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 ($\leq 3 \mu\text{m}$ thick) and slick ($> 3 \mu\text{m}$ 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 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 in order 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 can not 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 impact to marine birds and marine bird populations. Lack of

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1 standardized monitoring of marine bird contact with sheens and potential harm make
2 assessments of magnitude and extent of impact problematic.
3 **Keywords:** Seabirds, offshore oil and gas, petroleum, oil sheens, produced water, operational
4 discharges

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Draft

Introduction

It is well established that marine birds are negatively impacted by exposure to oil in the ocean (Alonso-Alvarez et al. 2007b; 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. 2007b; Balseiro et al. 2005; E.g., 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

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1 chronic, low-level oil discharges. Hydrocarbon discharges from these industries typically are
2 regulated in compliance with international protocols (e.g., International Convention for the
3 Prevention of Pollution from Ships (MARPOL)). Environmentally safe levels of operational
4 hydrocarbon discharges are determined through environmental impact assessments but may not
5 fully take into account effects to many marine organisms.

6 In Canada, environmental impact assessments for offshore oil and gas operations have
7 predicted no significant effects to marine birds (Husky Oil 2000; Mobile Oil 1985; Petro-Canada
8 1997); however, these conclusions appear to be based on a lack of data rather than data showing
9 no effects to marine birds (Fraser et al. 2006). For the first time in this review we provide data,
10 analysis, and discussion of sheen formation from operational discharges in Atlantic Canada. We
11 then review literature on effects of controlled doses of low levels of oil, externally and internally
12 on marine birds. From these data, we extrapolate to possible effects on marine bird from contact
13 with low levels of oil.

14 **Operational Discharges of Hydrocarbons from Offshore Oil Operations**

15 In Canada, allowable operational discharges of hydrocarbons can result in the formation
16 of oil sheens. Sheens are defined as hydrocarbon concentrations on water surfaces that are less
17 than or equal to 3 µm in thickness as opposed to slicks which are greater than 3 µm in thickness
18 (ERIN Consulting Ltd. & OCL Services Ltd. 2003). There are two main types of allowable,
19 operational discharges from offshore oil and gas drilling and production operations: 1) produced
20 water, 2) oil- or synthetic-based drilling muds and cuttings. Hydrocarbons also can be released as
21 a result of typical operating procedures that are not necessarily compliant with international
22 protocols such as storage displacement water, bilge and ballast water, deck drainage, produced
23 sand, well treatment fluids, and accidental discharges and blowouts. However, in this review we
24 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 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; http://www.cnsopb.ns.ca/pdfs/owtg_redraft.pdf; accessed Feb 2015). Regulations for produced water in other countries are similar, generally between 30 to 42 ppm allowable OIW (Iggunu 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 (OBM), water-based (WBM), synthetic-based (SBM), or enhanced mineral oil-based (EMOBM) muds. Canadian regulations state that SBM must contain polycyclic aromatic hydrocarbon (PAH) 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 6.9g/100g remaining oil on wet solids (Canada's Offshore Waste Treatment Guidelines, 2010; http://www.cnsopb.ns.ca/pdfs/owtg_redraft.pdf; accessed Feb 2015).

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

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(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; <http://www.cnlopb.ca/pdfs/ar2015e.pdf>). 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. & 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. & OCL Services Ltd. 2003). Canadian offshore operations report average hydrocarbon concentrations of 20 to 40 mg/L in produced water, and that these levels can be associated with sheens (ERIN Consulting Ltd. & 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. & 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. & 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 (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. & 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. & OCL Services Ltd. (2003) in order 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 five 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. & 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. & 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*

1 *Offshore Petroleum Drilling and Production Regulations* (Section 9(k) [http://laws-](http://laws-lois.justice.gc.ca/eng/regulations/SOR-2009-315/page-4.html?texthighlight=monitoring#s-9)
2 [lois.justice.gc.ca/eng/regulations/SOR-2009-315/page-4.html?texthighlight=monitoring#s-9](http://laws-lois.justice.gc.ca/eng/regulations/SOR-2009-315/page-4.html?texthighlight=monitoring#s-9)).

