OPERATIONAL SCIENCE ADVISORY TEAM
SUMMARY REPORT FOR FATE AND EFFECTS OF REMNANT OIL REMAINING IN THE BEACH ENVIRONMENT

Annex I: Water Birds

Introduction

Water birds are evocative symbols of the beach, and the effects of oil on wildlife. Numerous important species nest, winter, stop over, or permanently inhabit the northern Gulf (listed in Ecological Framework section), and all forage in the spill-affected area. Many water bird populations, especially those nesting on shores in temperate climates, are in decline as a result of human development and associated disturbances. Additional harm from natural disasters and large spills, such as the Deepwater Horizon (DWH) incident, can have serious consequences to these populations.

Hazards from DWH Incident

Chemical Hazards

<u>Components of crude oil</u>

As described in the Ecological Framework section, the chemicals of concern in the source crude oil are BTEX compounds and PAHs; generally BTEX is associated with acute effects and the PAHs with chronic effects. At the current state of weathering for most of the residual oil, chronic effects from PAHs are the main concern for risk to birds. PAHs are further divided into low and high molecular weight (MW) fractions; the response data on residual oil degradation have been analyzed for total PAHs and the high MW fraction.

While dose terms in toxicological studies of crude oil effects on birds are mostly expressed as mass or volume of oil, some information is available for toxicity of oil components. Much of this information is indirect, relying on different responses to different oils (for example, No. 2 fuel oil versus crude oils; Holmes et al. 1979) and indicating effects from both lighter and heavier oil fractions. Peakall et al. (1982) found that the aromatic fraction (two rings and higher) of Prudhoe Bay crude oil caused growth retardation and glandular changes in herring gull nestlings. PAH-specific information was reported for the response of mallard embryos (Hoffman and Gay 1981 in Eisler 1987), in which nanogram levels of 7,12-dimethylbenz(a)anthracene, chrysene, and benzo(a)pyrene reduced growth or increased mortality. Therefore, it is clear that high molecular weight PAHs do have serious effects on bird eggs.

Fate and transport related to water birds

Three forms of residual oil occur throughout the spill-affected area, meaning that exposure pathways to water birds are complete and exposure is largely governed by routes of entry to individuals. Potential routes of entry are inhalation, ingestion, and direct contact. Volatilization is likely to be insignificant at this stage of weathering and was not analyzed. Ingestion of oil may occur through contaminated prey items, from preening oiled feathers, and from incidental intake while foraging. Oiling of feathers is uncommon at this point in the spill, so ingestion from preening was not considered further. Direct contact is a well-known route for eggs, but uptake through skin in birds is thought to be unlikely because of shielding by feathers; this route of entry is not well studied, so this means of exposure was not analyzed.

Toxicity Analysis

Important routes of entry are through ingestion of oil and direct contact with eggs, so these were the focus of the toxicity analysis. For timeliness, the literature review was limited to primarily peer-reviewed journal articles that were readily retrievable and frequently referred to in assessments of crude oil effects on birds.

Ingestion

We found about 19 articles with suitable information, representing 6 water bird species (the mallard was the most common subject studied). Most studies expressed doses as a volume of oil administered to each bird or a percentage of oil in the diet. Prudhoe Bay and South Louisiana crudes were the most frequently tested. We developed a common dose term of mg crude oil x kg body mass^{-1} x day^{-1}. To obtain this term, measurements reported in the articles were preferred. Where article-reported values were not used, we converted oil volumes to masses using appropriate specific gravities, found body masses in NatureServe's Online Encyclopedia of Life, and calculated food ingestion rates using the Charadriiformes equation in Nagy (2001). For conservativeness, our goal was to find the lowest doses associated with effects that could be manifest at the population level (i.e., mortality, reproduction) or compromise individual fitness (i.e., growth, serious physiological or behavioral changes). Common-term doses were derived for the studies (Appendix); lowest observed effect levels (LOELs) and associated no observed effect levels (NOELs), where available, are summarized:

mg oil x kg BM^{-1} x day^{-1}	effect	bird	reference
250	**fewer eggs**	mallard	Coon and Dieter 1981
259	reduced avoidance behavior	mallard duckling	Szaro et al. 1978
42.8	**none**	mallard duckling	Szaro et al. 1978
263	**growth**, osmoreg., glands	herring gull chicks	Miller et al. 1978
248	increased testis weight	mallard	Patton and Dieter 1980
2,480	increased liver weight	mallard	Patton and Dieter 1980

