Guidance for Dispersant Decision Making: Potential for Impacts on Aquatic Biota

A Final Report Submitted to

The Coastal Response Research Center

Submitted by

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Abstract

This research provides guidance for oil spill response tradeoff decisions involving dispersant usage by estimating expected level of resource injury: the likely water volume adversely affected by naturally- or chemically-dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil. These results can be used to evaluate tradeoffs of dispersant use and plan monitoring activities, including for natural resource damage assessment.

The Oil Spill Impact Guide (OSIG) is based on a matrix of 1,080 oil fate and exposure model runs using Applied Science Associate's (ASA) Spill Impact Model Application Package (SIMAP) physical fates, exposure and oil toxicity models, where key variables determining impact are varied: oil type, weathering state, oil volume, environmental (e.g., wind speed, temperature) conditions, dispersant use, and toxicity to aquatic biota. The model application is for the surface mixing layer of open unrestricted water bodies, as opposed to near shorelines. Model results, including water volume where acute toxic effects would occur and the area of water surface oiled (which would impact wildlife, as well as socioeconomic uses), are summarized in both tabular and chart format. To put these impact volumes and areas in perspective, typical densities of biota in various geographical regions are used to provide a comparison of injuries with which to evaluate tradeoffs. The user of the guide can look up the order of magnitude of likely impact and interpolate between results for intermediate conditions to those run in the matrix of scenarios using regressions and the spreadsheet calculator provided.

Impacts for treated oil volumes < 500 gal (2 m^3) were non-measurable to all water column biota, including the most sensitive species. Thus, as a general conclusion, the tradeoff with respect to wildlife versus water column biota is in favor of dispersant use for oil volumes < 500 gal, while remaining protective of all species. Dispersing more than 5,000 gal of oil in a single location during a short period of time (<1 hour) could have some impact on biota in the surface mixed layer, depending on winds, degree of current shear, weathering state, temperature, and sensitivity of the aquatic biota exposed (i.e., toxicity). However, the volume and area of surface water where water column biota would be affected would be much less than the area affected by floating oil thick enough to impact wildlife. Furthermore, the model results showed that dispersant application on spills of < 5,000 gal (19 m^3) produced non-measurable impacts on water column organisms of *average* sensitivity to dissolved PAHs, regardless of dispersant effectiveness assumed or environmental conditions. Thus, if dispersant applications are spread out over wide areas or over time, such that each localized application does not exceed 500 gal (to protect all species) or 5,000 gal (to protect the average species) of oil dispersed, water column impacts can be held low while still accomplishing a reduction of impacts due to the floating oil.

In an actual incident, the potential benefits and risks of dispersant use depend on the sensitivity of resources present or absent in the area affected by the spilled oil. In addition to considering direct exposure and resulting impacts, long-term effects should be considered. Populations of long-lived species such as birds and marine mammals typically recover much slower from the impact of an oil spill than populations of species with a higher turnover rate such as zooplankton. In addition, the potential for long-term effects in intertidal areas that might be exposed to oil needs to be weighed in the balance. We expect that the research and lessons learned from this effort will contribute to efforts aimed at developing decision-support tools, and provide needed information related to spill response, specifically with respect to dispersant use.

Keywords: Oil spill impacts; dispersant; spill model; toxicity; impact tradeoffs; decision aid

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1.0 Introduction

There is considerable uncertainty and debate about the efficacy of dispersant use (Fingas, 2002) and the tradeoffs of impact caused by floating versus dispersed oil (NRC 1989, 2005; Lunel *et al.*, 1997,b; S.L. Ross, 1997; Trudel, 1998; Fingas and Ka'aihue, 2004). The National Research Council (NRC, 2005) summarizes the uncertainties with respect to impacts to water column organisms as being related to incomplete understanding of oil fate and toxicity (particularly sublethal and ecosystem-level implications), and calls for additional laboratory or tank experimentation and field monitoring to increase scientific understanding and verify models. However, there is considerable information available to indicate the acute effects of spilled oil on wildlife, shoreline habitats, and water column biota, which is utilized to provide guidance to the response decision-maker considering dispersant use.

The US Coast Guard (USCG) recently finalized new rules and guidance with respect to dispersant use as part of spill response (see USCG, 1999, 2009), which is expected to increase dispersant use on oil spills in US waters (NRC, 2005). In Europe, only Britain uses dispersants extensively (the Sea Empress being a documented case), although they may be used in Norway and France (Fingas, 2002). While dispersant use is rare in other jurisdictions, consideration of its use as an option for response is expected to increase (e.g., Kirby and Law, 2008). Thus, evaluation of the potential impacts of dispersant use as compared to other spill response options is needed in order to make informed decisions as part of spill response planning.

We do not address efficacy (feasibility and effectiveness) as part of this project. The reader is referred to reviews of dispersant effectiveness tests by NRC (1989, 2005), Fingas (2002), and Lewis et al. (2006, 2009). The present analysis addresses the tradeoffs related to potential impacts of dispersant use as compared to those of untreated oil. An effective application of dispersant may reduce impacts to wildlife (e.g. seabirds, furred marine mammals) and shoreline habitats (including resources using those habitats), but with the tradeoff that the dispersed oil may cause impacts to water column organisms. The 2005 report from NRC (NRC, 2005) identified future research needs for understanding dispersed oil in the marine environment, including the need to quantify these tradeoffs so that informed decisions, based on potential resulting biological impacts, can be made during spill response. The results of this project provide responders with guidance for evaluating tradeoffs of dispersant use. The guidance includes model estimates of water volume adversely affected (with respect to toxicity to aquatic biota) by dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil. To put these impact volumes and areas in perspective, typical densities of biota in various geographical regions and habitats are used to provide a comparison of injuries with which to evaluate tradeoffs.

The model results are also useful for planning monitoring activities for response effectiveness and natural resource damage assessment (NRDA), as the results indicate the size of dispersed oil and dissolved hydrocarbon plumes and potential impacts to water column biota. However, it is not feasible to directly measure differences in plankton (and other aquatic biota) densities within and outside of naturally- and chemically-dispersed oil plumes to provide evidence of acute water column effects. In order to quantify impacts, comprehensive sampling of each of the species affected would be needed in the exposed and unaffected areas. Because marine organisms are so patchy in their distribution, large numbers of stations and samples within stations are needed to accurately map abundance. Though many have tried during spills, such extensive sampling of all species is not operationally possible, given the rapidity at which the evidence disappears (by scavenging of killed organisms and by migration of animals into the impacted area). Even during the *North Cape* oil spill, a large, fully dispersed spill of light fuel oil where evidence (millions of dead organisms stranded on nearby beaches) indicated large impacts, it was not feasible to directly measure the water column impacts. Thus, modeling of oil fate and effects, combined with field observations and field-collected aquatic biota density estimates, were used to quantify water column injuries in the NRDA (NOAA et al., 1999; French McCay, 2003). Modeling is recognized as the most practical and reliable method for estimating water column acute toxic effects from spills. Modeling also provides estimates of areas swept by floating oil and shoreline oiled, within which wildlife and shoreline habitat impacts would occur.

Under previous funding by the State of California – Department of Fish & Game Office of Spill Prevention and Response (CA OSPR), computer simulations using the oil fates and biological effects model SIMAP (Spill Impact Model Application Package; French McCay, 2003, 2004) were made of natural and chemically-treated dispersion of large oil slicks (~ 1.5 square miles, 3.9 km^2), indicating that resulting plumes could persist for several days with polynuclear aromatic hydrocarbon (PAH) concentrations at levels toxic to at least sensitive aquatic organisms (French McCay et al., 2006). The scenarios examined were purposefully designed to be worst case: the highest potential oil volume that could be dispersed into the water column at a given location, i.e., the amount of oil that could be dispersed by a single sortie of a C-130 airplane [100,000 gal = 379 m^3 of crude oil] dispersed at 80% efficiency). Those results indicated that wildlife impacts (if oil were left floating) would be over a much larger area than water column impacts in the mixed layer (~10-20 m deep), and reductions of wildlife impacts would be much greater than increases in water column impacts, if dispersants are used to a maximum possible extent in offshore open waters. While some water column impact would be expected from dispersant use at this large scale, the area where wildlife impacts would occur would be much larger if dispersants were not used (French McCay et al., 2006).

Modeling was also performed in support of the US Coast Guard (USCG) Programmatic Environmental Impact Statement (PEIS) for its changes to Vessel and Facility Response Plan oil removal capacity (Caps) requirements for tank vessels and marine transportation-related facilities (USCG, 2009). Those model results, provided in French McCay et al. (2005), were based on dispersing 45-80% of large spill volumes (2,500 bbl [105,000 gal, 397 m^3] and 40,000 bbl [1,680,000 gal, 6359 m^3]), again demonstrating potential (quasi-) worst-case impacts to water column biota. Comparisons of potential water column impacts with wildlife, shoreline, and socioeconomic impacts, made on the basis of the percentages of resources affected and recovery time, indicated that large-scale and effective dispersant use on medium-large volume spills would reduce overall impact.

However, similar modeling for more typical (smaller) oil volumes that might be dispersed in localized areas has not previously been performed and no quantitative guidance has been available for response decision-makers. Dispersant use on smaller oil volumes might be more palatable to stakeholders if it can be shown that water column effects would be negligible or small, especially relative to alternative impacts on wildlife and shorelines. Thus in this project, a matrix of model scenarios, varying key input variables determining impact, was run for a range of smaller oil volumes more likely to be dispersed in an actual spill response. The model scenarios address spills on the surface of open unrestricted water bodies, as opposed to near shorelines. The objective was to estimate areas and resources impacted by floating oil, as compared to volumes of water made toxic by both naturally- and chemically-dispersed oil.

Crude oils of varying properties were examined with the modeling, as dispersants are not typically applied to light fuels (which naturally disperse quickly) or heavy fuel oil (which is too viscous to be dispersed). Modeling results in French McCay and Payne (2001) suggest that weathering state influences toxicity of dispersed oil plumes. This is because as oil weathers the soluble, and so bioavailable, aromatics (which are also volatile) evaporate quickly from floating oil. If weathered oil is dispersed, toxicity will be much less than for fresh unweathered oil.

Temperature is another important variable as volatilization, uptake rate into biota, and toxicity are all greatly enhanced at higher temperature. Bioassays have shown wide variation in toxic response to oil hydrocarbons, such that acute toxicity endpoints (e.g., Lethal Concentration to 50% of exposed organisms, LC50) vary by orders of magnitude among species and life stages (French McCay, 2002; McGrath and DiToro, 2006). Finally, oil viscosity, wind speed, and turbulent mixing (diffusion or in-water dispersion rate) determine the degree to which oil is naturally dispersed into the water column and the rate at which the subsurface plume dilutes to non-toxic concentrations.

A matrix of model runs of varying spill size, sampling a variety of environmental conditions, and using a range of potential toxicity values, was run to quantitatively describe the likely impacts of oil spills with and without dispersant use. Guidance for responders and decision-makers was developed based on these model results and provided in report, field-guide and spreadsheet-calculator formats. Response advisors can use this information to compare impacts with and without dispersant use. This Oil Spill Impact Guide (OSIG) includes estimates of the likely water volume adversely affected by dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil, with which they can evaluate tradeoffs of dispersant use and plan monitoring activities. To allow the user of the guidance to put these impact volumes and areas in perspective, typical densities of biota in various geographical regions and habitats are multiplied by the impact volumes/areas to provide a comparison of injuries with which to evaluate tradeoffs. Impacts for situations with proportionately different densities of biota may be calculated by ratio.