3 While specific protocols are not outlined in the Regulations, most operators direct platform and
4 rig personnel to watch for sheens as part of their daily activities, investigate sources if sheens are
5 observed, and report to the C-NLOPB within 24h of the incident (D.G. Taylor, D.G. Taylor Inc.
6 Personal Communication). Due to the somewhat unspecific protocols, lack of standardization in
7 effort, training, and possibly in reporting, the analyses and interpretation of these data are useful,
8 yet limited.

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

16 In 155 of the 290 reported sheen occurrences, there was one or more oil in water (OIW)
17 concentration measure for produced water reported in conjunction with the occurrence. In some
18 cases, a range of values were reported (e.g., OIW below 25 mg/L). If a range was given, rather
19 than actual concentrations, we used the largest number in the range for our calculations. Using
20 the maximum value potentially results in a greater value for OIW in association with sheen
21 occurrence than if we had actual OIW values for our calculations. We consider this a
22 conservative approach because we are exploring minimum threshold OIW values associated with
23 sheen detections. In 135 of the 290 reported sheens from produced water, there was either no
24 information on OIW, or it was reported that the OIW was 'in spec' (within specified allowable

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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 to 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 description, 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

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1 offshore operations (which frequently mention blue or colour sheens, but not specifically dark
2 colour).

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

8 **Fate of hydrocarbons from offshore oil and gas operations**

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

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

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23 **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 to 100% mortality of the auk population in a 1 km² area around a platform, resulting in 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 by external oiling of plumage, by 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. 2007a; 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

1. 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 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, 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. He 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 pre-oiling 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. Portier and Raffy (1934) were first to publish findings on 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 15g of oil at -10°C compared to control birds, and a similar response in black ducks (*Anas rubripes*). He described a dose dependent response of metabolic rate to oiling with 5 to 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 one hour 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 three hours after external application of 10 to 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*

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1 *adeliae*) with residual vegetable oil on their plumage had metabolic rates 50% higher than
2 control birds, and the authors hypothesized that exposure to oil could lead to mass losses of
3 penguins (Culik et al. 1991). Butler et al. (1986) dosed birds externally with 1.0 ml of crude oil
4 and found no change in metabolic rate; however, birds were maintained in relatively warm
5 temperatures during the experiment and were not exposed to water. Disruption of water
6 repellence of feathers has greater implications for heat loss and thus metabolic compensation for
7 birds that are on water or wetted after oiling as opposed to oiled birds in dry conditions (see
8 Jenssen 1994). Even with undisturbed, water-repellent feathers, seabirds floating on water
9 surfaces in medium and high latitudes require an increased metabolic rate in order to maintain
10 body temperature and further stress from cold water penetration can result in death (Stephenson
11 1997).

12 ***Behavioural effects***

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

19 Burger and Tsipoura (1998) applied fresh and weathered oil to the belly feathers of
20 sanderlings (*Calidris alba*) simulating 20% plumage oiling. Oiled birds spent less time resting
21 and more time bathing and preening, resulting in increased spread of oil on feathers and less time
22 feeding. The amount of oil evident on feathers steadily decreased over two weeks, but was never
23 completely eliminated. Similarly, Burger (1997) found that time spent preening was increased
24 and time spent feeding was decreased proportionally to amount of oil on semipalmated plovers

(*Charadrius semipalmatus*). She 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. He 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. He 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 he 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 2. Internal Toxicity below).

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 since preening resulted in oil being spread around and into feathers, enhancing metabolic heat loss (Jenssen and Ekker 1991).

2. 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;

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1 Briggs et al. 1997; Briggs et al. 1996; Burger and Tsipoura 1998; Esler et al. 2000; Goldsworthy
2 et al. 2000; Golet et al. 2002; Golightly et al. 2002; Irons et al. 2000; Khan and Ryan 1991;
3 Parsons and Underhill 2005; Stubblefield et al. 1995b; Wiens et al. 2001). Ingestion of oil, from
4 preening oiled feathers, drinking water with oil, or from oiled food sources, negatively impacts
5 reproductive ability (Butler et al. 1988; Cavanaugh and Holmes 1987; Holmes and Cavanaugh
6 1987), disrupts hepatic function (Gorsline and Holmes 1981, 1982; Gorsline et al. 1981),
7 osmoregulatory function (Holmes et al. 1978), increases metabolic rate (Butler et al. 1986),
8 causes anemia (Balseiro et al. 2005; Leighton et al. 1983; Newman et al. 1999), and oxidative
9 damage to red blood cells (Couillard and Leighton 1993; Newman et al. 1999). Reproductive
10 disruptions include increased embryo mortality, decreased hatchling success, and decreased
11 chick growth (Butler et al. 1988). Whether ingestion of low doses (i.e., dosage levels expected
12 from exposure to oil sheens) results in toxic effects to marine birds has not been well-studied. In
13 the following sections, we review studies that use controlled, relatively low doses of oil on adult
14 and juvenile seabirds, and seabird eggs.