BM – body mass

osmoreg. – osmoregulatory function

The two more serious LOELs, fewer eggs and reduced growth, were not associated with NOELs because the lowest experimental doses caused effects. Only a less serious LOEL, reduced avoidance behavior, was associated with a NOEL. When NOELs are not available, they are often estimated by dividing the LOEL by a factor of ten. We summarized the results as a low NOEL – LOEL range of 43 – 250 mg oil x kg body $mass^{-1}$ x day^{-1}, which was used to assess risk to beach-foraging birds.

Direct Contact with Eggs

Among eight articles researched, we found a LOEL of 1 µL south Louisiana crude, applied directly to mallard eggs, reported in three of them (Dieter 1977, Hoffman 1979, Szaro 1977). In each case, significant embryo mortality occurred and no associated NOELs were found. Crude oil LOELs of 10 µL and 20 µL were reported for other species, Louisiana heron (Macko and King 1980) and common eider (Dieter 1977), respectively. Macko and King reported that 4-week weathered oil was perhaps more potent than fresh oil, but Stubblefield et al. (1995) found 98-day weathered Exxon Valdez oil did not show significant effects to mallard embryos at up to 92 mg/egg (about 100 µL/egg). The effect of oil weathering on risk will be addressed in the exposure analysis; the LOEL of 1 µL was used to assess risk to eggs of beach-nesting birds.

Physical Hazards

Oil can have a profound effect on the physical properties of feathers, severely limiting their function in flight and thermal insulation. Most of the oil is now weathered to the point of not sticking to feathers. Areas where less weathered oil becomes exposed and affects plumage are being cleaned up.

New exposures excluded, at this stage of the cleanup, physical hazards to birds are from the cleanup activities themselves. Cleanup activities may disturb birds as they reproduce, forage, or rest, and these activities may remove materials important in foraging or roosting.

Severe effects, such are nest abandonment, may result from frequent disturbance of nesting areas, especially for colonial-nesting birds. Eggs laid on beaches may be destroyed by footfalls of cleanup workers or the tires of cleanup vehicles. Eggs of beach-nesting birds are likely to be overlooked because they have color patterns mimicking sand, to avoid detection by predators.

Disruption of foraging is a well-studied impact of human disturbance on beaches. Wintering piping plovers have had their active foraging time reduced by about one half when many people visit the beach (Burger 1991). The number of people within 100 m of sanderlings explained the greatest variation in foraging models (Burger and Gochfeld 1991). At a shorebird migration staging area, human disturbance at high levels may reduce by 50% the abundance of impacted species (Pfister et al. 1992). Pfister et al. concluded that long-term "disturbance is implicated as a potential factor in long-term declines in shorebird abundance…" The assertion is based on the lack of nutrition the reduced foraging time represents and its critical importance prior to long migrations. Reduced food is also likely to be critical when birds are at breeding locations and needing nutrition to develop eggs and feed young.

Oil cleanup activities on beaches are typified by large numbers of people and vehicles, and sometimes by heavy equipment. The effect of oil cleanup actions on bird foraging was measured directly in one study, where nearly 50% of sanderling and semi-palmated plover foraging time was interrupted by cleanup personnel and vehicles moving up and down beaches, compared to <5% disrupted on a beach with only walkers and joggers (Burger 1997).

Foraging and roosting is also impacted by the removal, in the oil cleanup process, of algae, shells, and organic debris (wrack) washed up on beaches. Fresh wrack is especially important because it tends to be colonized by invertebrates that are important prey of shorebirds. Older wrack is a source of organic matter and nutrients in beaches, and is important as cover for roosting shorebirds (de la Huz et al. 2005).

Best management practices (BMPs) were instituted in summer 2010 to ameliorate the impacts of cleanup operations on birds and other beach-dwelling resources. While the BMPs benefit birds in the active response areas, the benefits have not been evaluated or quantified.

To summarize, oil cleanup activities on beaches may be expected to harm birds directly, reduce materials important to shorebird foraging and roosting, and reduce foraging time up to 50%. While some impacts have been ameliorated by following BMPs, direct effects and reduced nutrition may be critical to migrating and reproducing birds, indicating medium to high risk.