2.0 Objectives

The goal of this research was to provide guidance for tradeoff decisions involving dispersant usage in the context of response activities and expected level of resource injury. This project was designed to provide responders and decision makers with a quick guide (as both a field handbook and an easy-to-use computer calculator application) allowing them to determine the likely water volume adversely affected by dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil, with which they can evaluate tradeoffs and plan monitoring activities, including for natural resource damage assessment. To allow such an analysis, the guide provides an assessment of impacts by spills of varying sizes under different environmental conditions with and without dispersant use. Thus, response advisors will be able to compare impacts with and without dispersant use, as well as be able to print reports for informing the Unified Command. The technical documentation for the guide is a report that contains all assumptions, model inputs and results of the analysis. A manuscript summarizing the analysis and findings is also being prepared for publication to fully disseminate the information to the oil spill response community.

The Oil Spill Impact Guide (OSIG) is based on a matrix of model runs using ASA's SIMAP physical fates, exposure and oil toxicity models (French McCay, 2002, 2003, 2004), where the key variables determining impact are varied: oil type, oil volume, degree of weathering, environmental (e.g., wind speed, temperature) conditions, dispersant use and assumed efficiency (effectiveness) in increasing entrainment of oil into the water, and toxicity to aquatic biota. Model results from the matrix (as areas and volumes impacted) are summarized in both tabular and chart format so that users of the guide can look up the order of magnitude of likely impact and interpolate between results for intermediate conditions to those run in the matrix of scenarios. Simple regression equations, and a spreadsheet for calculations, are provided to facilitate interpolation for intermediate volumes of oil spilled and portions of the spilled oil volume dispersed.

The OSIG includes estimates of the likely water volume adversely affected by dispersed oil and dissolved hydrocarbons, as well as the surface area impacted by floating oil, with which they can evaluate tradeoffs of dispersant use and plan monitoring activities. To allow the user of the OSIG to put these impact volumes and areas in perspective, typical densities of biota in various geographical regions and habitats are multiplied by the impact volumes/areas to provide a comparison of injuries with which to evaluate tradeoffs. Impacts for situations with proportionately different densities of biota may be calculated by ratio.

These objectives address goals of the CRRC by providing a new technology and integrative approach for spill response and assessment, disseminating results visibly and widely, and providing outreach and training. The objectives of this research have applicability to spill response decision making, net environmental benefit analysis, and education.

3.0 Methods

3.1 Model

Applied Science Associate's (ASA) Spill Impact Model Application Package (SIMAP) model (French McCay, 2003, 2004), which quantifies fates and concentrations of subsurface oil components (dissolved and particulate) as well as areas swept by floating oil of varying thicknesses, was run to simulate hypothetical oil spills with and without dispersant use under a range of potential environmental conditions. The model algorithms in SIMAP (French McCay, 2002, 2003, 2004) have been developed over the past two decades to simulate fate and effects of oil spills under a variety of environmental conditions. SIMAP was derived from the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME, French et al., 1996), which was developed for the US Department of the Interior (USDOI) as the basis of Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) Natural Resource Damage Assessment (NRDA) regulations [43 CFR PART 11 (1995), as amended at 61 Fed. Reg. 20609, May 7, 1996] for Type A assessments (http://www.doi.gov/oepc/wp_docs/43cfr11.html).

The three-dimensional physical fates model in SIMAP estimates distribution (as mass, areas and thicknesses of oil, and concentrations) of whole oil and oil components on the water surface, on shorelines, in the water column, and in sediments. Processes simulated include spreading (gravitational and by shearing), evaporation of volatiles from surface oil, transport on the surface and in the water column, randomized dispersion from small-scale motions (mixing), emulsification, entrainment of oil as droplets into the water (natural and facilitated by dispersant), dissolution of soluble components, volatilization of dissolved hydrocarbons from the surface water, adherence of oil droplets to suspended sediments, adsorption of soluble and semi-soluble aromatics to suspended sediments, sedimentation, stranding on shorelines, and degradation. Lower molecular weight aromatic hydrocarbons, i.e., monoaromatics and PAHs, are the soluble and semi-soluble components that are most bioavailable to aquatic biota, inducing most of the effects (French McCay, 2002). These and other “pseudocomponents” representing volatile aliphatic hydrocarbons are tracked separately from whole oil in the model.

Dispersant use is simulated by increasing the amount of oil entrained into the water and reducing the droplet size distribution of that entrained oil, as compared to natural wind- and wave-induced entrainment. The model does not calculate the effectiveness of a dispersant application (i.e., the fraction of treated oil that actually is entrained into the water), as this is determined not only by the dispersant and oil properties but by the logistical effectiveness of applying the dispersant on the oil, as well as environmental conditions. Rather, the model user defines efficiency of dispersant application as an assumed input, by telling the model the percentage (and so volume) of oil that is effectively dispersed in a given time period.

The biological effects model in SIMAP estimates short term (acute) exposure of biota of various behavior types to floating oil and subsurface contamination (in water and subtidal sediments), resulting percent mortality, and sublethal effects on production (growth). Mortality for each wildlife (bird, mammal, and reptile) behavior group is based on the area swept by surface oil over a threshold thickness that would oil an animal with a lethal dose, the probability of encounter with the oil on the water surface, and the probability of mortality once oiled. Toxicity to aquatic biota in the water and subtidal sediments is estimated from dissolved aromatic concentrations and exposure duration, using laboratory-based bioassay data for oil hydrocarbon mixtures (French McCay, 2002).

Impacts are estimated by species or species group for wildlife, fish and invertebrates by multiplying areas or volumes at various percentage losses by the density of animals per unit area or volume. However, equivalent areas or volumes of 100% loss (the weighted sum of lesser percentage losses) may be compared to estimate relative impacts to wildlife versus fish and invertebrates for spill response purposes, as well as in ecological risk assessments. The use of equivalent areas and volumes for 100% mortality as metrics is an innovative approach that allows quantitative comparisons to be made between impacts to surface-related and water column-related resources, without having to estimate species densities. Since densities of all biota are highly variable in time and space, in some cases potential end-users of model results have difficulty accepting assumed biological data. This approach avoids that controversy, getting to the issue at hand – evaluating tradeoff comparisons between impacts to wildlife and water column biota in determining the best course of action to minimize overall impacts to biological resources. However, both types of results, by area/volume or as number/biomass killed, are presented in the guidance.

3.2 Modeling Matrix and Inputs

A generic offshore spill site was used in the simulations, as the areas and volumes impacted would be similar in all offshore open-water areas under the same environmental conditions. Below is the matrix design that includes 360 physical fate model runs, each with three biological exposure and toxic effects model runs. The biological effects model was then run for all of the 1,080 (360 X 3) exposure scenarios (i.e., for 3 LC50 input assumptions) and for 6 representative regions of US offshore waters where we have previously compiled biological databases (i.e., from French et al., 1996), yielding 6,480 sets of model outputs.

- Oil fate matrix
    - Oil types (2): light (South Louisiana) and medium/heavy (Alaskan North Slope) crude oil;

- o Volumes of oil (released (5) and assumed chemically dispersed (3)): five oil volumes (to allow curve-fitting of results) over a range where oil could be treated in a single dispersant application (1,000 – 100,000 gal) and three effectiveness assumptions (i.e., percentage of oil actually dispersed) per oil volume spilled (i.e., 0%, 20%, or 50% of the oil is assumed dispersed), which sets the chemically-dispersed oil volume simulated;
  - o Oil weathering degrees (2): dispersant applied 12 hours or 24 hours after an instantaneous spill;
  - o Weather conditions (2): light wind (5 knots = 2.5 m/sec) and moderately high wind (15 knots = 5 m/sec), each inducing associated wave heights and turbulent mixing (diffusion or in-water dispersion rate, which determines the rate at which the subsurface plume dilutes to non-toxic concentrations) in the surface wave-mixed layer; and
  - o Water temperatures (3): low (5ºC), medium (15ºC), and high (25ºC), which affects weathering, uptake into biota, and toxicity.
- Toxicity: three LC50s covering the range of two standard deviations (95%) of species response (French McCay, 2002)
  - o Mean [50 ppb dissolved PAH];
  - o Sensitive [5 ppb dissolved PAH]; and
  - o Insensitive [400 ppb dissolved PAH].
- Biological databases (6) representing US continental shelf regions (i.e., biological provinces from French et al., 1996)
  - o Atlantic coast (province 15);
  - o Gulf of Mexico (province 37);
  - o North Pacific coast (province 44);
  - o Inland North Pacific (province 51);
  - o Inland northern North Pacific (province 55); and
  - o Arctic Ocean (province 73).

Oil Type and Properties

Crude oil spills are considered in the modeling matrix. Oil property data for typical crude oils, representative of oils that might be spilled in U.S. waters, were used (i.e., South Louisiana light crude and Alaskan North Slope crude, as in French McCay et al., 2005). South Louisiana (SLA) crude represents a light crude and Alaskan North Slope (ANS) a medium/heavy weight crude.

Table 3.2. Oil properties for Alaska North Slope (ANS) and South Louisiana (SLA) crude oils.

Property	South Louisiana Crude	Alaskan North Slope Crude	Source of Information (Reference)
API	34.5	29.9	Jokuty et al, (1999)
Density @ measurement temperature (g/cm^3) – API (16ºC)	0.852	0.876	Jokuty et al, (1999)
Density - measurement temperature (degrees C) – API (16ºC)	16	16	Jokuty et al, (1999)
Density @ measurement temperature (g/cm^3)			
Density - measurement temperature (degrees C)			
Viscosity @ measurement temperature (cp)	8	16	Jokuty et al, (1999)
Viscosity - measurement temperature (degrees C)	25	25	Jokuty et al, (1999)

Viscosity @ measurement temperature (cp)	10.10	18	Jokuty et al, (1999)
Viscosity - measurement temperature (degrees C)	15	15	Jokuty et al, (1999)
Surface Tension (dyne/cm)	25.9	27	Jokuty et al, (1999)
Pour Point (degrees C)	-28	-54	Jokuty et al, (1999)
Minimum Oil Thickness (microns)	10	50	Based on McAuliffe, (1987)
Fraction monoaromatic hydrocarbons (MAHs)	0.0148	0.0307	Jokuty et al, (1999)
Fraction 2-ring aromatics (PAHs)	0.0032	0.0038	A.D. Little (1996)
Fraction 3-ring aromatics (PAHs)	0.0051	0.0066	A.D. Little (1996)
Fraction Non-Aromatic Volatiles: boiling point < 180ºC	0.1652	0.0893	Jokuty et al, (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264ºC	0.1858	0.1332	Jokuty et al, (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380ºC	0.2759	0.2004	Jokuty et al, (1999)[1]
Saturated hydrocarbons (fraction of oil)	80.8	51	Jokuty et al, (1999)
Aromatic hydrocarbons (fraction of oil)	12.6	34	Jokuty et al, (1999)
Asphaltenes (fraction of oil)	0.8	5	Jokuty et al, (1999)
Resins (fraction of oil)	5.9	9	Jokuty et al, (1999)
Waxes (fraction of oil)	1.7		SLA: Jokuty et al, (1999)
Water-in-oil Emulsion Formation and Stability of Mousse	Stable	Stable	Assumed based on – SLA: NOAA (2000); ANS: Jokuty et al, (1999)
Maximum Mousse Water Content (%)	75	70	SLA: NOAA (2000); ANS: Jokuty et al, (1999)

[1] – Distillation data obtained from Jokuty et al. (1999) provided total hydrocarbon data by distillation cut. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.