15 ***Toxicity of oil to adult aquatic birds***

16 There are relatively few controlled-dose studies on direct toxic effects of low levels of oil
17 to adult marine birds. An early study showed acute oral LD₅₀ values for several petroleum-
18 derived products on waterfowl range from 7 to 20 ml/kg (Hartung and Hunt 1966). Some of the
19 toxic effects common to all the industrial oils they tested were lipid pneumonia, gastrointestinal
20 irritation, fatty changes in the liver, and adrenal cortical hyperplasia. They found that toxicity of
21 oils was greatly enhanced when birds were stressed by crowded conditions and cold
22 temperatures, lowering LD₅₀ values to 1 to 4 ml/kg. Translating these results to seabirds, for a
23 common murre (*Uria aalge*) weighing 1kg for example, as little as 1 ml of ingested oil could
24 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. 2007b). 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 to 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 to 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 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)

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1 fed female mallard ducks 3 ml/100 g dry food (no estimate was provided of actual amount of oil
2 ingested per bird) each day for 50 days. They found significant decreases in reproductive
3 hormones and significant delays in egg laying in the group fed oil. They hypothesized that such
4 sub-lethal effects could seriously threaten survival of seabird populations, which
5 characteristically have low annual recruitment of fledglings. Similarly, a series of studies using
6 low-doses of oil (2.5 ml/kg with ranges of actual doses from 0.02 to 0.3 ml per adult) found a
7 40% decrease in hatching success of Leach's storm-petrels, a decrease in chick survival up to
8 50% when a single member of a breeding pair was intubated, significantly lower weight gain of
9 chicks with oiled parents, and damage to adult nasal and adrenal glands (Miller et al. 1980;
10 Trivelpiece et al. 1984). The authors hypothesized that the decreased hatching success, chick
11 growth, and chick survival likely were due to temporary desertion of the burrow and/or impaired
12 ability of oil-treated adults to provide for their young.

13 Despite evidence that even small amounts of ingested oil can impact adult metabolic rate,
14 health, and reproductive output, there are other low- and high-dose studies that show no negative
15 impacts on adults. In a study on oxidative damage to red blood cells in adult rhinoceros auklets
16 (*Cerorhinca monocerata*) exposed to PBCO, low dose birds received 2.5 ml/kg oil/body weight
17 for five consecutive days (Newman et al. 1999). There were no negative effects on any of the
18 tested blood parameters. Stubblefield et al. (1995a) assessed acute and sub-acute toxicity of
19 weathered Exxon Valdez crude oil (WEVC) on mallard ducks. In the acute tests, ducks were fed
20 5g/kg body weight WEVC and observed for 14 d. They concluded that acute oral LD₅₀ exceeded
21 5 g/kg and they observed no treatment related toxicity during the study or in post-mortem
22 examination. They hypothesized that weathered oil may be less toxic than unweathered oil. In
23 addition, Alonso-Alvarez et al. (2007b), in the study described above on yellow-legged gulls, the
24 low dose of 0.04 ml of oil over four 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; Peakall et al. 1982). Tests of effects of ingestion of PBCO and Hibernia crude oil (HCO) 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 HCO for six consecutive days. Hepatic cytochrome P-450 was increased four-fold as well as increases in other hepatic and renal mixed function oxidase activities, suggesting that ingestion of toxins induced a metabolic response in order 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 five days, severe hemolytic anemia was evident (Leighton et al. 1983).

Miller et al. (1980), using lower doses than above, fed nestling herring gulls 1 ml of PBCO and examined changes in mass for four days, 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 (*Cephus grille*) with 0.1 to 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.

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Prichard et al. (1997) fed pigeon guillemot (*Cephus 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. 1995a), 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. 2007a).

