 41 mg/L.
2007	6	20	Suspected produced water discharge	Winds 11kn SE; swh 1.5 m; visibility 1/8 nm	Possibly produced water discharge	A sheen consisting of silvery patches was observed at the southwest corner of the installation. PW OIW checked and was 32.7 ppm.
2007	6	29	Suspected produced water discharge	Winds 26 kn Se; swh 1.9 m; visibility 2 nm	Possibly produced water discharge	A sheen approx. 10 m wide consisting of silvery finger-like projections was observed extending in a westerly direction. Produced water over board was 27.2 mg/L.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2007	7	6	Suspected produced water discharge	Winds 29 kn 225°; swh 1.0 m; visibility 5 nm	Possibly produced water discharge	A sheen approximately 10–15 m wide extending in a northerly direction. Morning OIW sample was 28 mg/L.
2007	7	27	Suspected produced water discharge	Winds 20 kn WNW; swh 2.0 m; visibility 7 nm	Possibly produced water discharge	Sheen, consisting of silvery finger-like projections approximately 20 m wide.
2007	8	27	Suspected produced water discharge	Winds 8 kn SE; swh 1.5 m; visibility 1/8 nm	Possibly produced water discharge	Sheen observed. Instantaneous OIW sample at 6:55 was 67.1 mg/L. OIW sample taken at10:05 was 9.3 mg/L. Average OIW from midnight to noon was 34.5 mg/L.
2007	8	28	Produced water discharge	NA	Produced water discharge	Sheen attributed to the produced water discharge. Sheen 1200 m².
2007	8	28	Suspected produced water discharge	Winds 29 kn N; swh 2 m; visibility 15 nm	Possibly produced water discharge	Silvery sheen with trace of color measuring 100m × 150 m.
2007	9	17	Suspected produced water discharge	Calm; swh 1.8 m; visibility 2 nm	Possibly produced water discharge	A light silvery sheen originating at the produced water outlet. The sheen measured approximately 20–30 m wide and extended in a southeasterly direction in narrow finger-like formations.
2007	9	18	Suspected produced water discharge	Winds 3 kn; swh 1 m; visibility 6 nm	Possibly produced water discharge	A light silvery sheen originating at the produced water outlet 08:00. The sheen measured approximately 20–30 m wide and extended in a southeasterly direction in narrow finger-like formations.
2007	10	4	Suspected produced water discharge	Winds 21 kn 230°; swh 1.6 m; visibilty 10 nm	Possibly produced water discharge	A light silvery sheen orginating at the produced water outlet. The sheen measured approximately 30–120 m wide extending to the southeast.
2007	10	26	Suspected produced water discharge	Wind NW at 19 kn; swh 2 m; visibility 15 miles	Possibly produced water discharge	A light silvery sheen was observed consisting of a number of narrow fingers that extended in a south easterly projection.
2007	11	6	Suspected produced water discharge	Wind 160° at 35 kn; swh 3 m; visibility 2 nm	Possibly produced water discharge	Light silvery sheen was observed consisting of a number of small patches that accumulated and drifted in a northerly direction. OIW readings at 0600 indicated 90 ppm and at 1030 was 32.2.
2008	2	6	Produced water discharge	Winds 20 kn SW; swh 2.9 m; sea temp –0.3 °C; air temp –4.0 °C; visibility 15 nm	NA	Sheen on the starboard side of the installation. Produced Water is within spec (21 ppm). Very calm sea states and therefore the sheen is being attributed to lack of natural dissipation of the produced water.
2008	2	27	Produced water discharge	NA	Produced water discharge	Silvery sheen. Produced water OIW 17 ppm.
2008	3	11	Suspected produced water discharge	Westerly at 4 kn; swh 3.5 m; visibility 12 nm	Possibly produced water	A light silvery sheen approximately 10 m wide consisting of silvery finger-like projections was observed on the south-east side of the installation and extending in a southwesterly direction away from the installation.
2008	3	12	Suspected produced water discharge	Southwest (260°) 15 kn; swh 1.9 m; visibility 15 nm	Possibly produced water discharge	A light silvery sheen approximately 100 m was observed on the southeast extending in a southwesterly direction approximately 700 m from the installation. OIW readings were 17.9 ppm at 06:32 and 18.2 ppm at 18:00.
2008	4	9	Produced water outlet	Wind ESE 18 kn; swh 2.0 m; visibility 12 nm	Produced water discharge	A light silvery sheen approximately 15 m wide consisting of silvery finger-like projections was observed on the south side of the installation extending in a SW direction. Sheen appears to have originated at the produced water outlet. OIW samples taken at 06:40 h indicated a high OIW reading of 94 ppm. Another OIW sample collected at 07:30 indicated a normal OIW reading of 7 ppm.
2008	5	2	Produced water outlet	Wind NNE 23 kn; swh 1.1 m; visibility 8 nm	Produced water discharge	A light silvery sheen approximately 30 m wide consisting of silvery finger-like projections was observed on the southeast area of the installation extending in a SE direction. The sheen appears to have originated from the PW discharge. OIW at 07:00 indicated 16 mg/L.

Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2008	5	5	Produced water outlet	Wind SW 7 kn; swh 2.0 m; visibility 8 nm	Produced water discharge	A light silvery sheen approximately 100 m × 100 m was observed on the southeast area of the installation. The sheen appears to have originated from the PW discharge. OIW samples taken at 07:00 indicated reading of 16.9 mg/L.
2008	5	11	Produced water outlet	Wind ENE 17 kn; swh 2.3 m; visibility 12 nm	Produced water discharge	A light silvery sheen approximately 70 m wide consisting of finger-like projections was observed to the southeast of the installation extending in a southwesterly direction. OIW samples taken at 07:00 indicated reading of 14.9 mg/L.
2008	5	21	Produced water outlet	Wind 240° WSW 14 kn; swh 1.5 m; visibility 15 nm	Produced water discharge	A light silvery sheen starting approximately 3 m wide extending approximately 100 M to the east in a northerly direction away from the installation. OIW samples taken at 07:00 indicated reading of 13.0 mg/L.
2008	6	1	Slops discharge	Slops discharge	Slops discharge	Sheen on starboard side 200 m × 1 m.
2008	6	6	Produced water outlet	Wind 360° N 22 kn; swh 1.7; visibility 3/4 nm	Produced water discharge	A light silvery sheen approximately 30 m wide with finger-like projections was observed at the southwest corner of the installation extending in a south easterly direction. OIW samples taken at 07:00 h indicated 44.9 mg/L. Samples taken at 09:40 h indicated 18.4 mg/L. OIW samples taken at 17:00 h indicated 10.5 mg/L.
2008	6	27	Produced water outlet	NA	Produced water	A sheen was noted overboard and produced water sample was discoloured. Produced water discharge was stopped. The sheen was approx. 150 m × 7 m, mostly silvery. Later in morning sheen 40 m × 40 m (60% open water and remaining was 80% silvery sheen) and another 100 m × 30 m (50% open water and remaining was 75% silvery sheen).
2008	7	3	Produced water outlet	NA	Produced water	Sheen at 15:45 local time was 10 m × 20 m. Produced water checks were OK.
2008	7	6	Suspected from black water tank	NA	Suspected from black water tank	Sheen noted on the starboard side of the installation. Produced water was confirmed as being within spec at the time. Black water tank being discharged at time to facilitate level transmitter replacement.
2008	7	9	Produced water outlet	NA	Produced water	Sheen reported starboard side installation. Believed to result of PW. PW was in spec. at 20 ppm.
2008	7	20	Produced water outlet	Wind 16 kn at 350° N; swh 1.4 m; visibility 4 nm	Produced water	Light silvery sheen approximately 20 m wide with finger-like projections was observed at the southeast corner of the installation extending in a southeast direction. Sheen originated at the produced water outlet. OIW samples taken at 7 am indicated 15.9 mg/L.
2008	7	29	Produced water outlet	Wind 23 kn at 250° WSW; swh 2 m; visibility nil	Produced water	Light silvery sheen was observed at the southwest corner of the installation. Sheen originated at the produced water outlet. OIW samples taken at 17:13 indicated 14.7 mg/L.
2008	8	2	Produced water outlet	Winds 9 kn 9°, swh 1.8 m, visibility 15 nm.	Produced water	Sheen with traces of color at produced water outlet. PW OIW At 7:00 21 mg/L.
2008	8	4	Produced water outlet	Winds 10 kn 60°. SWH 1.5 m, visibility 15 nm.	Produced water	Silvery grey sheen on southeast corner of installation. Sheen originating at produced water outlet extending away from installation in a south easterly direction. Production stable PW OIW at 7:00 16 mg/L.
2008	8	9	Produced water outlet	Winds 13 kn, SSE; swh 1.2 m; visibility 15 nm	Produced water	Silvery grey sheen observed on south side of installation. 40 m wide extending to the south narrowing to 5 m. Produced water 32.2 mg/L in am and sample at noon was 12 mg/L.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2008	8	11	Produced water outlet	Wind 18 kn SE; swh 1.5 m; visibility 15 nm	Produced water	Silver grey sheen with some rainbow around the edges observed on the south side of the installation. Sheen originated in the area of the produced water discharge extending in an easterly direction. PW OIW am 17 mg/L.
2008	8	29	Produced water outlet	Wind 130° ESE at 28 kn; swh 1.8; visibility 6 nm	Produced water	Silvery grey sheen with some rainbow coloring around edges was observed on south side of installation extending in a southeast direction. OIW samples taken in am indicated 24.6 mg/L.
2008	10	12	Produced water outlet	Wind 010° N 18 kn; swh 2.2 m; visibility 15 nm	Produced water	Light silvery sheen approximately 80 m wide with finger-like projections was observed at the southeast corner of the installation extending in a southwest direction. Sheen originated at the PW outlet. OIW samples taken at 07:00 indicated 27.3 mg/L. Second OIW sample taken at 14:32 resulted in 31.4 mg/L.
2008	10	13	Produced water outlet	Wind 030° NE 15 kn; swh 3 m; visibility 15 nm	Produced water	A light silvery sheen at the south and east sides of the installation and stayed close to the installation. Sheen originated at the PW outlet. OIW samples taken at 07:00 indicated 24 mg/L. Second OIW sample taken at 14:45 resulted in 46 mg/L.
2008	10	15	Produced water outlet	Wind 220° NE 17 kn; swh 2.3 m; visibility 15 nm	Produced water	A sheen was observed on the southeast corner of the installation along the east side. A second string like sheen was observed on the west side. The patchy silver sheen on the east side intensified to traces of color. Sheen originated at the PW outlet. OIW samples taken at 07:00 indicated 41.2 mg/L.
2008	10	17	Produced water outlet	Wind 080° NE 12 kn; swh 1.8 m; visibility 5/8 nm	Produced water	A light silvery sheen was observed on the south east corner of the installation and stayed close to the installation. OIW samples taken at 07:00 indicated 34.2 mg/L.
2008	10	19	Produced water outlet	Wind 360° N 16 kn; swh 3.0 m; visibility 15 nm	Produced water	A light silvery sheen was observed at the south east corner of the installation and stayed close to the installation. OIW samples taken at 07:00 indicated 34.2 mg/L. A second sample taken at 10:00 was 25.1 mg/L.
2008	11	24	Produced water outlet	Wind 080° NE 16 kn; swh 2.9 m; visibility 15 nm	Produced water	A light silvery sheen was observed at the South East corner of the installation and stayed close to the installation. OIW sample taken at 07:00 h was 32.1 mg/L.
2008	11	25	Produced water outlet	Wind 340° NW 26 kn; swh 2.4 m; visibility 15 nm	Produced water	A light silvery sheen was observed at the south east corner of the installation extending away from the installation in a finger-like pattern. OIW sample taken at 07:00 h was 21.3 mg/L.
2008	12	29	Produced water outlet	Very light variable winds; swh 3 m; visibility 15 nm	Produced water	A light silvery sheen was observed on the South West side of the installation and stayed close to the installation. OIW sample taken at 07:00 h was 26.0 mg/L. PW at 11:32 was 11.0 mg/L.
2009	4	20	Produced water outlet	Wind 290° westerly at 5 kn; swh 1.2 m; visibility 15 nm	Produced water	A light silvery sheen was observed on the south east corner of the installation. OIW sample taken at 07:00 h was 21.6 mg/L.
2009	5	12	Produced water outlet	NA	Produced water	NA
2009	6	7	Produced water outlet	Wind NNE 46 kn; swh 2.8 m; visibility 10 nm	Produced water	A light silvery sheen with finger-like projections was observed at the SE corner of the installation dispersing quickly as it moved in a SSW direction. The OIW sample taken at 18:00 h indicated 31.3 mg/L.
2009	6	11	Produced water outlet	Wind N 6 kn; swh 1.4 m; visibility 15 nm	Produced water	Light silvery sheen with finger-like projections was observed at the South East corner of the installation dispersing quickly as it moved in a SSE direction.
2009	7	1	Produced water outlet	Wind 120° at 6 kn; swh 1.6 m; visibility 10 nm	Produced water	A light silvery sheen was observed at the SE corner of the installation moving in westerly direction.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2009	7	1	Produced water outlet	NA	Produced water	Reported a sheen on the port side of the installation. PW oil content at 16 mg/L.
2009	7	1	Produced water outlet	Winds 22° 9 kn; swh 1.95 m 6.74 s	Produced water	Sheen observed starboard side of installation.
2009	7	7	Produced water outlet	NA	Produced water	Reported a sheen on the starboard side of the installation.
2009	7	13	Produced water outlet	Wind 250° 8 kn; swh 1.5 m; visibility 15 nm	Produced water	A light silvery sheen with finger-like projections was observed at the NE corner of the installation moving in a NE direction.
2009	7	28	Produced water outlet	Wind 155 T 10 kn, seas 1.3 m Hs 5.7 s	Produced water	Sheen observed on the starboard side of installation. 50% silvery sheen, 50% trace of color measuring 10 m × 5 m. Produced water in spec less than 20 ppm.
2009	8	7	Produced water outlet	Wind 24 kn, wind direction 200'T, Heading 230'T, seas 1.9 m 6.1 s	Produced water	Rosebuds forming on port side of installation developing into sheen. Silvery sheen 200 m × 2 m.
2009	8	10	Produced water outlet	16 kn of wind 188"T, wind direction 199'T, heading 1.0 m 5.3 s	Produced water	Rosebuds forming sheen reported on starboard side of installation. 200 m × 3 m. Silvery sheen. PW in spec as less than 25 ppm.
2009	8	12	Produced water outlet	21 kn 293'T, wind direction 226'T, heading 2.2 m 5.9 s	Produced water	Rosebuds forming sheen reported on the port side of installation. 150 m long by 3 m wide. 5% silvery sheen, 25% trace of color.
2009	10	2	Produced water outlet	Significant sea state 1.77 m @ 5.9 s, wind 12 kn, wind direction 299'T, heading 260'T	Produced water	Rosebuds forming sheen observed on the port side of the installation. 100 m × 5 m silvery sheen 25% trace of color.
2009	10	19	Produced water outlet	Wind 115 T 20 kn, seas 2.3 m Hs 6.8 s	Produced water	Sheen observed on the port side of installation 95% silvery sheen, 5% trace of color measuring 15 m × 5 m. Produced water in spec less than 20 ppm.
2009	10	20	Produced water outlet	Wind 320° at 18 kn; swh 2.2 m; visibility 3/9 nm in drizzle and fog	Produced water	A light silver or bluish sheen with finger-like projections was observed at the SE corner of the installation moving in a south easterly direction.
2009	10	23	Produced water outlet	Wind 130 T 13 kn, seas 1.5 m Hs 6.2 s	Produced water	Sheen observed on port and starboard side of installation: port side 15 m × 5 m silvery sheen; starboard side 50 m × 5 m silvery sheen. Produced water in spec less than 20 ppm. Drains discharge 11 ppm.
2009	11	2	Produced water outlet	Significant sea state 1.77 m 5.9 s, wind 12 kn, wind direction 299'T, heading 260'T	Produced water	Rosebuds forming sheen observed on the port side of the installation. 100 m × 5 m silvery sheen 25% trace of color.
2009	11	4	Produced water outlet	Significant sea state 2.97 m 7.1 s, wind 23 kn, wind direction 255'T, heading 211'T	Produced water	Sheen observed on starboard side of installation 50 m × 50 m silvery in color. Produced water in spec.
2009	11	8	Produced water outlet	Significant sea state 4.9 m 4.9 s, wind 16 kn, wind direction 291'T, heading 296'T	Produced water	Sheen observed on starboard side of installation 100 m × 1 m 95% silvery in color 5% trace of color. Produced water with in spec.
2009	11	11	Produced water outlet	Significant sea state 1.99 m 6.47 s, wind 11 kn wind direction 303'T	Produced water	Silvery sheen, 75 m × 3 m, observed on port side with rose buds noted toward midway along side of installation. PW in spec.