Volume of Oil Dispersed and Not Dispersed

The range of spill volumes (1,000 – 100,000 gal) was chosen to provide useful results for guidance. The highest potential oil volume that could be treated with dispersant *at a given location* would be that amount of oil that could be dispersed by a single sortie of a C-130, or 100,000 gal of oil. Thus, to a limited extent (i.e., to several hundreds of thousands of gallons of floating oil), higher volumes need not be run as the affected areas would be separated in space and time, and therefore the impacts of each treated oil volume could be considered separately and as additive.

The volume of oil dispersed by an application of chemical dispersant was examined as a percentage of spilled oil volume being treated (0% or no dispersant application, 20% of spill volume dispersed, or 50% of spill volume dispersed). The effectiveness range is considered realistic for dispersant applications at sea by the USCG (1999). Again, this guidance was not designed to investigate efficiency of the dispersant application itself; therefore the model inputs include volume (or percentage) of the initially-spilled oil that is dispersed and not the amount of dispersant applied. The model does no further calculations with the dispersed oil volume (such as estimating how effective the operation might have been); it simply entrains that volume of oil into the water at the time defined in the model inputs.

Weathering State of the Oil When Dispersed

In the environment oil weathers and degrades as its chemical components are removed or broken apart. In many cases, the time oil is left to weather on the surface of the water before dispersant is applied is a direct result of response time. Two weathering times (12 and 24 hours post spill) were included to represent two potential response times.

Wind Speed

The environmental conditions at the time of a spill can largely influence the effects on biota. Wind is an important force leading to natural dispersion via wind-driven waves and entrainment into the water column. Two wind speeds were modeled to represent light (0 – 12 kt) and moderate (12 – ~25kt) winds. Because wind speed can have a large influence on floating oil, the results from this guide should not be applied in situations where wind conditions are greater than ~25 knots. Payne et al. (2007a,b) and French McCay et al. (2007) found that dye tracking subsurface transport indicated that dispersed oil and dissolved components would be rapidly mixed vertically into a 10-15 meter mixed layer, but would not mix deeper on the time scale (hours) where toxicity may exist in a water column after a spill. Thus, it was assumed that dispersed oil mixes to the bottom of a 10-m mixed layer, but no further subsequently.

Temperature

Temperature is another important variable as volatilization, uptake rate into biota, and toxicity are all greatly enhanced at higher temperature. All runs were simulated during spring season conditions but three temperatures were used to cover the range of temperatures found in US waters in the spring. The three temperatures modeled represented cool (0 – 10^{o}C), moderate (10 – 20^{o}C), and warm (20 – 30^{o}C) water conditions.

Other Environmental Factors

Other environmental factors have been shown to have much less affect on model results (French McCay et al., 2006). Currents without horizontal velocity gradients (shear) will transport the plume but not change the volume of water affected. Effects of small scale horizontal current shear were not modeled in this study; only locally-forced wind-driven currents (i.e., characterized by vertical shear in the wave-mixed layer) were included in the oil spill modeling performed. To the degree that a subsurface dispersed oil plume is sheared, water concentrations and toxic effects will be reduced. Thus, the results in this modeling study are conservatively high with respect to water column impacts. The salinity assumed is that typical of open ocean areas of the US: 32 psu (ppt).

The diffusion of subsurface oil and dissolved components is dependent on the horizontal and vertical dispersion coefficients, which determine the amount of mixing during simulated small-scale motions: those turbulent eddies and motions at spatial and temporal scales smaller than the grid-cell size and time step used in the hydrodynamic model produce the advective (current) field. Hydrodynamic model applications typically cover large spatial domains in order to correctly set the appropriate forcing functions. Thus, they typically have grid cells on the order of 1 km or more. In most oil spills, with the exception of those where natural dispersion is extremely high and involves a large release of oil such as the *North Cape* oil spill (French McCay, 2003), the dimensions of the subsurface plumes are smaller than 1 km and very patchy (McAuliffe, 1987; French McCay, 2004; NRC 2005). Even with added chemical dispersant, the plume dimensions would be expected to be smaller in scale than the scale captured by the advective field typically input to oil transport models (French McCay and Payne, 2001). The turbulent motion is parameterized in Lagrangian transport models by employing a first-order random walk technique (i.e., randomizing position each time step using horizontal and vertical dispersion coefficients to scale the magnitude of the movements). Thus, the predicted subsurface concentrations of oil droplets and dissolved hydrocarbons from any oil spill model are highly dependant on the assumed small-scale turbulence parameters input to the model.

Empirical measurements have been used to parameterize the small scale mixing processes in many applications (Okubo, 1967; Okubo and Ozmidov, 1970) and vertical diffusion rate in the wave-mixed layer has been related to wind speed (Thorpe, 1995). As reviewed Okubo (1967), Okubo and Ozmidov (1970), French McCay et al. (2007) and measured by Payne et al. (2007a,b) and French McCay et al. (2007), appropriate horizontal dispersion coefficients for near-surface plumes are on the order of 1-10 m^2/sec. We employ Thorpe's (1995) vertical diffusion rate in the wave-mixed layer and 1 m^2/sec in the mixing layer below the wave-mixed layer for all simulations, based on these and similar measurements, as a conservatively slow dispersion rate.

These assumptions are infrequently discussed or recognized as to their importance (see French McCay, 2003, where sensitivity analysis varying these assumptions was used to calibrate the SIMAP model). For this project a sensitivity analysis was performed to quantify the difference in impacts due to uncertainty in the horizontal dispersion coefficient. The sensitivity analysis was completed for one portion of the matrix: light oil spilled at moderate temperatures without chemical dispersion.

<u>Toxicity</u>

Mortality is a function of duration of exposure – the longer the duration of exposure, the lower the (lethal) effects concentration (see review in French McCay, 2002; also Unger et al., 2007). The LC50 is the lethal concentration to 50% of exposed organisms. The incipient LC50 ($LC50_\infty$) is the asymptotic LC50 reached after infinite exposure time (or long enough that that level is approached, Figure 3.1). Percent mortality is a log-normal function of concentration, with the LC50 the center of the distribution.

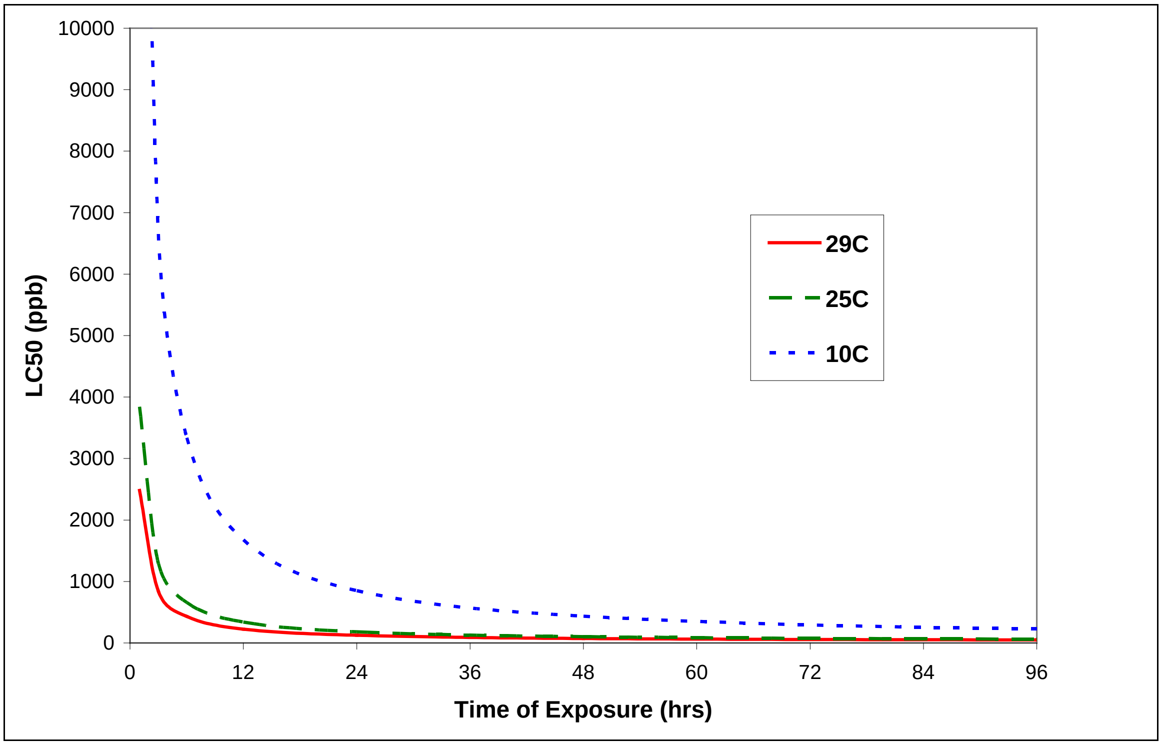

Figure 3.1. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.

The value of $LC50_{\infty}$ ranges from 5-400 µg/L for 95% of species exposed to dissolved PAH mixtures for over 96 hrs (French McCay, 2002; Figure 3.2). The $LC50_{\infty}$ for the average species is about 40-50 µg/L (ppb) of dissolved PAH (varying slightly among oils and fuels by percent composition of the PAH mixture). These LC50 values have been validated with oil bioassay data (French McCay, 2002), as well as in an application of SIMAP to the *North Cape* oil spill where field and model estimates of lobster impacts were within 10% of each other (French McCay, 2003). In the modeling matrix, three separate model runs were made assuming all species were characterized by each of three $LC50_{\infty}$ values: 5, 50 and 400 µg/L (ppb). For each run and $LC50_{\infty}$ assumption, fractional mortality rates of fish, invertebrates, and their eggs and larvae were computed in exposed water volumes as a function of temperature, concentration, and time of exposure. These fractional losses can then be multiplied by density of organisms in the volume to calculate an impact in numbers or biomass (kg), as was done for 6 representative biological data sets.