Birds at Risk

Among water birds, those nesting on beaches and shorebirds foraging on beaches are most likely to be exposed to the three forms of residual oil. Birds are more likely to be exposed to SSRBs than to buried or submerged oil, but interchange between the three forms occurred in the past and may still be expected. Examples of interchange are SSRBs separating from submerged mats and washing ashore, and erosion of buried oil in storms that may add to submerged mats.

We reviewed descriptions of water birds that nest, winter, stop over, or permanently inhabit the northern Gulf for those that forage or nest on beaches. Birds foraging on Gulf beaches include several species of sandpipers and plovers, red knots, marbled godwits, sanderlings, ruddy turnstones, dunlins, whimbrels, and willets. Bird species nesting on north Gulf beaches include American oystercatcher, black skimmer, Wilson’s plover, snowy plover, several terns, and the brown pelican.

Risk assessment for oil toxicity is based on comparing data from toxicity studies to estimates of exposure. To estimate exposure from ingestion, for example, one or more species have to be identified so that feeding rates may be quantified. Similarly, egg characteristics for one or more particular species need to be evaluated for embryo exposures. Typically small-bodied species are selected for conservativeness, or species with distinctive characteristics or special conservation status may be selected to focus the risk assessment. For foraging exposure, we selected the Western sandpiper (WESA) and the piping plover (PIPL). WESA has the smallest size among birds that usually probe the sand for invertebrate prey, and PIPL is a federally-listed species. For egg exposure, we selected the snowy plover (SNPL) and the least tern (LETE). Both are among the smallest beach-nesting birds, and their egg dimensions are similar (SNPL: 23x32 mm, LETE: 24x31 mm; NatureServe). Also, SNPL forages on beaches, suggesting exposure through ingestion, and LETE is a federally-listed species.

Exposure

Ingestion

Exposure models for ingested oil are estimates of food ingestion rate multiplied by proportions of SSRBs in the diet, proportions of oil in an SSRB, and proportions of oil remaining after weathering, then divided by the bird’s body mass. Estimates of food ingestion rate are from the Charadriiformes (an order that includes gulls and shorebirds) equation in Nagy (2001). Nagy’s equations use body mass as input to calculate feeding rate. The proportion of oil in an SSRB was set at 0.2, based on analyses of SSRBs associated with the spill. Body masses were taken from NatureServe’s online Encyclopedia of Life for WESA (0.023 kg) and PIPL (0.055 kg), resulting in feeding rates of 21.3 and 41.7 g/day (fresh weight), respectively. We saw the proportions of SSRBs in the diet and the extent of oil weathering as varying in space and time, and decided to address the variations as part of the exposure assessment.

Oil ingestion potentially includes oil in the bodies of ingested invertebrates in addition to oil swallowed incidentally while feeding. No measurements of oil in small invertebrates are available for this spill, and while pathways from the three forms of residual oil to invertebrates may be complete, they have not been quantified. So, the estimates of oil in the diet are based on incidental ingestion. The WESA probes sand in the swash zone for isopods and other invertebrates. Because they do not typically feed by sight, it seems possible that small residue balls, whether on or just below the surface, could be taken incidentally while probing the sand. We assume that small residue ball coverage at shallow depths is equivalent to SSRB coverage, small residue balls are equivalent to a prey item, and they are taken in direct proportion to the extent of their coverage. This approach seems conservative because SSRBs may be seen and avoided, and a small residue ball taken in the bill may be rejected, based on taste, texture, lack of movement, or other factors. On the other hand, we include no other estimates of oil ingestion, including oil that is in prey items and oil from preening. While oil on feathers is now uncommon in this spill, there are reports of shorebirds that have SSRBs sticking to their feet, legs, or undersides.

Oil degradation will continue to occur, and residual oil is currently estimated to have degraded an average of 80 to 95%, meaning that only 5 to 20% of the original distribution of compounds in the oil remains. The 80% value is an approximate midpoint for degradation rates of high molecular weight PAHs, while the oil as a whole has degraded at higher rates. As mentioned earlier, high molecular weight PAHs are associated with chronic effects in birds. While most residual oil is highly degraded, thick deposits that occasionally become uncovered, such as recently at Pass a Loutre, Louisiana, have characteristics of unweathered oil, such as the ability to stick to bird feathers.