Table A1 (continued).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2009	11	13	Produced water outlet	Wind 20 kn, wind direction 280'T, heading 330 T	Produced water	Sheen at port side and aft of installation. Sheen estimated at 100 m × 3 m silvery in color. PW in spec.
2009	11	14	Produced water outlet	Significant sea state 3.87 m 7.8 s, wind 21 kn, wind direction 325'T, heading 005 T	Produced water	Sheen observed midway along port side of installation 150 m × 3 m silver 95% trace of color 5%. Produced water in spec.
2009	11	22	Produced water outlet	Significant sea state 3.5 m 7.8 s, wind 25 kn, wind direction 280 T	Produced water	Silvery sheen on port and starboard side of installation, 2 m × 50 m port and 5 m × 50 m starboard. PW OIW at 25 ppm.
2009	11	24	Produced water outlet	Significant sea state 3.0 m 6.8 s, wind 22 kn, wind direction 290 T	Produced water	Silvery sheen on port side 5 m × 50 m. Volume estimate 0.02 L. PW OIW 25 ppm.
2009	11	25	Produced water outlet	Sea heights: 2.1 m (significant), wind: 280 at 21 kn, current: 1.8 kn setting to 075, visibility: 10 nm	Produced water	Sheen on the port commencing slightly aft of the overboard caisson extending forward for the length of the installation.
2009	12	5	Produced water outlet	Significant sea state 4.1 m 8.5 s, wind 23 kn, wind direction 290 T	Produced water	Silvery sheen on port and starboard side, 5 m × 50 m. PW OIW 25 ppm.
2009	12	14	Produced water outlet	Significant sea state 3.9 m 7.8 s, wind 11 kn, wind direction 311 T	Produced water	Silvery sheen on port side, 3 m × 60 m. PW OIW 25 ppm.
2009	12	15	Produced water outlet	Significant sea state 2.18 m 7.4 s, wind 6 kn, wind direction 323 T	Produced water	Silvery sheen on starboard side of installation, 150 m × 50 m. PW OIW less than 25 ppm.
2009	12	28	Produced water outlet	Significant sea state 3.1 m 8.3 s, wind 8 kn, wind direction 271 T	Produced water	Silvery sheen, 200 m × 3 m. PW OIW less than 25 ppm.
2009	12	30	Produced water outlet	Significant sea state 5.7 m 9.4 s, wind 18 kn, wind direction 190 T	Produced water	Silvery sheen 50 m × 3 m. PW OIW less than 25 ppm.
2010	1	3	Produced water outlet	Significant sea state 4.1 m 8.6 s, wind 29 kn, wind direction 100 T	Produced water	Silvery sheen 150 m × 5 m. PW OIW less than 25 ppm.
2010	1	5	Produced water outlet	Significant sea state 4.2 m 8.3 s, wind 28 kn, wind direction 210 T	Produced water	Silvery sheen 50 m × 5 m. PW OIW less than 25 ppm.
2010	1	6	Produced water outlet	Significant sea state 3.6 m 8.6 s, wind 21 kn, wind direction 120 T	Produced water	Silvery sheen 6 m × 30 m, 50% trace of color. 6 m × 80 m silvery sheen. PW OIW less than 25–40 ppm.
2010	1	6	Produced water outlet	Wind ESE 31 kn; waveheight 3 m; visibility 4 nm	Produced water	A sheen consisting of dispersed silver–blueish patches becoming windrowed as it extended further from the installation and was observed coming from the south east corner of the installation extending in a south westerly direction.
2010	1	14	Produced water outlet	Wind N 40 kn; waveheight 3.2 m; visibility 3 nm	Produced water	A silvery grey sheen was observed extending from the installation in finger-like formation in a south easterly direction.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2010	*1*	*23*	Produced water outlet	Significant sea state 3.9 m 7.1 s, wind 23 kn, wind direction 270 T	Produced water	Silvery sheen 200 m × 4 m silvery sheen PW OIW less than 25 ppm.
2010	2	10	Produced water outlet	—	Produced water	Silvery sheen observed on starboard side of installation approx. 20 m × 2 m. Produced water within spec.
2010	2	15	Produced water outlet	Significant sea state 4.8 m 8.6 s, wind 35 kn, wind direction 15 T	Produced water	Sheen was observed on port side of installation, approx. 1 m × 30 m. PW OIW 25–40 ppm.
2010	2	17	Produced water outlet	Significant sea state 4.0 m, wind variable, wind direction 240 T	Produced water	Sheen was observed approx. 10 m × 2 m. PW OIW 0–25 ppm.
2010	2	20	Produced water outlet	Significant sea state 3.3 m, wind 12 kn, wind direction 100	Produced water	Silvery sheen was observed approx. 3 m × 1 m. PW OIW 0–25 ppm.
2010	2	27	Produced water outlet	Significant sea state 2.2 m 8 s, wind light	Produced water	Sheen was observed approx. 10 m × 100 m. Produced water in spec.
2010	3	2	Produced water outlet	Significant sea state 4.1 m 7.7 s, wind 31 kn 85 T	Produced water	Silvery sheen was observed approx. 50 m × 100 m. Produced water in spec.
2010	3	3	Produced water outlet	Significant sea state 5.3 m 9.5 s, wind 11 kn 200 T	Produced water	Silvery sheen was observed approx. 5 m × 50 m. Produced water in spec.
2010	3	9	Produced water outlet	Significant sea state 2.8 m, wind 34 kn 190 T	Produced water	Silvery sheen was observed approx. 75 m × 1 m. Produced water in spec 0–25 ppm.
2010	3	10	Produced water outlet	Significant sea state 2.5 m 3.6 s, wind 14 kn 300 T	Produced water	Silvery sheen was observed approx. 100 m × 2 m. Produced water in spec 0–25 ppm.
2010	3	14	Produced water outlet	Wind North 30 kn; waveheight 3 m; visibility 15 nm	Produced water	Silvery grey sheen was observed projecting from installation in finger-like formation, moving in a south easterly direction. OIW sample taken this morning was 36.4 mg/L.
2010	3	17	Produced water outlet	Significant sea state 2.6 m 6.8 s, wind 18 kn 257 T	Produced water	Silvery sheen was observed approx. 100 m × 25 m, 5% trace of color. Produced water in spec 0–25 ppm.
2010	3	24	Produced water outlet	Wind ESE 32 kn; waveheight 2.8 m; visibility 15 nm	Produced Water	Silvery gray sheen was observed projecting from installation in finger-like formation moving in a south westerly direction. OIW sample in the morning was 55.4 mg/L.
2010	3	30	Produced water outlet	Significant sea state 2.3 m 8.2 s, wind 10 kn 160 T	Produced water	Silvery sheen was observed approx. 5 m × 25 m. Produced water in spec.
2010	4	4	Produced water outlet	Wind NW 16 kn; waveheight N/A; visibility 15 nm	Produced Water	Silvery gray sheen was observed projecting from installation in finger-like formation moving in a south easterly direction. PW OIW sample taken in morning was 42.4 mg/L.
2010	4	7	Produced water outlet	Significant sea state 1.7 m 5.0 s, wind 27 kn 275 T	Produced water	Silvery sheen was observed approx. 5 m × 100 m, 95% silvery, 5% trace of color. Produced water in spec.
2010	4	14	Produced water outlet	Significant sea state 1.9 m, wind 19 kn 341 T	Produced water	Silvery sheen was observed approx. 200 m × 4 m, 95% sheen, 75% silvery 25% open water. PW OIW 0–25 mg/L [lab result 13.1 mg/L].
2010	4	15	Produced water outlet	Significant sea state 1.1 m 4.7 s, wind 12 kn 345 T	Produced water	Silvery sheen was observed approx. 200 m × 2 m, 75%, 35% silvery, 25% open water. PW OIW 0–25 mg/L [lab result 13.1 mg/L].
2010	4	19	Produced water outlet	Wind ESE 110° 40 kn; waveheight 2.7 m; visibility 5 nm	Produced water	A silvery gray sheen was observed projecting from installation in finger-like formation moving in a south westerly direction. OIW sample from morning was 27.3 mg/L.
2010	4	20	Produced water outlet	Significant sea state 3.4 m 7.1 s, wind 14 kn 207 T	Produced water	Sheen observed on port side of installation approx. 100 m × 2 m, 95% silvery, 5% trace of color. Produced water in spec.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2010	4	21	Produced water outlet	Significant sea state 2.6 m 6.8 s, wind 16 kn 248 T	Produced water	Sheen observed on port side of installation approx. 150 m × 1 m, 95% silvery, 5% trace of color. Produced water in spec.
2010	5	2	Produced water outlet	Significant sea state 2.6 m 7.5 s, wind 20 kn 125 T	Produced water	Sheen observed on port side midway along installation approx. 100 m × 3 m, 95% silvery, 5% yellowish brown. Produced water in spec.
2010	5	3	Produced water outlet	Significant sea state 1.9 m 6.9 s, wind 7 kn 288 T	Produced water	Sheen observed on port side midway along installation approx. 200 m × 3 m, 95% silvery, 5% yellowish brown. Produced water in spec.
2010	5	13	Produced water outlet	Significant sea state 2.3 m 6.8 s, wind 6 kn 180 T	Produced water	Sheen approx. 3 m × 100 m, 95% silvery, 5% trace of color. Produced water in spec.
2010	5	28	Produced water outlet	Significant sea state 2.1 m 7.7 s, wind 17 kn 70 T	Produced water	Sheen port side midway along installation approx. 3 m × 150 m, 95% silvery, 5% trace of color. Produced water in spec.
2010	5	28	Produced water outlet	Wind ESE 100° 20 kn; waveheight 1.4 m; visibility 3 nm	Produced water	Silvery gray sheen was observed projecting from installation in finger-like formation moving in a south westerly direction. OIW sample last night was 4.6 mg/L. OIW sample from morning was 26.5 mg/L.
2010	6	2	Produced water outlet	Significant sea state 3.0 m, wind 12 kn 16 T	Produced water	Sheen starboard side approx. 3 m × 50 m. Produced water in spec.
2010	6	9	Produced water outlet	Significant sea state 2.8 m 6.8 s, wind 34 kn 170 T	Produced water	Sheen starboard side approx. 2 m × 150 m, Produced water in spec.
2010	6	12	Produced water outlet	Significant sea state 1.3 m 5.6 s, wind 10 kn 90 T	Produced water	Silvery sheen starboard side approx. 2 m × 100 m. Produced water in spec.
2010	6	13	Produced water outlet	Significant sea state 1.6 m 7.3 s, wind 3 kn 316 T	Produced water	Sheen starboard side approx. 3 m × 100 m. Produced water in spec.
2010	6	18	Produced water outlet	Wind S 44 kn; waveheight 2.0 m; visibility 2 nm in light rain	Produced water	Silvery grey or bluish sheen was observed originating from produced water outlet and projecting out from the installation in long finger-like formation, moving in a south westerly direction.
2010	6	26	Produced water outlet	Significant sea state 1.2 m 4.5 s, wind 18 kn 315 T	Produced water	Sheen starboard side approx. 5 m × 100 m, 95% silvery, 5% trace of color. Produced water in spec.
2010	7	5	Produced water outlet	Significant sea state 1.4 m 5.2 s, wind 13 kn 315 T	Produced water	Sheen approx. 2 m × 100 m, 95% silvery, 5% trace of color. Poduced water in spec.
2010	7	5	Produced water outlet	Significant sea state 1.4 m 5.2 s, wind 13 kn 315 T	Produced water	Sheen approx. 20 m × 200 m, 75% silvery, 15% trace of color, 5% dull color, 5% dark color.
2010	7	6	Produced water outlet	Significant sea state 1.6 m 5.7 s, wind 13 kn 121 T	Produced water	Sheen observed port side midway along installation approx. 50 m × 25 m, 25% silvery, 5% trace of color, 70% open water.
2010	7	7	Produced water outlet	Significant sea state 1.7 m 6.0 s, wind 22 kn 248 T	Produced water	Sheen approx. 100 m × 3 m, 75% silvery, 25% trace of color.
2010	7	8	Produced water outlet	Wind calm at 0 kn; swh 1.1 m; visibility 15 nm	Produced water	Silvery grey sheen observed originating from produced water outlet and projecting out from the installation in finger-like formation, moving in a southeasterly direction. PW OIW sample taken in the morning was 6.1 mg/L.
2010	7	8	Produced water outlet	Significant sea state 1.4 m 5.8 s, wind 22 kn 248 T	Produced water	Sheen approx. 150 m × 50 m, 40% open water 50% silvery, 8% trace of color, 2% dull color.
2010	8	10	Produced water outlet	Significant sea state 1.3 m 5.7 s, wind 14 kn 200 T	Produced water	Sheen approx. 20 m × 50, 95% silvery, 5% trace of color.
2010	8	11	Produced water outlet	Wind 150° at 4 kn; swh 0; visibility zero	Produced water	A silvery grey sheen was observed originating from produced water outlet and projecting out from the installation in finger-like formation, moving in a southwesterly direction.
2010	8	12	Produced water outlet	Significant sea state 1.84 m 5.8 s, wind 10 kn 240 T	Produced water	Sheen approx. 3 m × 100 m, 95% silvery, 5% trace of color.

Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2010	8	14	Produced water outlet	Significant sea state 1.0 m 602 s, wind 8 kn 145 T	Produced water	Sheen approx. 20 m × 100 m, 95% silvery, 5% trace of color.
2010	8	18	Produced water outlet	Sea state 1.5 4.9 s, wind 13 kn 276 T	Produced water	Sheen observed on starboard side approx. 100 m × 2 m, 100% silvery.
2010	8	19	Produced water outlet	Sea state 1.0 5.9 s, wind 3 kn 290 T	Produced water	Sheen observed on port side approx. 100 m × 100 m, 60% open water, 40% silvery.
2010	8	19	Produced water outlet	Sea state 0.95 5.7 s, wind 7 kn 226 T	Produced water	Sheen observed on port side approx. 100 m × 3 m, 95% silvery 5% trace of color.
2010	8	20	Produced water outlet	Sea state 1.3 5.9 s, wind 6 kn 084 T	Produced water	Sheen observed on port side approx. 100 m × 100 m, 50% open water, 50% silvery.
2010	8	21	Produced water outlet	Wind 070° 31 kn; swh 1.7 m; visibility 15 nm	Produced water	A silvery grey sheen was observed originating from produced water outlet moving in a south westerly direction.
2010	8	23	Produced water outlet	Sea state 1.8 m 5.7 s, wind 17 kn 016 T	Produced water	Rosebuds developing into sheen observed on starboard side of installation.100 m × 2 m, 75% silvery sheen, 20% open water, 5% trace colour.
2010	8	24	Produced water outlet	Sea state 1.6 m 6.7 s, wind 10 kn 045 T	Produced water	Rosebuds developing into sheen observed on port side of installation. 150 m × 25 m: 65% silvery sheen, 30% open water, 5% trace colour.
2010	8	25	Produced water outlet	Sea state 1.2 m 6.6 s, wind 3 kn 026 T	Produced water	Rosebuds developing into sheen observed on port side of installation approx. 150 m × 50 m, 40% open water, 50% silvery, 10% trace of color.
2010	8	25	Produced water outlet	Wind NE 050° 15 kn; swh 1.4 m; visibility 15 nm	Produced water	A silvery grey sheen was observed originating from produced water outlet and stayed in close proximity to installation.
2010	8	27	Produced water outlet	Sea state 1.67 m 6.3 s, wind 4 kn 170 T	Produced water	Rosebuds developing into sheen observed on port side of installation approx. 150 m × 5 m, 95% silvery, 5% trace of color.
2010	8	29	Produced water outlet	Sea state 3.06 m 9.2 s, wind 5 kn 027 T	Produced water	Sheen observed on port side approx. 150 m × 3 m, 95% silvery, 5% trace of color.
2010	8	30	Produced water outlet	Sea state 3.42 m, wind 13 kn	Produced water	Sheen observed on port side approx. 100 m × 5 m, 95% silvery, 5% trace of color.
2010	8	30	Produced water outlet	—	Produced water	Sheen observed on port side approx. 50 m × 50 m.
2010	9	2	Produced water outlet	Sea state 3.452 m 6.47 s, wind 20 kn	Produced water	Sheen observed on port side approx. 150 m × 5 m, 70% silvery, 30% trace of color.
2010	9	3	Produced water outlet	Sea state 1.9 m 7.14 s, wind 10 kn 300	Produced water	Sheen observed on port side approx. 100 m × 3 m, 75% silvery, 25% trace of color.
2010	9	4	Produced water outlet	Sea state 2.0 m 6.7 s, wind 20 kn 198	Produced water	Sheen observed on port side approx. 150 m × 3 m, 95% silvery, 5% trace of color, 50 m × 50 m 75% open water, 20% slivery sheen, 5% trace of color.
2010	9	9	Produced water outlet	Sea state 2.1 m 5.9 s, wind 9 kn 350	Produced water	Sheen observed approx. 100 m × 3 m, 95% silvery, 5% trace of color.
2010	9	12	Produced water outlet	Sea state 2.2 m 6.8s, wind 11 kn 290	Produced water	Sheen observed approx. 100 m × 5 m, 95% silvery, 5% trace of color.
2010	9	18	Produced water outlet	Wind westerly at 52 kn; swh 2.8 m; visibility 4 nm	Produced water	A silvery grey sheen with finger-like projections was observed originating from produced water outlet moving in a north easterly direction.
2010	10	15	Produced water outlet	Sea state 2.6 m 6.3 s, wind 17 kn 350	Produced water	Sheen observed approx. 150 m × 4 m, 95% silvery, 5% trace of color.
2010	11	1	Produced water outlet	Sea state 3.1 m 7.3 s, wind 15 kn 100	Produced water	Sheen observed approx. 5 m × 100 m, 95% silvery, 5% trace of color.
2011	1	4	Produced water outlet	Sea state 3.0 m 7.37, wind 15 kn 121	Produced water	Sheen observed approx. 150 m × 3 m, 95% silvery, 5% trace of color.

Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2011	5	4	Produced water outlet	Wind NE 5 kn; wave height 1.7 m; visibility 15 nm	Produced water	Silvery sheen with a trace of brown colour was observed originating from the produced water outlet.
2011	5	6	Produced water outlet	Wind NE 26 kn; wave height 0.9 m; visibility 4 nm	Produced water	A barely visible sheen was observed originating from produced water outlet. The sheen was moving in a southerly direction away from the installation.
2011	5	20	Produced water outlet	Winds 15 kn 17; waves 1.3 5.5 s; visibility 5 nm	Produced water	Rosebuds developing into sheen observed port side of installation 150 m × 30 m. PW OIW in spec 0–25 ppm.
2011	5	25	Produced water outlet	Winds 15 kn 296; waves 1.8 7.4 s; visibility 1/2 nm	Produced water	Rosebuds developing into sheen observed port side of installation. PW OIW in spec 0–25 ppm. Sheen measured 100 m × 50 m, 70% open 30% silvery.
2011	6	17	Produced water outlet	27 kn from 10°; swh 2.5 m; visibility 8 nm	Produced water	A barely visible sheen was observed originating from the produced water outlet. The sheen was moving in a southerly direction away from the installation.
2011	7	2	Produced water outlet	Winds were 16 kn at 260 T seas 2.3 m and visibility was 1/8 mile	Produced water	A sheen was reported measuring 5 m × 100 m.
2011	7	5	Produced water outlet	18 kn from 210°; swh 1.5 m; visibility 0.5 nm	Produced water	A silvery sheen with a trace of brown color was observed originating from the produced water outlet moving in a north easterly direction.
2011	7	17	Produced water outlet	Winds were 27 kn at 201 T seas 2.5 m 5.7 s and visibility was 1/8 mile	Produced water	Rosebuds developing into sheen on port side side of the installation, 50 m × 4 m, 80% open water 20% silvery sheen.
2011	7	26	Produced water outlet	10 kn from 180°; swh 1.5 m; visibility 12 nm	Produced water	A silvery gray transparent sheen originating from the produced water outlet was reported moving away from the installation in a north westerly direction.
2011	7	30	Produced water outlet	11 kn from 080°; swh 1.0 m; visibility 6 nm	Produced water	A silvery gray transparent sheen originating from the produced water outlet was reported moving away from the installation in a north easterly direction. PW samples were within regulatory limits.
2011	8	9	Produced water outlet	8 kn from WNW; swh 0.4 m; visibility 6 nm	Produced water	A silvery gray sheen with finger-like projections was observed originating from the produced water outlet.
2011	9	15	Produced water outlet	Winds were 19 kn at 250 seas 1.7 m 7.1 s and visibility was 1/8 mile	Produced water	Rosebuds on port side side of the installation forming sheen 200 m × 4 m, 95% silvery sheen 5% trace of color.
2011	10	8	Produced water outlet	Winds were 10 kn at 315 seas 2.3 m 6.9 s and visibility was 15 mile	Produced water	Sheen 5 m × 100 m, 95% silvery 5% trace of color.
2011	10	24	Produced water outlet	18 kn from 340°; swh 2.4 m; visibility 8 nm	Produced water	Silvery sheen with finger-like projections observed originating from the produced water outlet and moving slowly away from the installation.
2011	10	25	Produced water outlet	12 kn from 360°; swh 2.0 m; visibility 15 nm	Produced water	A silvery sheen with finger-like projections was observed originating from the produced water outlet and moving away from the installation slowly. PW OIW at 06:17 was 19.7 mg/L.
2011	11	20	Produced water outlet	Winds were 30 kn at 240 seas 4.1 m 7.5 s and visibility was 5 nm	Produced water	Sheen 5 m x 100 m, 95% silvery sheen 5% trace color, observed on starboard side of installation, PW OIW within spec (0–25 ppm).
2011	12	1	Produced water outlet	Winds were 33 kn at 215 seas 2.0 m 5.2 s and visibility was 6 nm	Produced water	Sheen 5 m × 10 m, 90% silvery sheen 10% trace of color, observed on port side of installation. PW OIW within spec (0–25 ppm).

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2011	12	13	Produced water outlet	Winds were 11 kn at 310 seas 3.1 m 7.0 s and visibility was 15 nm	Produced water	Sheen 100 m × 5 m, 95% silvery sheen 5% trace of colour, observed on port side. Produced water in spec.
2011	12	23	Produced water outlet	Winds were 5 kn at 290 seas 3.9 m 7.7 s and visibility was 15 nm	Produced water	Sheen 3 m × 80 m, 95% silvery sheen 5% trace of color. PW within spec 0–20.7 ppm.
2011	12	26	Produced water outlet	Winds were 7 kn at 270 seas 2.9 m 7.6 s and visibility was 15 nm	Produced water	Sheen 3 m × 60 m, 95% silvery sheen 5% trace of color. Produced water within spec 0–19 ppm.
2012	1	10	Produced water outlet	Winds were 7 kn at 145 seas 2.0 m 7.5 s and visibility was 15 nm	Produced water	Sheen 75 m × 3 m, 85% silvery sheen 5% trace of color, 10% open water. Produced water in spec.
2012	1	22	Produced water outlet	Winds were 6 kn at 170 seas 2.2 m 7.0 s and visibility was 8 nm	Produced water	Sheen 200 m × 2 m, 80% silvery sheen 10% trace of color, 10% open water. Additional area within sheen 7 m × 7 m 50% silvery sheen and 50% yellowish brown. Produced water within spec 0–30 ppm.
2012	3	30	Produced water outlet	Wind 070° at 18 kn; swh 1.9 m; visibility 15 nm	Produced water	Barely visible sheen observed originating from the produced water outlet.
2012	4	7	Produced water outlet	Winds were 17 kn at 090 seas 2.2 m and visibility was 8 nm	Produced water	Sheen 3 m × 50 m, 80% silvery sheen 10% barely visible, Produced water in spec.
2012	4	18	Produced water outlet	Wind 220° 15 kn; swh 1.0 m; visibility 0.25 nm	Produced water	A silvery sheen with finger-like projections was observed originating from the produced water outlet.
2012	4	19	Produced water outlet	Wind 280° 6 kn; swh 0.4 m; visibility 1–2 nm	Produced water	A silvery sheen was observed originating from the produced water outlet slowly drifting in a southerly direction.
2012	5	8	Produced water outlet	Wind 070° 20 kn; swh 1.5 m; visibility 12 nm	Produced water	A barely visible sheen was observed originating from the produced water outlet. The sheen is moving away from installation in a finger-like pattern going out 1 km.
2012	5	9	Produced water outlet	Wind 000° 0 kn; swh 1.8 m; visibility 10 nm	Produced water	A barely visible sheen was observed originating from the produced water outlet. The sheen pattern is scattered patches, hovering around south end of installation to further than 0.5 km from installation.
2012	5	24	Produced water outlet	Wind 35 kn 360 T; swh 1.6 m; visibility 4 nm	Produced water	Sheen observed midway along starboard side of installation 2 m × 100 m: 20% open water, 10% barely visible, 70% silvery sheen. PW OIW in spec (0–20 ppm).
2012	5	27	Produced water outlet	Wind 330°; 20 kn; swh 0.9 m; visibility 8 nm	Produced water	A silvery sheen was observed originating from the produced water outlet slowly drifting in a southeasterly direction.
2012	5	27	Produced water outlet	Wind 18 kn 220 T; swh 1.1–2.0 m; visibility 1/8 nm	Produced water	Sheen observed starboard side midway along installation 3 m × 150 m: 30% open water, 10% barelyvisible, 60% silvery sheen. Produced water within spec (0–25 ppm).
2012	6	5	Produced water outlet	Wind 50° 6 kn; swh 0.4 m; visibility 1/8 nm	Produced water	A silvery sheen was observed originating from the produced water outlet slowly drifting in a south easterly direction. Production and produced water numbers were normal.
2012	6	11	Produced water outlet	Wind 90° 12 kn; swh 0.8 m; visibility 6+ nm	Produced water	A silvery sheen was observed originating from the produced water outlet slowly drifting slowly in a southerly direction. OIW analyzer trending low with no spikes. OIW sample from morning was 26.2 mg/L.
2012	6	14	Produced water outlet	Wind 90° 25 kn; swh 1.0 m; visibility 8 nm	Produced water	A silvery sheen was observed originating from the produced water outlet slowly drifting in a westerly direction from the south end of the installation. OIW analyzer trending low with no spikes. OIW sample taken last night was 33.5 mg/L and this morning sample at 06:20 was 31.1 mg/L.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2012	6	16	Produced water outlet	Wind 60° 26 kn; swh 1.3 m; visibility 15 nm	Produced water	A barely visible sheen was observed originating from the produced water outlet slowly drifting in a southerly direction from the south end of the installation. The formation of the sheen is finger-like projections out approximately 800 m from the installation. OIW sample taken last night was 23.5 mg/L and this morning sample was 17.5 mg/L.
2012	6	18	Produced water outlet	Wind 60° 8 kn; swh 1.0 m; visibility 15 nm	Produced water	A silvery sheen was observed originating from the produced water outlet slowly drifting in a south westerly direction from the south end of the installation. The sheen is a meandering narrow band projecting out approximately 5 km. OIW analyzer trending low with no spikes. OIW sample taken last night was 41.4 mg/L and this morning sample was 22.8 mg/L.
2012	6	19	Produced water outlet	Wind 130° 6 kn; swh 0.8 m; visibility 15 nm	Produced water	A silvery sheen was observed originating from the produced water outlet slowly drifting in a north westerly direction from the south end of the installation. OIW analyzer trending low with no spikes. OIW sample taken last night was 23.3 mg/L and this morning sample was 76.6 mg/L. and a second morning sample taken 1.5 h later was 20.8 mg./L.
2012	6	20	Produced water outlet	Wind 0° 0 kn; swh 1.0 m; visibility 2 nm	Produced water	A silvery-greyish sheen was observed originating from the produced water outlet and around the full perimeter of the installation. The sheen extends outward from the west side of the installation. OIW analyzer trending low with no spikes. OIW sample taken last night was 21.4 mg/L and this morning sample was 10.0 mg/L.
2012	6	21	Produced water outlet	Wind 130° 25 kn; swh 1.2 m; visibility 1/8 nm	Produced water	A silvery-greyish sheen was observed originating from the produced water outlet around the south end of the installation, and extending in a southerly direction. OIW analyzer trending low with no spikes. OIW sample taken last night was 16.7 mg/L and this morning sample was 10.0 mg/L.
2012	6	25	Produced water outlet	Wind 060° 8 kn; swh 1.2 m; visibility 8 nm	Produced water	A silvery-greyish sheen was observed originating from the produced water on the south end of the installation and extending in a south westerly direction in a narrow band out approximately 4 km. OIW analyzer trending low with no spikes. OIW sample taken last night was 35.0 mg/L and this morning sample was 32.5 mg/L.
2012	6	26	Produced water outlet	Wind 110° 9 kn; swh 1.3 m; visibility 15 nm	Produced water	A silvery sheen was observed originating from the produced water on the south end of the installation and extending in a southerly direction out approx. 400 m. OIW analyzer trending low with no spikes. OIW sample taken last night was 37.8 mg/L and this morning sample was 24.9 mg/L.
2012	6	28	Produced water outlet	Wind SSW 20 kn; swh 1.75 m; visibility 3/8 nm	Produced water	A silvery sheen was reported originating from the produced water on the south end of the installation and extending in a north westerly direction approximately 1 nm. OIW in the AM was 42 mg/L, and 43 mg/L in the PM.
2012	6	29	Produced water outlet	Wind 210° 30 kn; swh 3.1 m; visibility 1/2 nm	Produced water	A sheen with a trace of bronze was reported originating from the produced water outlet. The sheen approx. 500 m × 300 m is staying close to the southeast corner of the installation. OIW in the AM of was 49 mg/L.