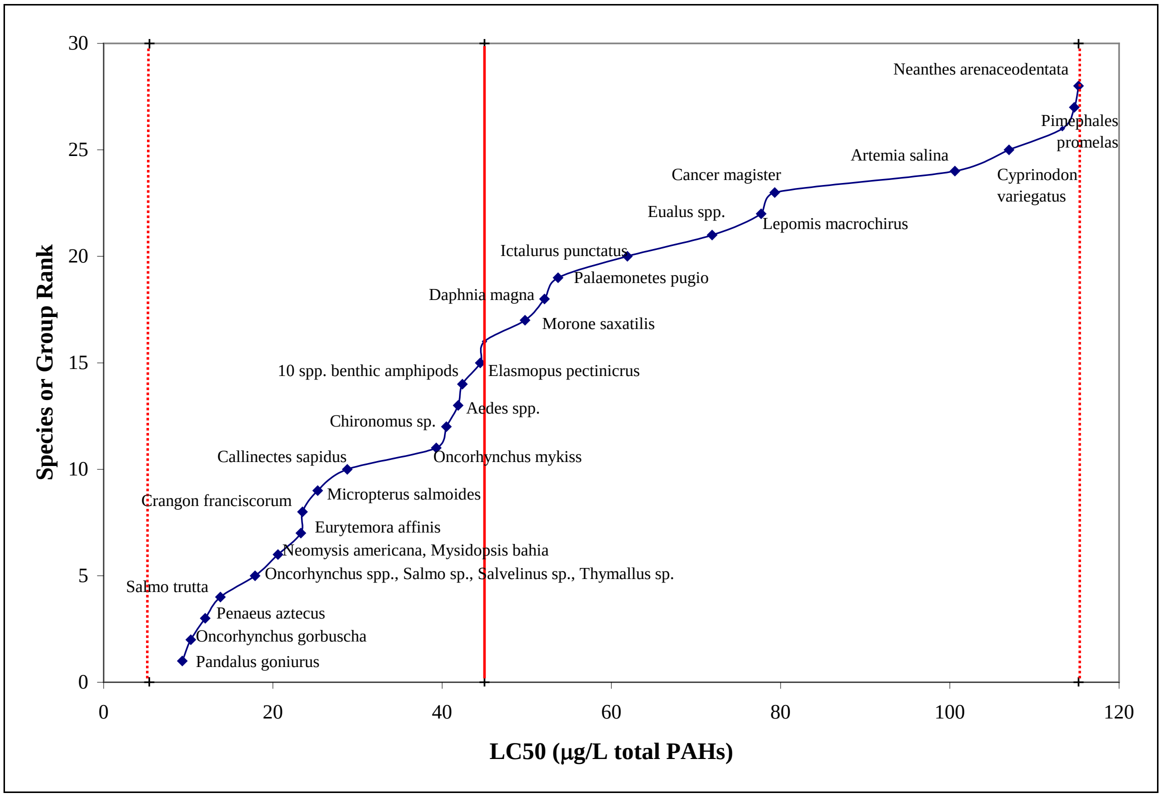

Figure 3.2. Variation in LC50 for dissolved PAH mixtures from fuel and crude oils, by species in rank order of sensitivity.

Densities of Biological Resources Potentially Exposed

Biological databases were chosen to represent open water areas around the U.S. Because of the volume of results, not all biological databases available could be analyzed. However, the biological impacts are proportional to the area or volume of impact. Therefore, if a spill occurs in an area where biological abundances are known (in number per unit area) the results can be multiplied by the area of impact generated by the model to calculate the specific injuries.

3.3 Analysis of Results

The key model results from these runs are the volume of water where acute toxic effects would occur (which would impact to subsurface organisms, particularly plankton) and the area of water surface oiled (which would impact wildlife, as well as socioeconomic uses). Potential water-column impacts, assuming each of the range of toxicity values characterizing 95% of species noted above, were summarized as equivalent water volumes of 100% loss. Percent mortalities for each water volume affected were summed (weighed by the volume) to estimate a total equivalent volume for 100% mortality. In this way, mortality may be estimated on a volume basis, rather than necessitating estimates of species densities to evaluate potential impacts. Similarly, areas of impact to wildlife of various percentage losses were summed to calculate equivalent areas of 100% impact for birds, marine mammals and sea turtle species and/or behavior groups. These oiled areas also indicate the potential area for socioeconomic impacts.

Model results from the matrix are summarized in both tabular and chart format so that users of the guide can look up the order of magnitude of likely impact and interpolate between results for intermediate conditions to those run in the matrix of scenarios. The total impact for a spill with a specific response, defined by volume spilled and percentage of that volume chemically dispersed, is the sum of impacts for the volume of oil not dispersed plus those for the volume of oil effectively dispersed. Regressions were developed to facilitate such interpolations for intermediate volumes of oil spilled and dispersed, which may employed in an Excel calculator provided to users of the guide so they can readily access results. Statistics and sensitivity analyses are provided to quantitatively describe the uncertainty of the results and model.

3.4 Preparation of Guidance

The OSIG is available in four forms:

1. This report, which describes the technical approach, assumptions and results of the modeling and guidance development;
2. Tables of results and regression statistics, as text and excel files (organized in a folder structure described below);
3. A field guide in PDF format; and
4. A calculator as a spreadsheet application that will facilitate interpolations.

3.4.1 OSIG Field Guide

The field guide is a hard copy of the summarized results that can be taken into the field by first responders and used during decision-making. The field guide consists of both a summary of the project and results and charts that show the tradeoffs. The 24 charts that depict the impacts for surface oiling and water column toxicity for average species (LC50 = 50 ppb) for spills of 100,000 and 50,000 gal for each oil are organized by wind speed and water temperature. Each chart shows impacts of dispersing oil after 12 or 24 hours of weathering on the surface. Appendix A contains the content of the OSIG Field Guide.

3.4.2 OSIG Excel Calculator

In situations where a computer is available during the decision-making process, a Microsoft Excel-based calculator will facilitate interpolations. The user will select the environmental conditions (wind, weather, temperature, and turbulence conditions), the oil type, oil weathering state (i.e., hours of weathering before dispersant is applied), and biological region. The user will then enter the total spill volume and the amount of oil assumed dispersed for a specific response scenario. The amount of oil dispersed can be estimated as the product of the dispersant volume applied, a treatment ratio (e.g., 20 parts oil per part dispersant), and an assumed efficiency of that treatment (typically 1-50%, and 80% under ideal conditions; USCG, 1999).

To estimate total area swept by oil, the calculator will sum the area swept by oil for (1) the volume of oil not dispersed over the entire course of the spill plus (2) the volume of oil effectively dispersed before the time it is treated. To estimate equivalent water volume of 100% loss of biota for the entire spill volume, the calculator will sum the equivalent volume of 100% loss for (1) the volume of oil not chemically dispersed (i.e., contamination from natural entrainment) plus (2) the volume of oil effectively dispersed. The results will consist of estimates of surface area swept and water volume impacted for the oil volume and dispersant response scenario being evaluated. Selection options are based on the conditions used in the model matrix and whereas input parameters interpolate in-between cases to derive results. The calculator was designed to present two cases side-by-side. This presentation allows for the user to examine the tradeoffs of all variables. Additionally, this allows the user to gauge the amount of uncertainty associated with each of the input parameters.

3.5 Review Webinar

Dr. French-McCay presented the results of the study and the guidance tools to a panel of reviewers and potential users of the guidance via a several-hour conference call/Web Ex meeting on 27 August 2009. A recording of the meeting can be found online (https://asascience.webex.com/asascience/ldr.php?AT=pb&SP=MC&rID=12903427&rKey=3a2f43e43a7036be). The review panel included a Gulf coast responder, from a community where dispersant use is looked upon favorably, as well as other responders and scientific support personnel who provide guidance and technical advice to response organizations: Troy Baker (NOAA OR&R), Nancy Kinner (NOAA/UNH Coastal Response Research Center and UNH), Amy Merten (NOAA/UNH Coastal Response Research Center and NOAA OR&R), Charlie Henry (NOAA OR&R), Chris Barker (NOAA OR&R), Jordan Stout (NOAA OR&R), Kurt Hansen (US Coast Guard Research and Development Center), Bruce Hollebone (Environment Canada), and Daniel Hahn (NOAA OR&R). Additional representative members of the spill response community were invited to attend the conference call/Web Ex meeting to hear the presentation of the Oil Spill Impact Guide and to participate in a discussion of the results of the study.

4.0 Results

The matrix of model runs was designed to cover the variables that are most likely to generate variability in the results; which are wind speed, weathering time, and volume of spill. Wind, while not sensitive to direction because the modeled spill is in open water with no shoreline, influences the results via its speed. Higher wind speeds create more natural entrainment and thus dispersion of floating oil. However high entrainment does not always mean a significant reduction in surface area oiled; spillets can resurface behind the main slick as the wind pushes it beyond where the oil was originally entrained and the oil is swept over a greater surface area of the water. The weathering of oil on the water surface allows for the toxic components to evaporate off without causing impacts in the water column. Therefore, the longer oil sits on the surface the less toxic it will be to planktonic organisms when it is eventually dispersed into the water column. Wind speed and temperature also play a role in the evaporation of toxic components. Finally, the volume of the spill, and the volume that is dispersed, greatly affects the impact. The undispersed volume is what accounts for wildlife impact while the dispersed volume is what accounts for water column injuries. Because all of these variables can be manipulated at once, the uncertainties in the model results due to these variables are best investigated by comparing two scenarios side-by-side using the calculator; varying one factor at a time will elucidate the variation that each factor can have on total impact.

4.1 Overview of Findings Based on Model Results

Impacts are estimated by species or species group for wildlife, fish and invertebrates by multiplying areas or volumes at various percentage losses by the density of animals per unit area or volume. However, equivalent areas or volumes of 100% loss (the weighted sum of lesser percentage losses) may be compared to estimate relative impacts to wildlife versus fish and invertebrates for spill response purposes, as well as in ecological risk assessments. Model results for South Louisiana crude, a light oil, are summarized here in a series of charts showing the magnitudes of impacts and trends with volume and other variables. Complete results for the other oil and environmental variables can be found in the digital appendices which are outlined in section 4.2.

Since densities of all biota are highly variable in time and space, some end-users of model results may wish to use more specific biological data. In this case, the result by area/volume can be used in conjunction with other biological data sets to estimate number/biomass losses. Results presented here include both area/volume and number/biomass killed for representative biological data sets.

4.1.1 Wildlife Impacts

4.1.1.1 Light Oil at Light Winds

In light winds, modeled at 5 knots but applicable for 0-12 knots (above 12 knots breaking waves increase the rate of natural dispersion), the area where wildlife (birds, marine mammals, sea turtles) would be oiled with a lethal dose if present is a function of oil volume spilled (Figure 4.1) and volume not dispersed (Figure 4.2).