We used ranges of SSRB cover and extent of degradation to estimate oil ingestion rates for WESA and PIPL (Tables 1 and 2; green cells indicate values below NOEL, yellow cells indicate values below LOEL). Because the ingestion decreases with more oil degradation, the tables actually predict the reduction in toxicity of the remaining components of fresh oil. The conservativeness of the SSRB approach is apparent from inspecting the tables. As SSRB cover approaches 100%, oil ingestion increases linearly, even though a bird feeding exclusively on oil is likely to forage elsewhere. Estimates may be more realistic at low SSRB coverage.

Table 1. Estimated WESA oil ingestion (mg oil x kg body mass^{-1} x day^{-1})

SSRB cover (%)	**Oil degradation (%)**					
	0	**50**	**75**	**80**	**95**	**99**
100	185,217	92,609	46,304	37,043	9,261	1,852
20	37,043	18,522	9,261	7,409	1,852	370
3	5,557	2,778	1,389	1,111	278	56
1	1,852	926	463	370	93	19
0.5	926	463	232	185	46	9
0.1	185	93	46	37	9	2

Table 2. Estimated PIPL oil ingestion (mg oil x kg body mass^{-1} x day^{-1})

SSRB cover (%)	**Oil degradation (%)**					
	0	**50**	**75**	**80**	**95**	**99**
100	**151,636**	**75,818**	**37,909**	**30,327**	**7,582**	**1,516**
20	**30,327**	**15,164**	**7,582**	**6,065**	**1,516**	**303**
3	**4,549**	**2,275**	**1,137**	**910**	**227**	**45**
1	**1,516**	**758**	**379**	**303**	**76**	**15**
0.5	**758**	**379**	**190**	**152**	**38**	**8**
0.1	**152**	**76**	**38**	**30**	**8**	**2**

PIPLs tend to feed on the surface more than by probing the substrate, so they may see and avoid SSRBs most of the time. Accordingly, a more appropriate representation of their exposure is in Table 3, which has entries set at 0.33 of the levels in Table 2. This is based on assuming surface feeding is 67% of all foraging. (The small differences in oil ingestion between Table 1 (WESA) and Table 2 (PIPL) are based on the different body masses of the two birds.) The ranges of oil ingestion in the tables are comparable to the NOEL – LOEL range derived in the toxicity section.

Table 3. Estimated PIPL oil ingestion, assuming most foraging on surface (mg oil x kg body mass^{-1} x day^{-1})

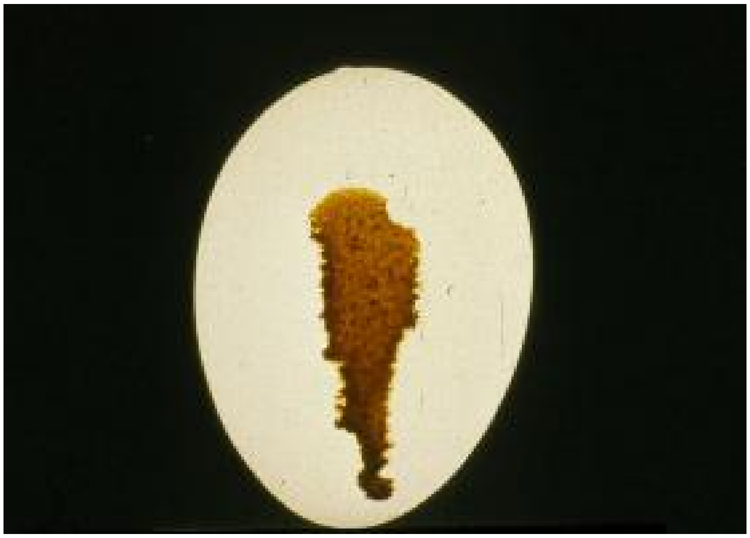
SSRB cover (%)	**Oil degradation (%)** 0	**50**	**75**	**80**	**95**	**99**
100	50,545	25,273	12,636	10,109	2,527	505
20	10,109	5,055	2,527	2,022	505	101
3	1,516	758	379	303	76	15
1	505	253	126	101	25	5
0.5	253	126	63	51	13	3
0.1	51	25	13	10	3	1

Direct Contact with Eggs

SNPLs may nest singly or in loose colonies on beaches and other dry, flat areas where vegetation is sparse or absent. LETEs nest in colonies; nests are shallow depressions in similar habitat to SNPL. LETEs may be in mixed-species colonies with common terns, black skimmers, least terns, royal terns, Sandwich terns, or Caspian terns. Nests of these birds tend to be well above normal high tide, but are seldom far from water and are subject to flooding during unusually high tides or storm surges. Therefore, nests may co-occur with SSRBs or be in areas where previously buried oil has become uncovered by shifting sands. Also, SSRBs may be moved by strong winds into nesting areas.