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Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2012	7	14	Produced water outlet	Wind 0° 0 kn; swh 1.0 m; visibility 15 nm	Produced water	A silvery sheen was reported originating from the produced water outlet and staying close to the installation from the southwest corner along the south side and east side to the northeast corner. OIW in the AM was 33.2 mg/L.
2012	7	15	Produced water outlet	Wind 330° 14 kn; swh 2.5 m; visibility 15 nm	Produced water	A silvery sheen with traces of brown was reported originating from the produced water on the southeast end of the installation. The sheen is moving away from the installation in a westerly direction out approximately 1 km away from installation. OIW in the AM was 29.9 mg/L.
2012	7	18	Produced water outlet	Wind 060° 8 kn; swh 1.0 m; visibility 15 nm	Produced water	A silvery sheen was observed originating from the produced water outlet and slowly drifting in a south westerly direction from the south end of the installation. The formation of the sheen is a narrow band extending out approximately 5 km. OIW analyzer trending low with no spikes. OIW sample taken last night was 41.4 mg/L and this morning sample was 22.8 mg/L.
2012	7	25	Produced water outlet	Wind 090° 12 kn; swh 0.8 m; visibility 0.5 nm	Produced water	A silvery bluish sheen with faint traces of brown was reported originating from the produced water on the southeast end of the installation and trailing off in a south west direction. The faint traces of brown in the sheen dispersed quickly as the sheen moved away from the installation. OIW sample in the PM of Jul 24/12 was 18.3 mg/L. OIW sample in the AM of July 25/12 was 25.8 mg/L.
2012	8	10	Produced water outlet	Wind 360 at 9 kn; swh 1.0 m; visibility 0 nm	Produced water	A silvery bluish sheen was reported originating from the produced water on the southeast end of the installation and staying within 200 m from installation. OIW sample in the PM of Aug 9/12 was 24.4 mg/L. OIW sample in the AM of Aug 10/12 was 29.9 mg/L.
2012	8	11	Produced water outlet	Wind 360 at 9 kn; swh 1.0 m; visibility 0 nm	Produced water	A silvery bluish sheen was reported originating from the produced water on the southeast end of the installation and drifting in a south easterly direction out approximately 500 m. OIW sample in the PM of Aug 10/12 was 33.8 mg/L. OIW sample in the AM of Aug 11/12 was 43.0 mg/L.
2012	11	1	Produced water outlet	Wind 080° 5 kn; swh 2.2 m; visibility 3 nm	Produced water	A silvery bluish sheen was reported originating from the produced water on the southeast end of the installation and drifting in a southerly direction out approximately 750 m. OIW sample in the PM of Oct 31/12 was 14.5 mg/L. OIW sample in the AM of Nov 1/12 was 13.5 mg/L. PM sample for Nov1 was 33.1 mg/L.
2012	12	12	Produced water outlet	Wind 280° 29 kn; swh 4.0 m; visibility 6+ nm	Produced water	A silvery bluish sheen was reported originating from the produced water on the southeast end of the installation and was drifting in an easterly direction out approximately 750 m.
2013	4	11	Produced water outlet	Wind 35 kn 258; swh 1.9 m 5.5 s; visibility 12 nm	Produced water	Sheen 5% open water 5% trace of color, 90% silvery sheen measuring 10 m × 10 m mid ship Starboard side of installation. Produced water within spec (0–17 ppm).
2013	5	22	Produced water outlet	Wind 15 kn 280; swh 1.5 m 6.4 s; visibility 12 nm	Produced water	Sheen observed off midway along port side about 2 m × 50 m, 5% open water, 5% trace of color. 90% silvery sheen. Produced water in spec (0–8 ppm).
2013	5	24	Produced water outlet	Wind 250° 5 kn; swh 0.3 m; visibility 1/2–1 nm	Produced water	A silvery bluish sheen was reported originating from the produced water on the southeast end of the installation. The sheen was drifting in a north easterly direction Production was steady. There were no sea birds in the area encompassed by the sheen.

Table A1 (*continued*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2013	6	5	Produced water outlet	Winds 22 kn 276 T SWH 2.3 m 5.5 s visibility 10 nm.	Produced water	Slivery sheen 100 m × 50 m 50% open water Sheen midway along port side. Produced water with in spec, 0–25 ppm.
2013	6	7	Produced water outlet	Wind 234° at 12 kn visibility 18 nm seas 1.3 m at 5.1 s interval, vessel heading 200°	Produced water	Sheen on port side approx. 175 m × 35 m, 25% barely visible, 75% silvery. Source is identified as produced water. PW in spec.
2013	6	8	Produced water outlet	Northerly 10 kn, visibility 14 (95/90) nm, seas 0.9 m, vessel heading (97/92) 109 true	Produced water	Sheen 100 m × 100 m, 70% open water, 30% silvery sheen. Produced water is in spec.
2013	6	8	Produced water outlet	Wind 220° 16 kn; swh 1.2 m; visibility 10 nm	Produced water	A silvery grey sheen was reported originating from the produced water on the southeast end of the installation and extending about 200 m and then drifting in a northeasterly direction for about 6–700 m.
2013	6	16	Produced water outlet	Wind 060° 26 kn; swh 1.3 m; visibility 15 nm	Produced water	A barely visible sheen was observed originating from the produced water outlet slowly drifting in a southerly direction from the south end of the installation in finger-like projection out approximately 800 meters from installation. OIW sample taken last night was 23.5 mg/L and this morning sample was 17.5 mg/L.
2013	7	2	Produced water outlet	—	Produced water	Sheen reported port side of installation 100 m × 30 m 5% open water, 90% silvery sheen, 5% yellowish brown. Produced water in spec 0–25 ppm.
2013	7	7	Produced water outlet	Wind 160° 6 kn; swh 0.2 m; visibility 10 nm	Produced water	A silvery bluish sheen was reported originating from the produced water on the southeast end of the installation and drifting in a southwest direction. PW OIW in am was 12.4 mg/L.
2013	7	9	Produced water outlet	Winds 3 kn 220 T; swh 0.8 m 5.7 s; visibility 1/8–1/2 nm in mist	Produced water	Sheen midway along port side 80 m × 3 m, 20% open water, 80% silvery sheen. Produced water in spec.
2013	7	11	Produced water outlet	Winds 9 kn 113 T; SWH 1.44 m 4.61 s; visibility 0–1/2 nm	Produced water	Sheen on port side 50 m × 20 m, 80% open water, 15% silvery sheen, 5% trace of color. Produced water in spec.
2013	7	13	Produced water outlet	Winds 16 kn; swh 1.1 m 4.8 s; visibility 0 nm	Produced water	Sheen on starboard side 30 m × 20 m, 60% open water, 40% silvery sheen, 50 m × 2 m, 30% open water, 70% silvery sheen. Produced water in spec.
2013	7	14	Produced water outlet	Winds 10 kn; swh 0.8 m 4.5 s; visibility 0 nm	Produced water	Sheen on port side 175 m × 30 m, 75% open water 25% silvery sheen second sheen starboard side 2 m × 10 m, 95% open water, 5% silvery sheen. Produced water in spec.
2013	7	17	Produced water outlet	Winds 19 kn; swh 2.35 m 5.97 s; visibility 2 0 nm	Produced water	Sheen midway along port side 150 m × 30 m, 85% open water, 15% silvery sheen. Produced water in spec.
2013	7	24	Produced water outlet	Winds 22 kn 156 T; swh 0.92 m 3.9 s; visibility 0 nm	Produced water	Sheen on starboard side 100 m × 30 m, 90% open water, 10% silvery. Produced water in spec.
2013	7	26	Produced water outlet	Winds 22 kn 156 T; swh 0.92 m 3.9 s; visibility 0 nm	Produced water	Sheen on starboard side 175 m × 30 m 85% open water, 10% silvery sheen, 5% barely visible. Produced water in spec 19.9 ppm.
2013	7	28	Produced water outlet	Winds 30 kn 240; swh 1.2 m; visibility 1/8 nm	Produced water	A dull grey to silver sheen originating from the produced water on the southeast end of the installation and drifting in a south southwest direction from the installation in a triangular shape. PW OIW in AM was 24.6 mg/L.

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Table A1 (*concluded*).