Embryos: There is some evidence that oil on eggs may negatively impact developing embryos, and 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 since 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 to 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 to 8.5 d old, there was 100% mortality. Exposure at 9 d old with 12 µl of PBCO

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1 resulted in 32% embryo mortality, indicating that embryos may be particularly sensitive at
2 certain developmental stages. Conversely, Stubblefield et al. (1995b) found no negative impacts
3 on hatchling survival or growth after application of WEVC to 1/6 to 1/3 of mallard eggs. They
4 concluded that their results may differ from similar studies that found negative impacts of crude
5 oil on eggs because of the use of less toxic weathered oil in their study, as opposed to
6 unweathered oil. Hoffman and Albers (1984) estimated LD₅₀ levels of various types of crude
7 and refined petroleum for mallard embryos. They found that many of the petroleum products
8 were embryotoxic and had LD₅₀ of 0.3 to 5 µl/egg.

9 Laughing gulls (*Leucophaeus atricilla*) dosed with 2.5 ml of oil to the breast feathers
10 transferred oil to eggs, resulting in 41% embryo mortality compared to 2% for controls (King
11 and Lefever 1979). They speculated that the cause of mortality was from egg smothering and/or
12 toxicity of the oil, rather than behavioural changes in the incubating adults. Albers (1980)
13 exposed breeding mallards to water with 100 ml or 5 ml of PBCO per m² of water surface area
14 and observed breeding behaviour, hatching success, and duckling survival. The oil thicknesses
15 that the birds were exposed to correspond to oil films 0.1 mm and 0.005 mm thick for the high
16 and low treatments respectively. The 0.005 mm treatment is only slightly thicker than a sheen
17 (which are up to 0.003 mm thick). He found that there was oil transfer from adults to eggs in
18 both treatments, in a dose dependent fashion. Hatching success (proportion of eggs hatched) was
19 96, 80, and 47% in the control, low, and high treatment groups respectively. Survival rate of
20 hatchlings and incubation behaviour of adults did not appear to differ among treatments. He
21 concluded that sub-acutely oiled birds continue to incubate their eggs normally, but that transfer
22 of oil to eggs could have devastating effects on embryos and hatchability.

23 24 **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/m² of sea surface. Thicker sheens that show trace colours are 0.1 μm , and bright to dark colour sheens are approximately 0.3 to 3 μm thick with a corresponding volume of 0.3 to 3 ml/m². 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 x 52 x 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 what 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 ml and 5 ml when birds are exposed to sheens. In order 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 m² of sheen and pick

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up all of the oil from the area. A bird swimming through a colour sheen ($\sim 1\text{--}3\ \mu\text{m}$ thick) could come in contact with 1 ml of oil in 0.3 to 1 m² of surface, making it likely that these thicker sheens could result in significant oil transfer. In order for a bird to pick up 5 ml of oil from a trace colour sheen ($\sim 0.1\ \mu\text{m}$ thick), it would have to swim through the equivalent of approximately 50 m² of sheen and pick up all of the oil from the area; not a likely scenario. Yet, a bird swimming through a colour sheen ($\sim 1\text{--}3\ \mu\text{m}$ thick) could come in contact with up to 5 ml of oil less than 2 m² 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. Below, 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. 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, personal communication).

Internal

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1 It is unlikely that exposure to oil sheens resulting from discharges of hydrocarbons within
2 regulated amounts would cause acute toxic effects to adult seabirds. However, a number of
3 studies have found sub-lethal effects and reproductive effects on adult birds, when as little as
4 0.02 to 3 ml of oil was ingested, singly or over a number of days. The primary route of internal
5 exposure for birds exposed to sheens is from preening oiled feathers (although ingestion can also
6 occur from 'drinking' oiled water and eating oiled food).