From studies of bird embryo toxicity discussed in the toxicity section, as little as 1 µL of fresh crude oil placed on an egg can cause significant embryo mortality. To characterize exposure, we consider what surface area may be associated with this threshold, what oil-sand mixture characteristics may result in oil transfer to eggs, and other aspects of exposure.

The photo below (from the Canadian Cooperative Wildlife Health Centre) shows 10 µL of crude oil on a chicken egg.



Perhaps 20% of the area seen is covered by the oil. So, 1 µl may cover 2% of the egg. An average commercial chicken egg is about 50 mm long; on a smaller egg, such as a SNPL's (32 mm long; NatureServe), the coverage may be twice as much, or 4%. Visualizing an egg lying on sand, it seems likely that at least 4% of the bottom half would be covered by the sand.

Whether oil in sand can transfer to an egg's surface depends on a number of factors, including the amount of oil in the sand. The effective porosity of sand is about 30%, so if oil represents about 20% of the mass of an SSRB, the majority of the sand's pores are filled with oil. Therefore, it is possible that the oil is available for transfer, especially if flattened by deposition or movement of an egg. SSRBs counted on treated beaches had average diameters $\leq$ 5 mm, with an overall average of 4 mm. If an egg compresses a 4-mm SSRB to an average thickness of 1 mm, the area of the flattened SSRB would be about 34 mm^2. Assuming a SNPL egg (32 x 23 mm) may be described as a sphere of 28 mm diameter, its surface area on one side would be 1,232 mm^2, making the flattened SSRB about 3% of this area. Based on the rough analysis in the preceding paragraph, 2 average SSRBs in close proximity (within about 2 cm^2) would be needed to reach the toxicity threshold.

Similar conditions may be found among SCAT categories for buried oil. Oil-filled pores (OP; oil flows out when disturbed) and partially-filled pores (PP; pore spaces filled with oil) are conditions with the potential to transfer oil to an egg, if the oil becomes exposed at the sand surface. Other conditions for buried oil that may indicate the potential for transfer to a 32 mm-long egg would be distributions that are at least continuous or broken (> 50% coverage) in bands of > 1 cm width. The frequency with which buried supratidal oil reaches the surface is unknown, but it is probably low. Because small amounts of oil may affect eggs, the removal of exposed oil, for instance after storms, should remain in maintenance and monitoring plans.

Oil degradation is likely to affect the toxicity of residual oil to eggs. A way to account for degradation is to increase the threshold surface area that would have to be covered before toxicity may be assumed. If 4% coverage of the bottom half of an egg is toxic for fresh oil, then oil that is 80% degraded would need to cover 16% of the bottom half of an egg. Based on our rough analysis, 6 average SSRBs would need to occur in about 2 cm^2 of sand to provide 16% coverage. Likewise, oil that is 95% degraded would need to cover 80% of the bottom half. While 16% coverage seems possible for an egg lying on oiled sand, 80% coverage is unlikely, unless the egg is rolled around.

Other variables, like stickiness, viscosity, and temperature of the oil, will affect its ability to transfer from its sand matrix to an egg. Conclusions are hindered by not knowing the physical characteristics of the residual oil, but it is likely that increased temperatures will make the oil more likely to transfer.