YYYY*	MM*	DD*	Source	Weather conditions	Reason for sheen or phenomenon	Miscellaneous
2013	8	3	Produced water outlet	Winds 24 kn 165 T; swh 1.2 m 3.8 s; visibility 3/4 nm in mist	Produced water	Sheen midway along starboard side 50 m × 3 m, 20% open water, 80% silvery sheen. Produced water in spec 0–14 ppm.
2013	8	29	Produced water outlet	Winds 23 kn 040°; swh 1.5 m; visibility 6 nm	Produced water	A silvery sheen was reported originating from the produced water on the southeast end of the installation and drifting in a south-southeast direction. Immediately below the installation the sheen was triangular shaped and the edge of the sheen had a dull color. As you moved away from the installation the sheen quickly trailed off with many small striated patches.
2013	8	31	Produced water outlet	Winds 39 kn; shw 5.5 m 7.9; visibility 4 nm	Produced water	Sheen on port side 100 m × 15 m, 90% open water, 5% barely visible, 5% silvery sheen. Produced water in spec 1 ppm.
2013	9	2	Produced water outlet	Winds 17 kn	Produced water	Sheen on starboard side 125 m × 50 m, 95% open water, 5% barely visible.
2014	1	6	Produced water outlet	Wind 16 kn 330, swh 5.8 m 8.3 s, visibility 22 nm	Produced water	Sheen midway along port side 150 m × 3 m 100% silvery. Produced water in spec 0–25 ppm.
2014	2	17	Produced water outlet	Winds 34 kn 241 T, swh 5.9 m 8.6 s	Produced water	Sheen midway along port side 100 m × 30 m, 95% open water, 5% silvery sheen. Produced water in spec at 27.5 ppm.
2014	3	20	Produced water outlet	Winds 3 kn 210 T, swh 2.7 m 8.2 s	Produced water	Sheen midway along port side 150 m × 15 m, 98% open water 2% silvery, Produced water in spec at 12.1 ppm
2014	4	1	Produced water outlet	Winds 25 kn 70 T, swh 2.6 m 6.2 s, visibility 0.5 nm	Produced water	Sheen midway along port side 150 m × 30 m, 90% open water, 10% silvery sheen. Produced water 15.9 ppm.
2014	5	5	Produced water outlet	Winds 1 kn 305 T, swh 3 m 11 s, visibility 0.0 nm	Produced water	Sheen midway along port side 150 m × 100 m, 85% open water, 12% silvery, 3% dull color. Produced water 19.9 ppm.
2014	7	16	Produced water outlet	Winds 15 kn 285 T, swh 1.3 m 4.8 s, visibility 1/4 nm in fog	Produced water	Sheen midway along port side, 80 m × 3 m, 8% open water, 90% silvery, 3% dull color. Produced water 0–25 ppm.
2014	8	6	Produced water outlet	Winds 9 kn 170 T, swh 0.14 m 7.7s, visibility 15 nm	Produced water	Sheen midway along starboard side, 50 m × 3 m, 10% open water, 10% barely visible, 80% silvery. Produced water 27.2 ppm.
2014	9	18	Produced water outlet	Winds 20 kn 110 T, swh 2 m 5.5 s, visibility 7 nm	Produced water	Sheen midway along starboard side, 150 m × 15 m, 98% open water, 2% silvery sheen.
2014	9	19	Produced water outlet	Winds 10 kn 280 T, swh 1.5 m 6.5 s, visibility 6 nm	Produced water	Sheen midway along starboard side, 200 m × 10 m, 95% open water, 5% silvery sheen.
2014	12	26	Produced water outlet	Winds 17 kn 239 T, swh 3.4 m 8.5 s, visibility 1 nm	Produced water	Sheen along starboard side, 200 m × 10 m, 95% open water, 5% silvery.
2015	2	9	Produced Water Outlet	Winds NNE 11 kn, swh 0.8 m, visibility 6+ nm	Produced water	Silvery sheen reported originating from the produced water on the southeast end of the installation and drifting in a southeast direction as many small striated patches. PW OIW in AM was 20.7 mg/L.
2015	2	15	Produced Water Outlet	Winds light and variable 285 T, swh 4 m 8.6 s, visibility 15 nm	Produced water	Sheen observed 2 m × 50 m, 5% open water, 95% silvery sheen.
2015	2	24	Produced Water Outlet	Winds 4 kn 280 T, swh 2.6 m 7.5 s, visibility 2 nm	Produced water	Sheen 250 m × 10 m, 80% open water, 10% silvery sheen, 5% trace of color, 4% bright bands of color, 1% dull color. Produced water in spec 23.6 ppm.
2015	5	11	Produced Water Outlet	NA	Produced water	Sheen observed on midway along starboard side of installation 10 m × 100 m (60% open water, 5% silvery sheen, 15% trace of colour, 20% bright band of colours). PW OIW in spec: am sample 18 ppm.

Note: Data was obtained from the Canadian-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) with platform identification removed for privacy. Sheen observation protocol and effort was not supplied with these data.

Table A2. Laboratory and field controlled-dose studies of effects of oil, internally and externally on marine birds.

Age	Species tested	Factors tested	Oil type	Test conditions	Results	Reference
External dosing						
Adults	Sanderlings (*Calidris alba*); semi-palmated plovers (*Charadrius semipalmatus*)	Behaviour	Nigerian light crude oil	Observation of naturally oiled birds from lightly (1%–15%) to heavily (>30%) oiled (note: this was not controlled dosing)	Heavily oiled birds experienced decreased time feeding and preening and increased time standing	Burger (1997)
Adults	Sanderlings (*Calidris alba*)	Behaviour and weight	Nigerian light crude oil	Fresh and weathered oil swabbed on belly feathers to simulate 20% oiling	Oiled birds spent less time resting, more time preening and bathing, were more aggressive, declined in average weight by 10%, and food consumption by 59%	Burger and Tsipoura (1998)
Adults	Leach's storm petrels (*Oceanodroma leucorhoa*)	Metabolic rate	PBCO	1.0 mL PBCO on breast and abdominal plumage and held in 16–21 °C air (not on water)	No change in metabolic rate	Butler et al. (1986)
Adults	Adélie penguins (*Pygoscelis adeliae*)	Metabolic rate	Vegetable oil	Oral dose of oil spread on feathers while preening "lightly oiled"; metabolism measured in air and on water	Increased heart rate, erratic behaviour, and metabolic rate 50% higher after oiling and when in/on 2–6 °C water	Culik et al. (1991)
Adults	Magellanic penguins (*Spheniscus magellanicus*)	Hormonal, reproductive	Crude oil	Measured hormones of live birds lightly to moderately oiled from spill (note: this was not controlled dosing)	Hormone disruption in oiled birds and even lightly oiled birds did not establish nests with eggs	Fowler et al. (1995)
Adults	Mallard ducks (*Anas platytyrhynchos*); Black ducks (*Anas rubripes*)	Metabolic rate	Various	5–50 g applications metabolic rate measured ducks in air at various temperatures	Dose-dependent increase in metabolic rate up to 100%	Hartung (1967)
Adults	Common eiders (*Somateria mollissima*); Mallard ducks (*Anas platyrhynchos*)	Heat loss	Statfjord crude oil	2.5–70 mL applications metabolic heat production resting in 5.5–6.5 °C water	Dose-dependent increase in heat loss when dose higher than 2.5 mL; 369% higher than normal in 70 mL group, and hypothermic within 70 min	Jenssen and Ekker (1991)
Adults	Common murres (*Uria aalge*); thick-billed murres (*Uria lomvia*)	Pathology; weight loss	Crude oil	Lightly to moderately contaminated on the breast, wings, feet, and head	Liver, kidney, and intestine necrosis; hematocrit values 43% below normal; weight loss of 7 fold	Khan and Ryan (1991)
Adults	Mallard ducks (*Anas platytyrhynchos*)	Metabolic rate	PBCO	50 μm thick simulated oil slick in swimming tank with seawater	13% increase in metabolic rate	Lambert et al. (1982)
Adults	Mallard ducks (*Anas platytyrhynchos*); Scaup	Metabolic rate; thermal conductance	Boundary Lake crude	Ducks placed on water with 50–400 mL oil, metabolic rate measured in air	Dose-, length-of-exposure-, and temperature-dependent increase in thermal conductance up to 98%; increase in metabolic rate by 33%	McEwan and Koelink (1973)
Adults, embryos	Leach's storm petrels (*Oceanodroma leucorhoa Viellot*)	Oil transfer and egg hatching	PBCO	Syringe used to apply 0.10 mL, or 0.50 mL PBCO on abdominal plumage and breast; intubation of 0.02 or 0.10 mL PBCO	Reduced attendance at burrow; parents oiled with 0.5 mL rejected up to 88% of visibly oiled eggs, 8% hatching success; 20% hatching success with intubated parents	Butler et al. (1988)
Embryos	Mallard ducks (*Anas platyrhynchos*)	Oil transfer and egg hatching	PBCO	Adults exposed to slicks 0.1 and 0.005 mm thick	Oil transferred to eggs; lower hatching success in dose-dependent fashion significant at 0.1 mm thick	Albers (1980)
Embryos	Leghorn chickens	Pathology	PBCO and SLCO	5 to 20 μL applied to shells of fertile eggs at various stages	5 μL of PBCO 100% mortality in 8–8.5 d old embryos; liver necrosis, edema, distention of heart, enlarged spleen; dose related	Couillard and Leighton (1989, 1990, 1991)
Embryos	Mallard ducks (*Anas platyrhynchos*)	LD_{50}	Crude and refined petroleum	Applied to eggs in various doses	Embryotoxic and moderately teratogenic; LD_{50}s of 0.3 to 5 μL per egg	Hoffman and Albers (1984)

Table A2 (*continued*).