7 Studies show that birds will preen 50% to, 'most' and 'all' of the oil from their feathers
8 over a few days (Birkhead et al. 1973; Camphuysen 2011; Hartung 1963, 1964; Stubblefield et
9 al. 1995a). Using the conservative estimate of 50% of oil on plumage preened and ingested, a
10 bird fouled with 0.04 ml of oil on its plumage could experience sub-lethal toxic effects described
11 in previous sections. Since a sheen can have up to 3 ml of oil per m², it is plausible that a seabird
12 swimming in a sheen could pick up at least 0.04 to 2 ml of oil on its feathers. It is reasonable to
13 propose then, that some sub-lethal toxic effects are experienced by adult seabirds from sheen
14 exposure. It is important to emphasize that some studies on adult birds (reported in previous
15 sections and in Table A2) found no effects of low levels of oil ingestion on factors they tested.
16 Possible explanations for differences between study findings are the use of weathered vs.
17 unweathered oil, species, and/or size of bird tested, and responses tested. Therefore, sub-lethal
18 effects of sheens to adult seabirds is expected to vary based on factors such as age of oil that a
19 bird contacts (weathered or unweathered), bird species and size, and feeding mode.

20 Nestlings are more susceptible to acute toxicity from low levels of oil ingestion than adult
21 birds, showing consistent, negative effects with ingestion levels as low as 0.1 ml. Nestlings
22 however, do not come in direct contact with sheens, and transfer rates to nestlings from oiled
23 adults have not been quantified. It is plausible that adults exposed to oil sheens could transfer

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1 small amounts of oil to nestlings at sufficient dosages to cause toxic effects, based on the low
2 nestling toxicity threshold.

3 Like nestlings, eggs will not come in direct contact with sheens; however, embryos are
4 susceptible to even minute amounts of oil. King and Lefever (1979) showed that 2.5 ml of oil
5 applied to incubating laughing gulls resulted in 41% embryo mortality (compared to 2% in
6 controls); it therefore follows that birds exposed to thicker sheens could pick up oil at levels that
7 cause significant embryo mortality. Albers (1980) found transfer of oil to eggs from adults that
8 were oiled from slicks that were only slightly thicker than sheens. There was decreased hatching
9 success of eggs compared to control eggs, making it one of the few studies to show a direct
10 causal link between oil sheens and decreases in reproductive output. With an LD₅₀ for mallard
11 embryos of 0.3 to 5 µl a bird would need to pick up only 0.1 ml of oil and transfer about 5% to
12 an egg in order for the egg to be dosed with 5 µl of oil. While species will differ in their
13 susceptibility to oil, these findings make it plausible that some amount of embryo mortality is
14 occurring from seabird exposure to sheens. However, it should be noted that exposure of adults
15 (and consequently, nestlings and eggs) to oil discharged in the production areas in Atlantic is
16 unlikely during breeding because most Atlantic species do not travel during foraging trips as far
17 as oil platforms, which lie approximately 300 km offshore. Leach's Storm-Petrel are an
18 exception as birds breeding in Nova Scotia have been shown to fly 1000s of kilometres in single
19 foraging trips during the breeding season (Pollet et al. 2014).

20 21 **Population Effects**

22 Studies of marine bird populations following major oil spills indicate that there are both
23 short- and long-term negative impacts to populations (Esler et al. 2002; Esler et al. 2000; Golet et
24 al. 2002; Irons et al. 2000; Lance et al. 2001; Votier et al. 2005). Population effects following oil

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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). As well, 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. And, birds may 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 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 to 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

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on seabird populations are only speculative at this point and specific research is critical before possible implications for population level impacts to 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. Resultantly, low levels of external oiling could have more significant impact 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

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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 due to 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 are having long-term effects on populations is speculative at this point due to lack of data on 1. Incidence of seabird oiling around platforms, 2. 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, 3. controlled studies that directly quantify effects of sheens on seabirds 4. long term in pelagic seabird abundance in Atlantic Canada.

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Tables

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. It is used as the standard reference for observation and quantification of oil on water (CAPP 2009).

Appearance	Thickness (µm)	Volume (L/km ²)
Barely visible	0.04	50
Silver sheen	0.07	100
First colour trace	0.1	200
Bright colours	0.3	400
Dull colours	1	1,200
Dark colours	3	3,600

Table A1. Sheen occurrence around offshore oil and gas production platforms in the Canada-Newfoundland and Labrador offshore area. 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. PBCO = Prudhoe Bay crude oil, SLCO = South Louisiana crude oil, WSLCO = weathered South Louisiana crude oil.

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Figure Captions

Figure 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.

Figure 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.

Figure 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 hour, from sunrise to sunset at the middle of each month for latitude 46.75°N.

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