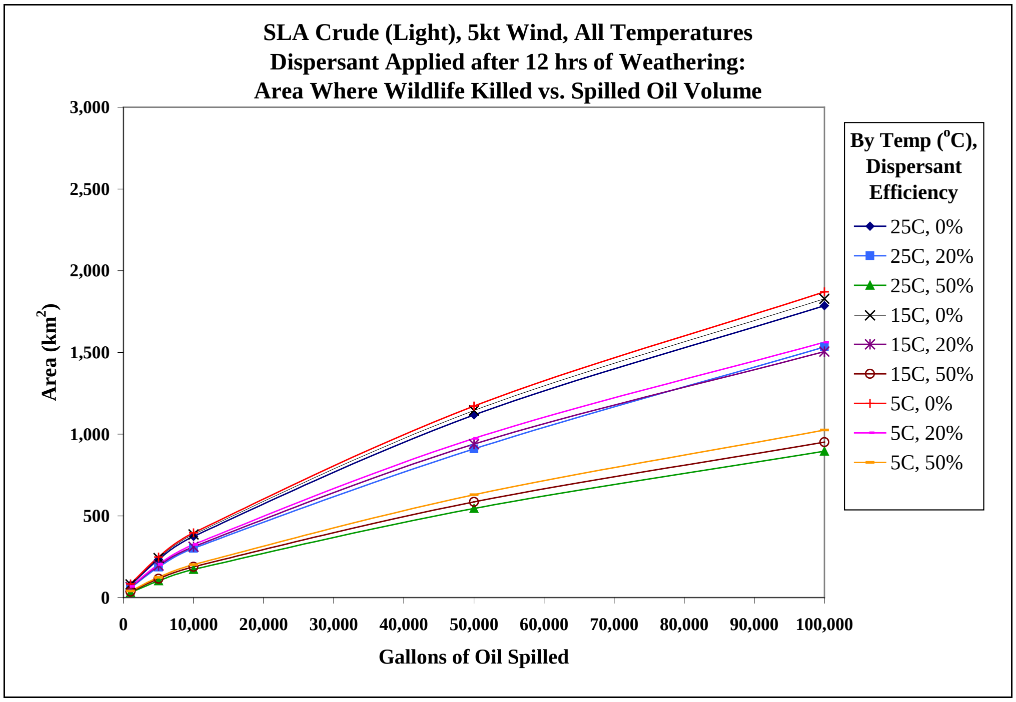

Figure 4.1. Area impacted versus volume spilled for South Louisiana crude under 5 kt winds. The swept area of impact is that where a lethal dose would affect wildlife, if present.

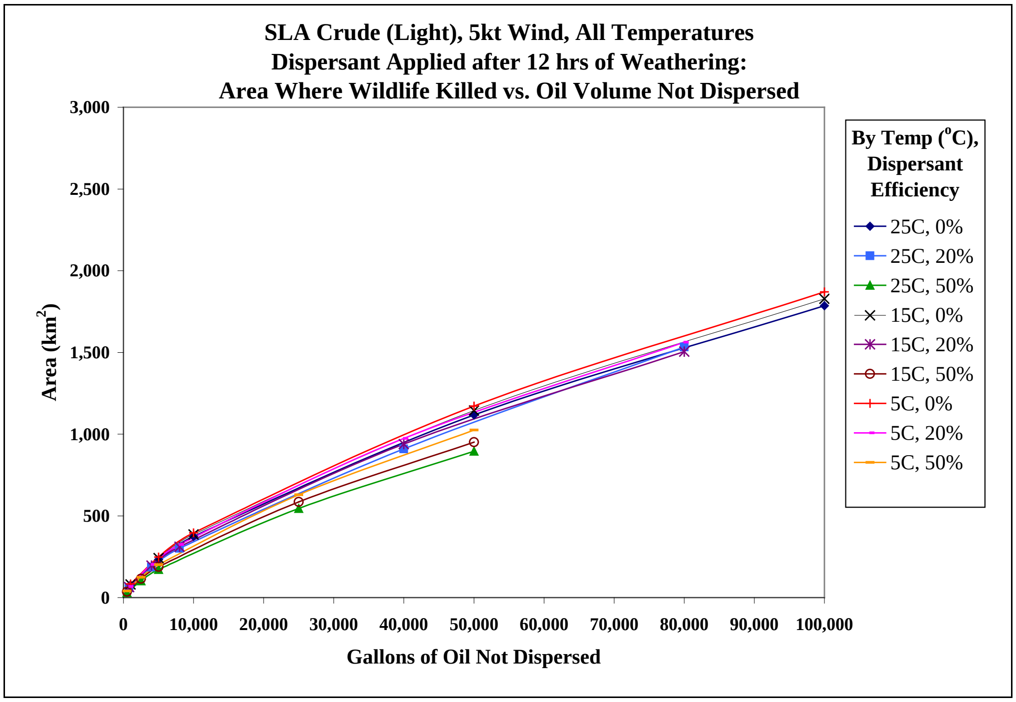

Figure 4.2. Area impacted versus volume of oil not dispersed, for South Louisiana crude under 5 kt winds. The swept area of impact is that where a lethal dose would affect wildlife, if present.

From Figure 4.1, it is apparent that the wildlife impact increases with volume of oil, but that the rate of change of impact lessens with increasing oil volume. The effect of temperature is small at this wind speed, primarily by affecting the loss rate via evaporation such that area swept is slightly less at higher temperature. The curves in Figure 4.1 fall out by percent efficiency of the dispersant application (which affects the volume of oil on the water surface). However, if the results are plotted against volume of oil that is not effectively chemically dispersed, all the data overlay each other such that a single curve would describe the trend, regardless of temperature and efficiency of the dispersant application (Figure 4.2). A power curve fits the data well, as shown in Figure 4.3.

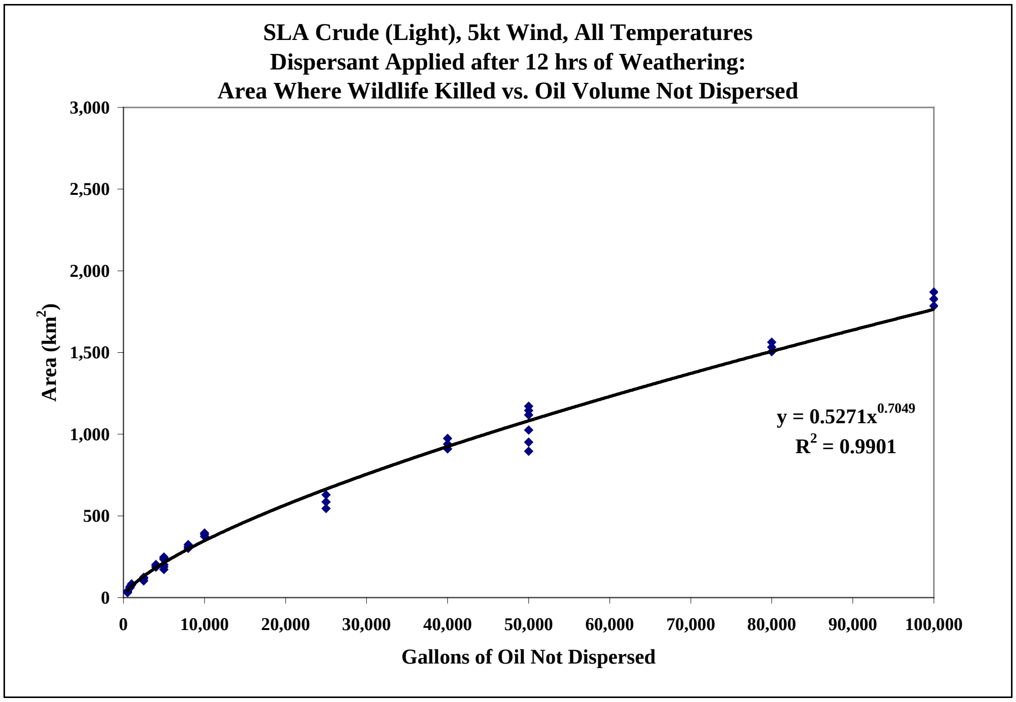

Figure 4.3. Power curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude under 5 kt winds. Data includes results for the various temperatures and percentages of oil dispersed.

The difference between oils is small, with the heavier oil (ANS Crude) having a larger area of impact at larger spill volumes than lighter oil (SLA Crude) (Figure 4.4). This is because of the higher percentage of the oil evaporated over time for the lighter crude, which contains a larger percentage of volatiles.

Under light wind conditions, the difference in impact, *for the same amount of oil not dispersed and remaining on the water surface*, is very small when comparing the effect of weathering time before dispersant is applied. Figure 4.5 shows a slightly higher area of impact for oil weathered only 12 hours as compared to 24 hours, reflecting the degree to which a portion of the floating oil has evaporated. For *the same volume of oil* remaining after dispersant is applied, but with a longer weathering time prior to that point, slightly more of the oil is lost to the atmosphere, leading to a smaller swept area. In other words, if the oil is left to weather until 24 hours after the spill before the dispersant application, the impact to wildlife is slightly lower because the oil remaining after dispersal of a certain percentage has slightly less volume due to the higher loss to evaporation.

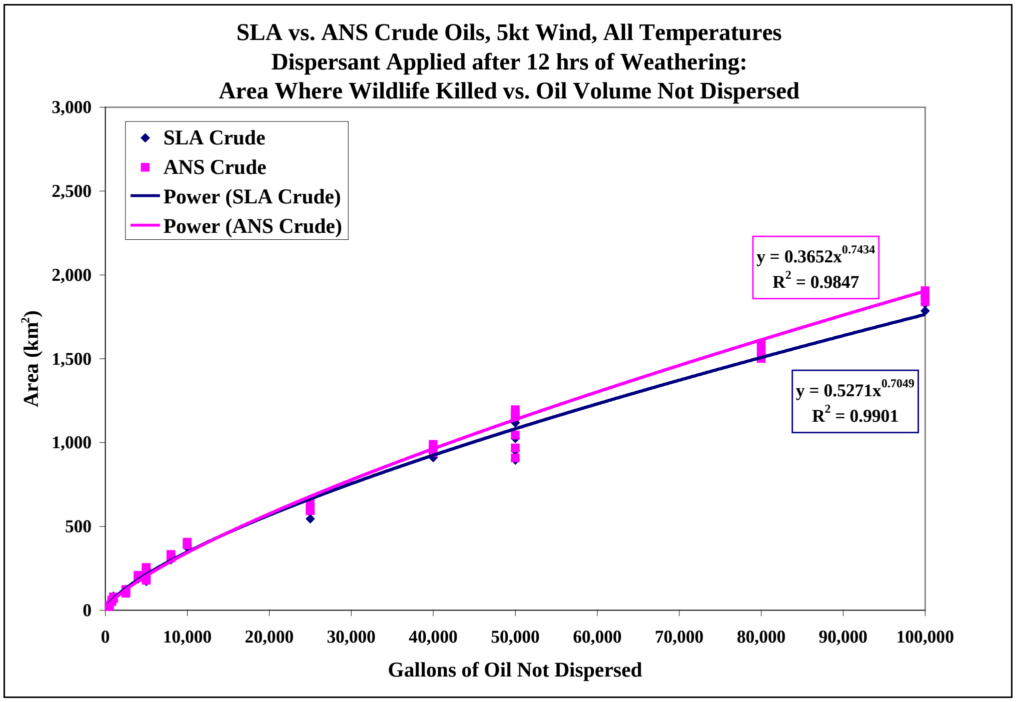

Figure 4.4. Power curve fit to area impacted versus volume of oil not dispersed, for South Louisiana and Alaska North Slope crude oils under 5 kt winds. Data includes results for the various temperatures and percentages of oil dispersed.