Risk Analysis

By using the toxicity threshold as a consideration in the egg exposure assessment, some indications of risk have already been discussed. With fresh oil in SSRBs, a total of 2 SSRBs would need to be depressed by an egg to cross the toxicity threshold, and with 80 to 95% oil degradation, 6 to 30 SSRBs would be needed. Because the nests are flat and birds typically roll their eggs, the potential exposure area is larger than the area under an egg. If the "rolling" area for an egg may be described by a radius of 0.1 m, the area would be 0.031 m^2. Six SSRBs would need to be in this area to cross the toxicity threshold under current conditions; 6 SSRBs in 0.031 m^2 represents 193 SSRBs/m^2. The highest count of SSRBs on treated beaches is 917 per meter (Dauphin Island); the average beach width in the spill area is 83.2 m, so the high count results in a coverage of 11 SSRBs/m^2. So, it is possible but unlikely that treated beaches will have enough SSRB cover to harm bird eggs under current conditions. Risk to eggs may result from buried oil becoming exposed in the future, if the oil fills the sand pores in an area of about 1 cm^2 or greater.

A wide range of potential risks exists for birds ingesting oil while foraging, depending on the extent of oil degradation, SSRB coverage, and extent of surface foraging (Tables 1 through 3). The colored cells in the tables represent levels below the NOEL (green: possible risk) and levels between the NOEL and LOEL (yellow: low risk). Uncolored areas are medium or high risk. Medium and high risk levels could not be distinguished because time was not available to further analyze the toxicity data. Current, post-treatment conditions for SSRBs may be assessed by the combinations of 1% SSRB coverage, 0.1% SSRB coverage, and 80% oil degradation. The combinations for PIPL (Table 3) indicate low risk, while those for the WESA (Table 1) indicate a range from low to medium/high risk.

An important aspect of foraging in oiled environments that has not been quantified is the avoidance of oiled areas and the rejection of oiled "prey" (including SSRBs). During and after the IXTOC I spill, shorebirds avoided foraging on oil mats (Tunnel et al. 1982), so it is realistic to assume that foraging would not occur at high SSRB coverage. At less obvious oiling levels, there is evidence to suggest that shorebirds reject oiled prey. Andres (1999) "occasionally observed adult [oystercatchers] rejecting prey items, but only on persistently oiled substrates."

Interpretations of this observation could range from ‘all oiled prey is rejected but only observed occasionally,’ to ‘oiled prey is only rejected occasionally.’ Articles reviewed for ingested toxicity data mention both lack of discrimination between oiled and un-oiled food and intolerance to (regurgitation of) oil. Having no quantitative data on how sand-probing birds locate prey or how they may reject inappropriate ‘prey,’ the quantitative estimates for WESA risk have not been adjusted. On balance, the ingestion risk may be overestimated. The potential condition for WESA at 1% SSRB coverage and 80% oil degradation is less a medium/high risk and more a borderline situation between low and medium risk.

Uncertainty

Uncertainty is associated with all aspects of a risk assessment and can include errors in design, measurement, analysis, omission and judgment, as well as the consequences of assumptions.

Field measurements of oil effects, as well as feeding, bioavailability, and toxicity tests on residual oil, would be more certain than assessing risks as mainly a literature evaluation and modeling exercise. It is not known whether a field and laboratory approach would increase or decrease perceived risk.

We dismissed inhalation and injection routes, as well as direct contact in adults. This underestimates risk.

The ingestion LOEL was the lowest among six species and the egg LOEL was the lowest of three species. While this is protective, it may overestimate average risk conditions.

There was not an exhaustive search of the oil toxicity literature, for both ingestion and egg contact routes. Because more toxicity data would likely lower toxicity thresholds, this underestimates risk.

The impacts of cleanup activities were not quantified for this spill. Whether cleanup activities for this spill had more or less impact on birds than literature studies is unknown.

Specific issues that may be important in this analysis include the ingestion estimate (Table 4; likely overestimated), the egg exposure estimate (likely overestimated) and omission of evaluations for cumulative, indirect, and long-term risks (overall risk likely underestimated).

Table 4. Major uncertainties and sources of variability associated with risk estimates.

Uncertainties/Sources	Underestimate	Overestimate	Unknown	Comments
Ingestion estimate		X		Oil ingestion model assumes that all SSRBs encountered are consumed, when probing sand for prey items. Underestimated aspects of ingestion (oil in prey, oil from preening) are likely less important.
Egg exposure estimate		X		Egg exposure model assumes oil transfers from sand matrix to egg
Omitted evaluations of cumulative, indirect, and long-term risks	X			Such risks are more likely on large grain (e.g., cobble) beaches or coasts with exposed bedrock or macro vegetation

To summarize, risks from the three forms of residual oil to foraging birds range from low to medium. Risks to eggs of beach-nesting birds are possible, but unlikely. Risks from cleanup activities are medium to high.