Age	Species tested	Factors tested	Oil type	Test conditions	Results	Reference
Embryos	Laughing gulls (*Larus atricilla*)	Oil transfer and egg hatching	No. 2 fuel oil	Syringe used to apply 2.5 mL No. 2 fuel oil to breast feathers	41% embryonic mortality compared to 2% in controls	King and Lefever (1979)
Internal dosing						
Adults	Cassin's auklets (*Ptychoramphus aleuticus*)	Egg hatching	Bunker C fuel oil, PBCO	Fed gelatin capsule of 300, 600, or 1000 mg bunker C fuel oil or 1000 mg PBCO	Reduced egg laying and egg hatching at medium and high doses	Ainley et al. (1981)
Adults	Leach's storm petrels (*Oceanodroma leucorhoa*)	Metabolic rate	PBCO	Intubation with 0.1 mL PBCO	Increased metabolic rate by up to 25%	Butler et al. (1986)
Adults	Mallard ducks (*Anas platyrhynchos*)	Hormonal, reproductive	SLCO	3 mL crude oil per 100 g dry food for 50 days (no estimate of actual oil amount consumed per bird) to females	Reproductive hormone levels were depressed and egg laying delayed compared to controls	Cavanaugh and Holmes (1987)
Adults	Mallard ducks (*Anas platyrhynchos*)	Hepatic enzyme induction, corticosterone levels; food consumption	Kuwait, SLCO and Santa Barbara channel crude oil, No. 2 fuel oil, PBCO	Fed various concentrations of petroleum estimated to range from 0.4 to 7 mL/kg body weight per day for 50 d (10 d 1982 study)	Chronic exposure resulted in increases in hepatic liver enzymes; tolerated the contaminated food with few signs of "overt distress"	Gorsline and Holmes (1981, 1982); Gorsline et al. (1981)
Adults	Mallard ducks (*Anas platyrhyncho*)	Toxicity, various	Light fuel oil No. 1; diesel oil; SAE 10 W lube oil; SAE 10-W-30 lube oil; cutting oil	Intubated with 2 g/kg fuel oil; 2–24 mL/kg diesel oil; 2 mL/kg 10-W-30 lube oil; 1, 2, or 5 mL/kg cutting oil	Up to 61% lipid pneumonia in pollution-killed ducks; increased diarrhea, anemia, GI irritation, liver, kidney and pancreatic damage; increased weight of adrenal glands; motor disturbances; LD_{50}s ranged from 7 to 24 mL/kg and decreased LD_{50}s at lower temperatures	Hartung and Hunt (1966)
Adults	Pekin ducks (*Anas platyrhynchos*)	Food consumption, osmo-regulation, mortality	Kuwait, SLCO, No. 2 fuel oil, PBCO	Fed various amounts from 6 mL SLCO, 6 mL of Kuwait crude oil, or 3 mL of No. 2 oil for 50 d (1978); approximately 1–7 mg/kg body weight per day for 50 d (1979); evaluated at 27 and 3 °C	Hyperphagia possibly due to impaired intestinal absorption; increased mortality; cold stress increased mortality effects of ingested petroleum oils	Holmes et al. (1978, 1979)
Adults	Rhinoceros auklets (*Cerrorhinca monocerata*)	Blood: packed cell volume, haemoglobin concentration etc.	PBCO	0, 2.5, or 10 mL oil/kg of body weight for 5 consecutive days	No differences between groups in any blood parameters.	Newman et al. (1999)
Adults, chicks	Herring gulls (*Larus argentatus*); Leach's storm petrels (*Oceanodroma leucorhoa*)	Effects on chick metabolism; effects of adult dosing on chicks	PBCO	Intubation of chicks 1 mL; intubation of adults with 0.1 mL PBCO when chicks 3–5 d or 15 d old.	Increase in metabolic rate of chicks dosed with oil; when adults dosed, increased mortality in chicks 3–5 d old; reduced weight gain at 15 d; nest visitation unchanged; nasal and adrenal gland weights and thyroxine levels increased	Miller et al. (1980)
Adults, chicks	Mallard ducks (*Anas platyrhynchos*)	LD/LC_{50}, food consumption, weight, growth, systemic toxicity	Weathered *Exxon Valdez* crude oil	Oral feeding; birds monitored for toxicity and mortality	No acute or subacute effects on adults (LD_{50} > 5000 mg/kg) or ducklings (LC_{50} > 50 000 mg/kg diet)	Stubblefield et al. (1995*a*)
Adults, chicks	Leach's storm petrels (*Oceanodroma leucorhoa*)	Chick survival; weight gain; organ weights	PBCO	Intubation with 0.1 mL in adults or 0.05 mL in chicks	Chick survival reduced by 30% with one parent oiled and 48% when both oiled; decreased weight in chicks after adults dosed; adult nasal and adrenal gland weight increased	Trivelpiece et al. (1984)

Table A2 (*concluded*).

Age	Species tested	Factors tested	Oil type	Test conditions	Results	Reference
Adults, chicks, eggs	Mallard ducks (*Anas platyrhynchos*)	Mortality, body weight, food intake, reproductive, hatching success; shell thickness	Weathered *Exxon Valdez* crude oil	Multiple acute and subchronic toxicity tests including oral feeding including 5000 mg/kg body weighted 200 mg, 2000 mg, 20000 mg/kg; 1/3–1/6 egg covered	No significant differences in mortality, body weight, food consumption, reproductive parameters, or hatching; egg shell thickness decreased at highest dosage; increased embryo mortality at high doses of 125 mg/egg	Stubblefied et al. (1995*b*)
Chicks	Herring gulls (*Larus argentatus*)	Growth rate; behaviour; mortality	Weathered SLCO	Chicks intubated with 0.2 mL oil, 0.5 mL oil, and corn oil	Depressed weight gains; no significant behavioural changes; higher mortality at 0.5 mL (59%) than 0.2 mL (35%) or controls (38%)	Butler and Lukasiewicz (1979)
Chicks	Herring gulls (*Larus argentatus*); Leach's storm petrels (*Oceanodroma leucorhoa*)	Growth rates, organ weights, mortality	Weathered SLCO, PBCO	Chicks intubated with 1 mL of PBCO or equivalent aromatic fraction in 1 mL of PBCO	Depressed growth rates and increased nasal gland and adrenal weights in whole oil and AR-2 fraction; AR-2 liver hypotrophy; 53% of chicks of dosed parents survived (100% of controls survived)	Butler et al. (1979)
Chicks	Mallard ducks (*Anas platyrhyncho*)	Hepatic enzyme induction; corticosterone levels	SLCO or fractionate	Fed 3 mL crude oil per 100 g dry food or one of four proportionate fractionates separated by boiling point	Whole and two fractions of oil induced hepatic napthalene metabolism and decreased levels of corticosterone	Gorsline and Holmes (1982)
Chicks	Herring gulls (*Larus argentatus*)	Enzyme induction	PBCO, HCO	Intubated with 0, 4, or 10 mL/kg PBCO or 10 mL/kg HCO for 6 d	Hepatic cytochrome P-450 activity increased 4-fold; renal and liver mixed-function oxidase activity induced	Lee et al. (1985)
Chicks	Herring gulls (*Larus argentatus*); Atlantic puffins (*Fratercula arctica*)	Hemolytic anemia, Heinz body formation, oxidative stress	PBCO	Gulls fed gelatin capsule of either 1, 4, 10, or 20 mL/kg PBCO per day; puffins fed 5 or 10 mL/kg PBCO per day	Severe hemolytic anemia (>50% decrease in packed cell volume and hemoglobin); increased oxidative stress (99% increase in Heinz body formation)	Leighton et al. (1983)
Chicks	Black guillemots (*Cepphus grylle*)	Growth rates, organ weights, osmo-regulation	Weathered SLCO	Chicks intubated with a single dose of 0.1, 0.2, or 0.5 mL	Depressed growth rates; increased nasal gland and adrenal weight (3×), transient rise in sodium, no significant change in liver weight or Na, K-ATPase activities	Peakall et al. (1980)
Chicks	Herring gulls (*Larus argentatus*)	Weight gain, organ weights, sodium levels	PBCO	Chicks intubated with 1 mL PBCO or PBCO aromatic fraction of high or low molecular weight	Depressed weight gain, increased adrenal and nasal gland weight, and transient increase in sodium levels in treatments with PBCO and AR-2 fraction	Peakall et al. (1982)
Chicks	Pigeon guillemots (*Cepphus columba*)	Blood proteins, sodium levels, enzyme induction, growth and body mass	Weathered PBCO	Fed 0.05 or 0.20 mL	Weak effect on blood proteins; no effects on sodium levels, liver enzymes, growth and body mass; concluded that lack of significant effects may be due to oil being "weathered"	Prichard et al (1997)

Note: PBCO, Prudhoe Bay crude oil; SLCO, South Louisiana crude oil.