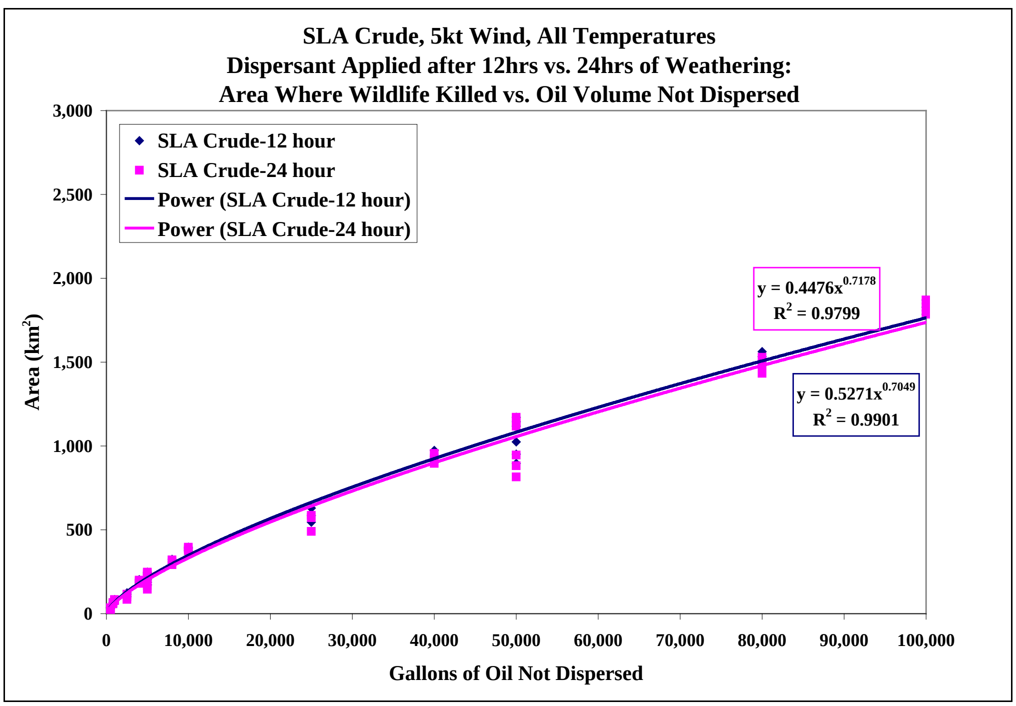

Figure 4.5. Power curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude dispersed at 12 or 24 hours after the spill, under 5 kt winds. Data includes results for the various temperatures and percentages of oil dispersed.

The direct impact to wildlife is calculated as the area swept with enough oil to impart a lethal dose, multiplied by animal density (# km^{-2}) and by the probability of being present (considering habitat, time of day, and percentage of the time spent at the water surface). Figure 4.6 shows the number of birds oiled if the spill occurred in an area with similar avian abundances to the Atlantic Coast. This is a similar function as area impacted because the results are proportional; Figure 4.7 shows the power curve regression.

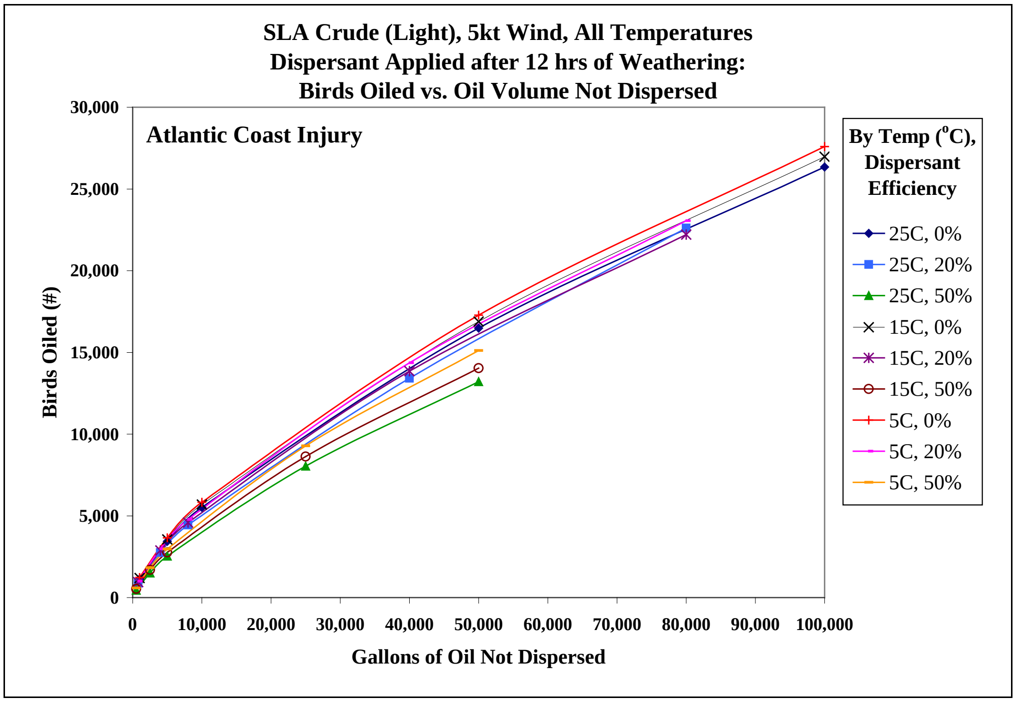

Figure 4.6. Number of birds oiled versus volume of oil not dispersed, for South Louisiana crude under 5 kt winds. The number of birds oiled is representative of an avian community along the Atlantic Coast.

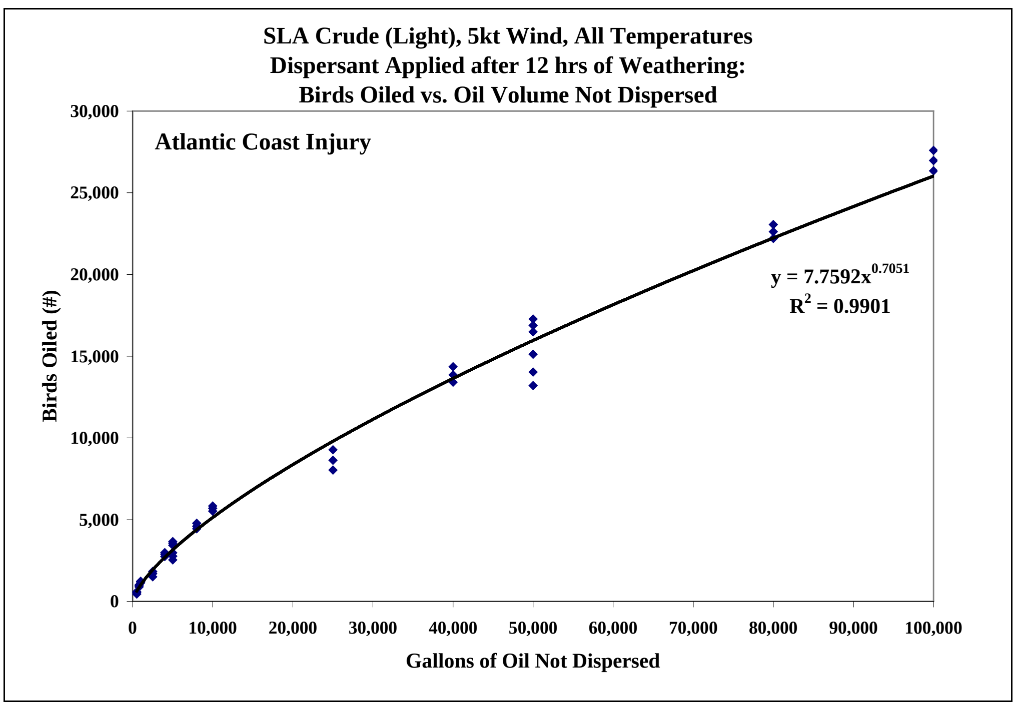

Figure 4.7. Power curve for number of birds oiled versus volume of oil not dispersed, for South Louisiana crude under 5 kt winds. The number of birds oiled is representative of an avian community along the Atlantic Coast.

4.1.1.2 Light Oil at High Winds

In high winds, modeled at 15 knots but applicable for 12 to ~25 knots, the area where wildlife (birds, marine mammals, sea turtles) would be oiled with a lethal dose if present is a function of oil volume spilled (Figure 4.8) and volume not dispersed (Figure 4.9). These results are not applicable for wind speeds above ~25 knots.

From Figure 4.8, the trend still holds that the wildlife impact increases with volume of oil, but that the rate of change of does not lessen with increasing oil volume as it did under the light wind conditions (Figure 4.1). By comparing Figures 4.8 & 4.9 to 4.1 & 4.2 it becomes apparent that the results are much more variable at the higher wind speed. At higher wind speeds, the effect of temperature and wind speed on evaporation rate are more apparent. The largest area of impact occurs at the coolest temperatures whereas the lowest impact occurs at high temperatures, regardless of amount spilled, because of higher evaporation rates at higher temperature, an effect that increases with wind speed (Figure 4.9). A single power curve fits this data less well, shown in Figure 4.10.

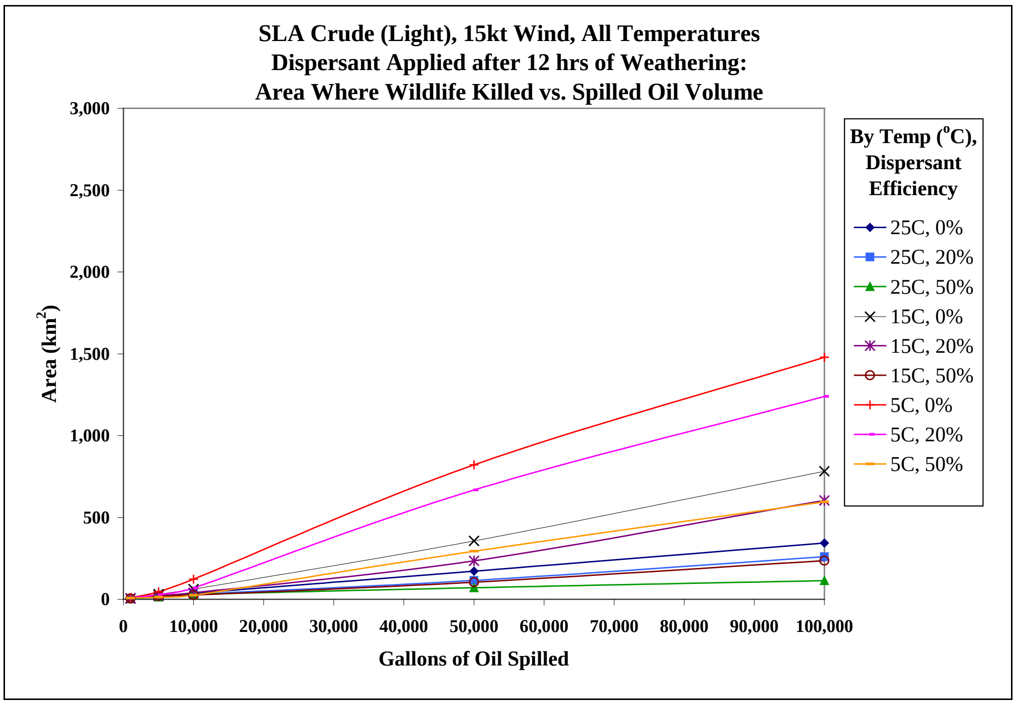

Figure 4.8. Area impacted versus volume spilled for South Louisiana crude under 15 kt winds. The swept area of impact is that where a lethal dose would affect wildlife, if present.