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NOEL	LOEL	measurement	species	life stage	body mass (kg)	feeding rate (g dry)	toxicant dose no effect	toxicant dose low	toxicant dose unit	toxicant description 1	toxicant description 2	toxicant sp gravity	reference
	636	endocrine dysfunction	black guillemot		0.275			0.2	mL/bird	oil, S LA		0.875	Peakall et al 1981
	262.5	growth, osmoreg, glands	herring gull	chicks				0.3	mL/kg BM	oil, S LA		0.875	Miller et al. 1978
	2218	growth, glands	herring gull	nestling	0.4			1	mL/bird	oil, Prudhoe Bay		0.887	Peakall et al 1982
	887	weight loss	herring gull	nestling	1			1	mL/bird	oil, Prudhoe Bay		0.887	Peakall et al 1985
	854	endocrine dysfunction	herring gull		0.512			0.5	mL/bird	oil, S LA		0.875	Peakall et al 1981
	2188	endocrine dysfunction	Leach's storm petrel		0.04			0.1	mL/bird	oil, S LA		0.875	Peakall et al 1981
42.8	428	avoidance behavior	mallard	duckling	0.125	21.4	250	2500	ppm diet	oil, S LA			Szaro et al. 1978
261	2611	egg production	mallard	adult	1.082	113	2500	25000	ppm diet	oil, S LA			Dieter 1977
	1044	egg production	mallard	adult	1.082	113		10000	ppm diet	oil, S LA			Holmes in Dieter 1977
	250	fewer eggs	mallard	adult	1.27	127		2500	ppm diet	oil, S LA			Coon and Dieter 1981
209	2089	eggshell thickness	mallard	adult	1.082	113	2000	20000	mg/kg food	oil, Prudhoe Bay	98 day weathered		Stubblefield et al. 1995
259	2591	growth	mallard	adult	1.1	114	2500	25000	ppm diet	oil, S LA			Szaro et al. 1978
	3500	immune response	mallard					4	mL/kg BM.day	oil, S LA		0.875	Rocke et al. 1984
	1400	intestinal absorption	mallard	duckling	0.125			0.2	mL/bird	oil, Santa Barbara		0.875	Crocker et al. 1974

248	2481	liver function	mallard	adult	1.3	129	2500	25000		oil, S LA			Patton and Dieter 1980
5000		mortality	mallard	adult	1.082	113	5000		mg/kg BM	oil, Prudhoe Bay	98 day weathered		Stubblefield et al. 1995
849	2608	mortality	mallard	adult			0.97	2.98	mL/kg BM.day	oil, S LA		0.875	Holmes et al. 1979
	2538	mortality	Pekin duck	adult				2.9	mL/kg BM	oil, S LA		0.875	Holmes et al. 1978
0	43	organs, plasma	mallard	duckling	0.125	21.4	0	250	ppm diet	oil, S LA			Dieter 1977
	248	testes weight	mallard	adult	1.3	129		2500		oil, S LA			Patton and Dieter 1980
364	none	inflammation	pigeon guillemots	nestling	0.487		0.2		mL	oil, Prudhoe Bay	5-6 yr. weathered	0.887	Pritchard et al. 1997
	1774	liver weight	sandhill crane	15 wk				2	mL/kg BM	oil, Prudhoe Bay		0.887	Fleming et al. 1982
92		mortality	mallard	egg			92		mg/egg	oil, Prudhoe Bay	98 day weathered		Stubblefield et al. 1995
	1	mortality	mallard	egg				1	uL/egg	oil, S LA			Dieter 1977
	20	mortality	common eider	egg				20	uL/egg	oil, S LA			Dieter 1977
	1	mortality	mallard	egg				1	uL/egg	oil, S LA			Hoffman 1979
	1	mortality	mallard	egg				1	uL/egg	oil, S LA			Szaro 1977
	10	mortality	Louisiana heron	egg				10	uL/egg	oil, Libyan	4-8 wk weathered		Macko and King 1980
10		mortality	laughing gull	egg			10		uL/egg	oil, Libyan	4-8 wk weathered		Macko and King 1980

Note: NOEL and LOEL units for eggs are as published, for birds they are mg oil x kg body mass^{-1} x day^{-1}