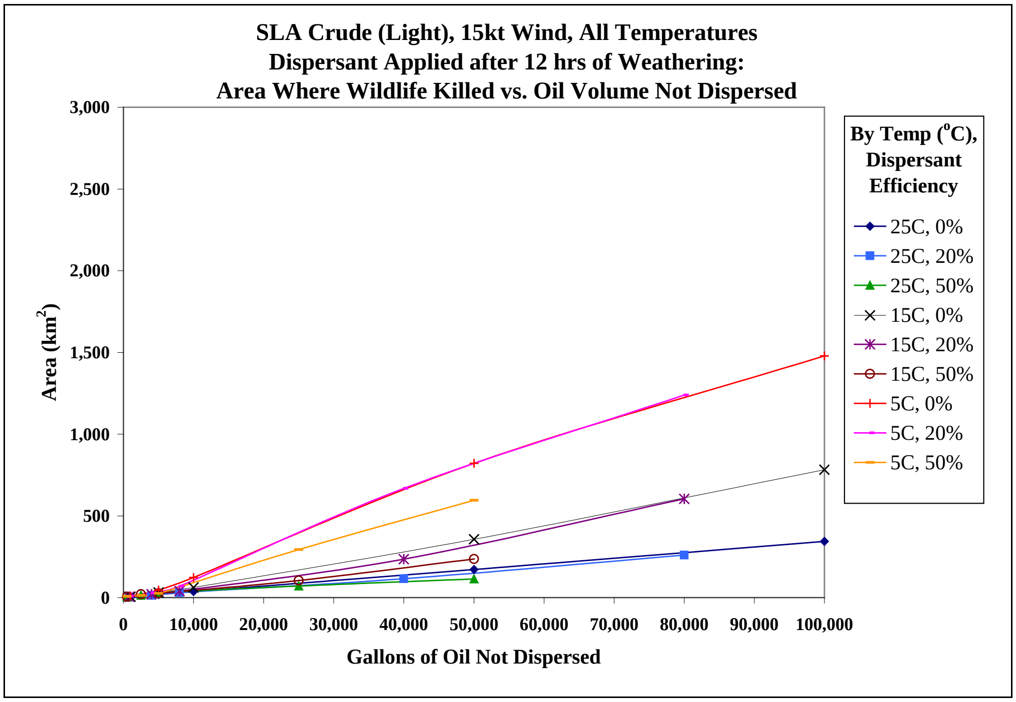

Figure 4.9. Area impacted versus volume of oil not dispersed, for South Louisiana crude under 15 kt winds. The swept area of impact is that where a lethal dose would affect wildlife, if present.

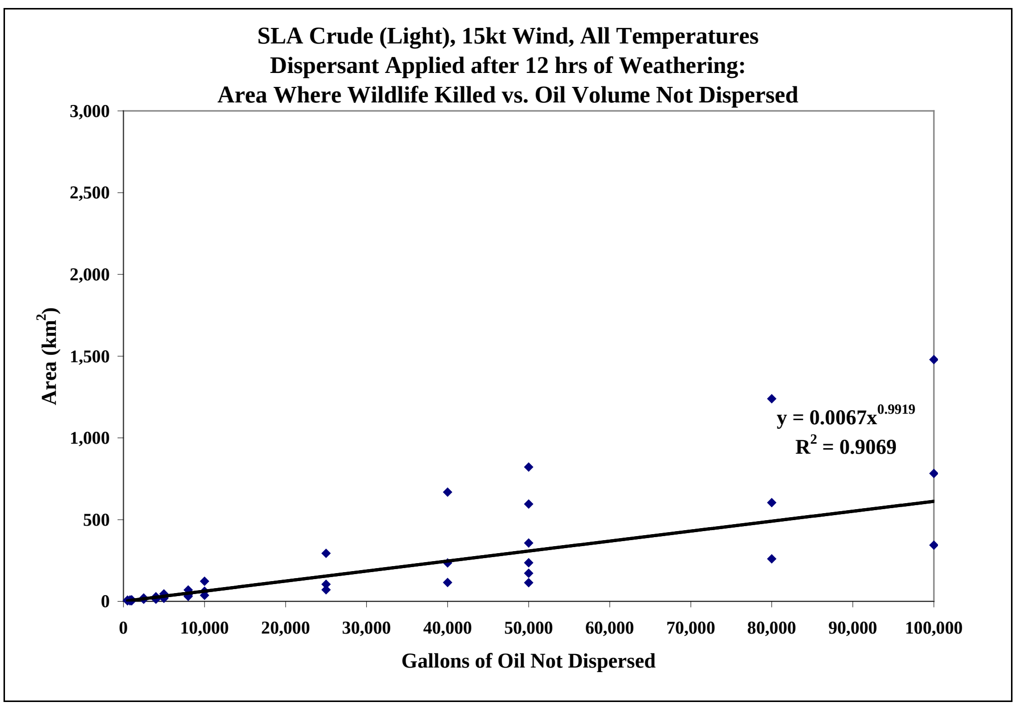

Figure 4.10. Power curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude under 15 kt winds. Data includes results for the various temperatures and percentages of oil dispersed.

Because the effect of evaporation is considerable at this higher wind speed, comparisons between oils and weathering times were investigated only at 25ºC. The difference between oils at larger spill volumes shows that the heavier oil (ANS Crude) has a larger area of impact than lighter oil (SLA Crude) which evaporates more easily and therefore has a smaller area of impact (Figure

4.11). The difference between the effects of weathering time before dispersant is applied is very small, with a longer weathering period resulting in only a slightly higher area of impact (Figure 4.12), again for a given amount of oil remaining floating after dispersant application.

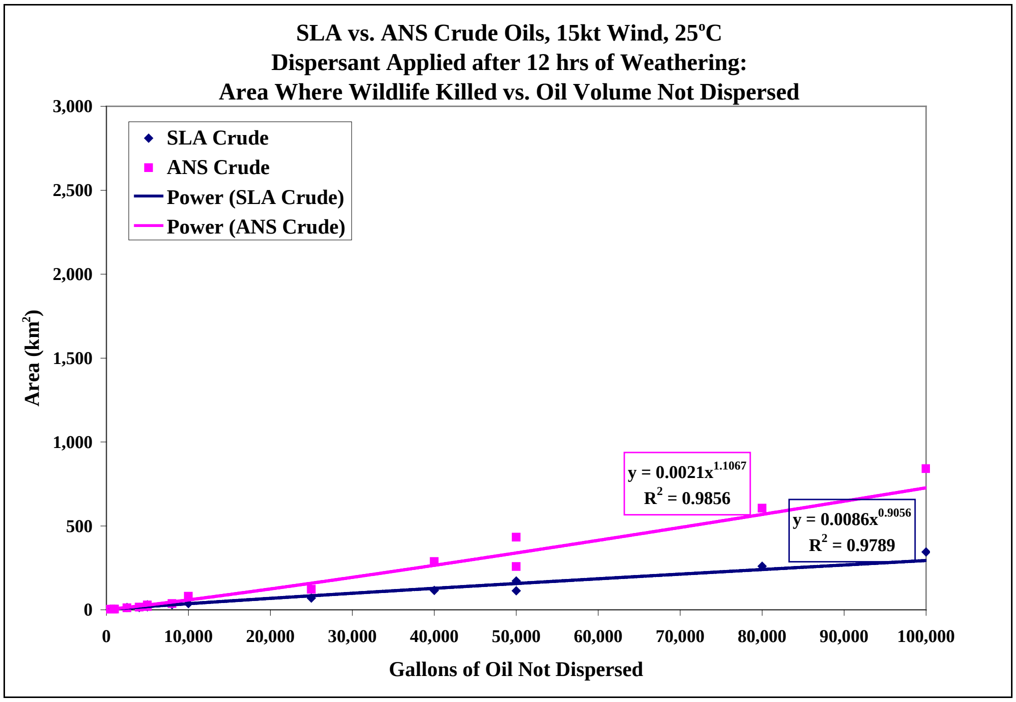

Figure 4.11. Power curve fit to area impacted versus volume of oil not dispersed, for South Louisiana and Alaska North Slope crude oils under 15 kt winds. Data includes results for all percentages of oil dispersed after 12 hours of weathering at 25°C.

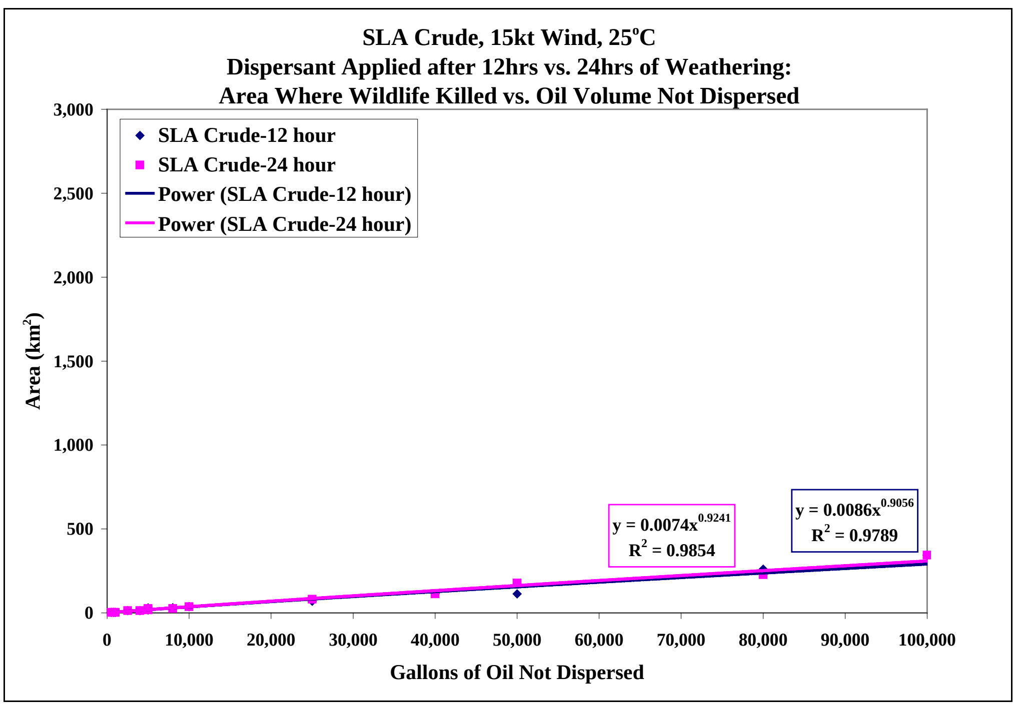

Figure 4.12. Power curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude dispersed at 12 or 24 hours after the spill, under 15 kt winds. Data includes results for all percentages of oil dispersed at 25°C.

Again, the direct impact to wildlife is a similar function as area impacted because the results are proportional (Figure 4.13); Figure 4.14 shows the power curve regression. Comparing Figures 4.13 & 4.14 to 4.6 & 4.7 shows there are larger direct impacts to birds at higher wind speeds and cooler temperatures. However, when averaged over all temperatures, impacts are less at higher wind speeds. This is due to the natural entrainment of surface oil into the water column.

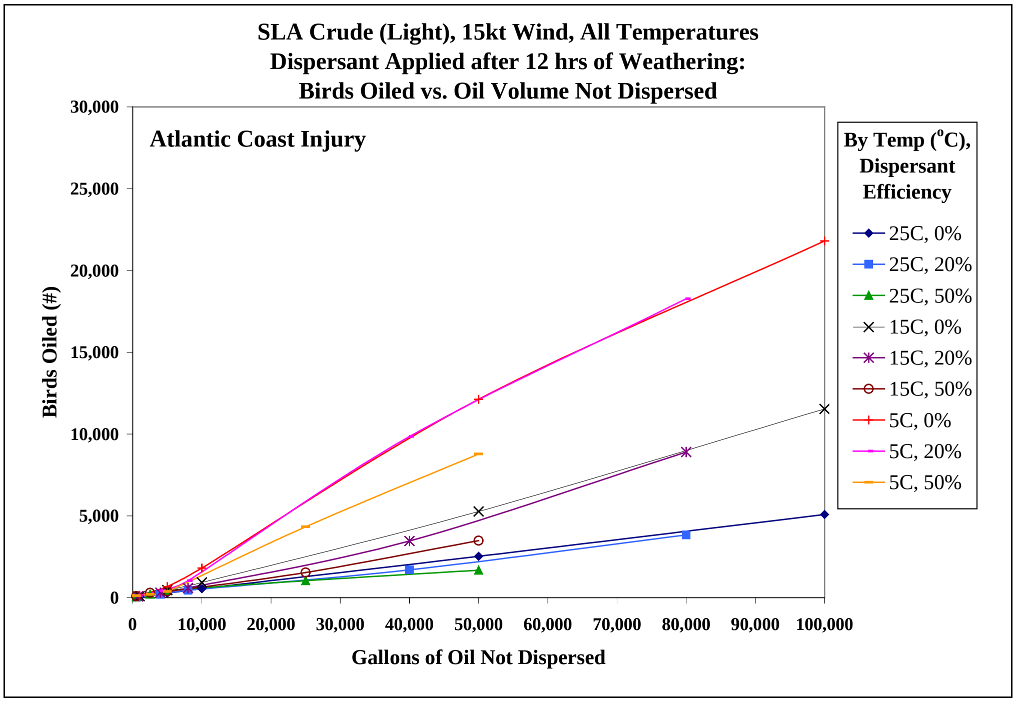

Figure 4.13. Number of birds oiled versus volume of oil not dispersed, for South Louisiana crude under 15 kt winds. The number of birds oiled is representative of an avian community along the Atlantic Coast.

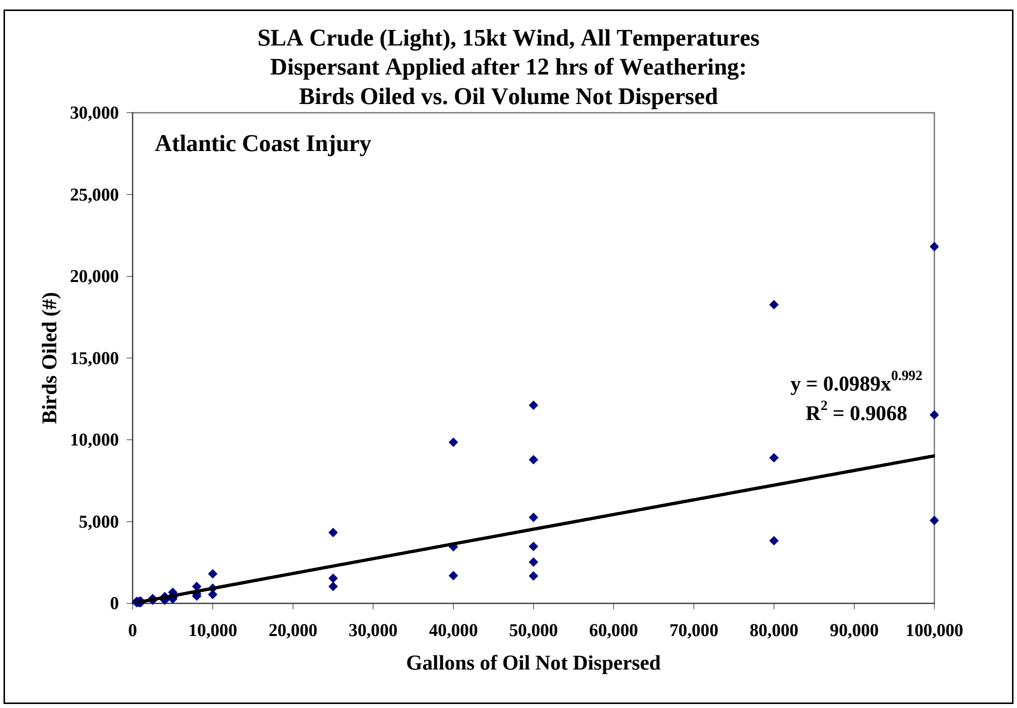

Figure 4.14. Power curve for number of birds oiled versus volume of oil not dispersed, for South Louisiana crude under 15 kt winds. The number of birds oiled is representative of an avian community along the Atlantic Coast.

4.1.2 Water Column Impacts

For fish and invertebrate impacts, the amount of oil dispersed into the water column is the major factor contributing to toxicity in the water column. The direct impact to aquatic biota may be calculated as the area (volume of the mixed layer divided by mixed layer depth) affected by a lethal dose, multiplied by animal density averaged over the mixed layer (# km^{-2}) and by probability of being present (considering habitat, time of day, and percentage of the time spent in the mixed layer).

4.1.2.1 Light Oil at Light Winds

Figures 4.15-4.17 show the area (of a 10-m deep mixed layer) where water column biota (e.g., plankton), if present, would be exposed to a lethal dose of dissolved aromatic hydrocarbons as a function of oil volume chemically dispersed into the water at warm, moderate, and cool water temperatures.

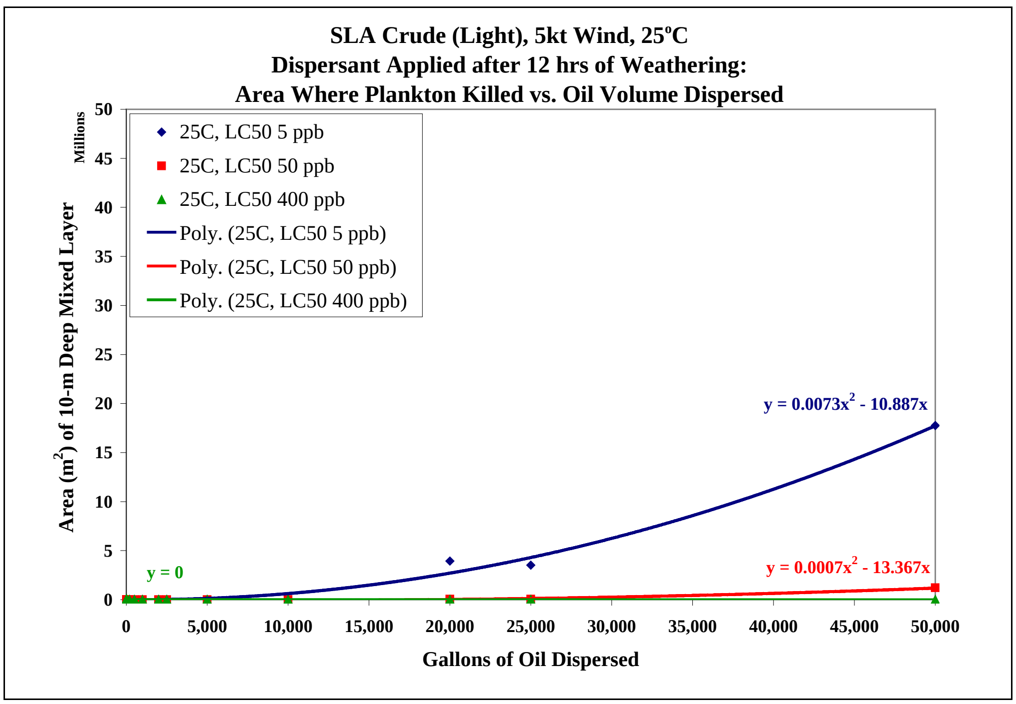

Figure 4.15. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed, for South Louisiana crude under 5 kt winds and 25ºC. The area of impact is that where a lethal dose would affect plankton for each LC50.

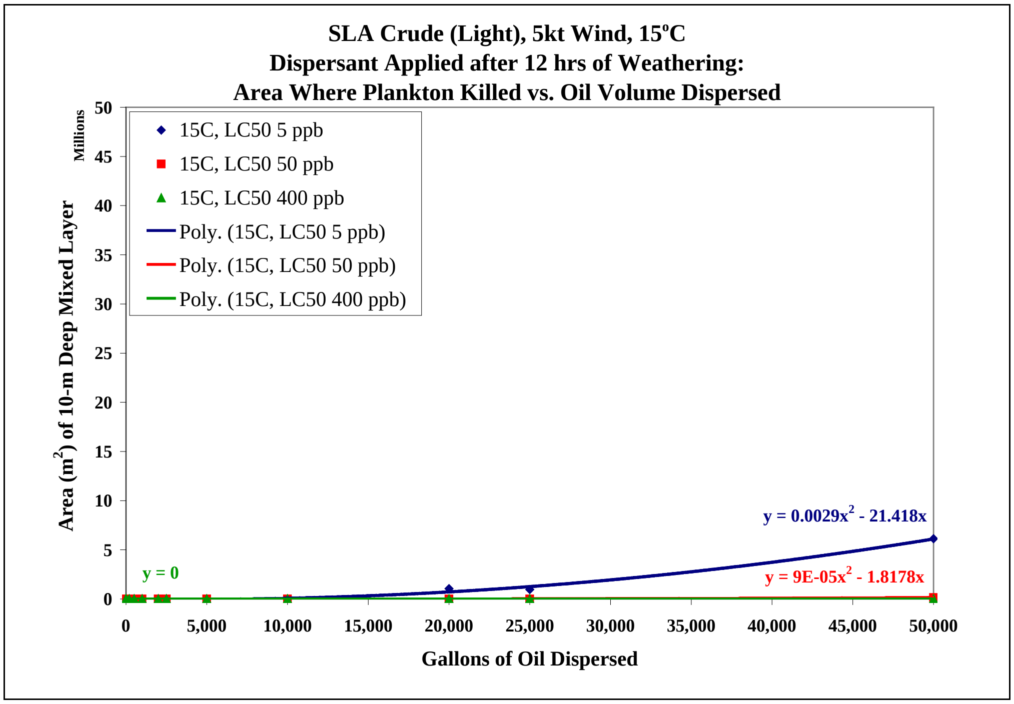

Figure 4.16. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed, for South Louisiana crude under 5 kt winds and 15°C. The area of impact is that where a lethal dose would affect plankton for each LC50.

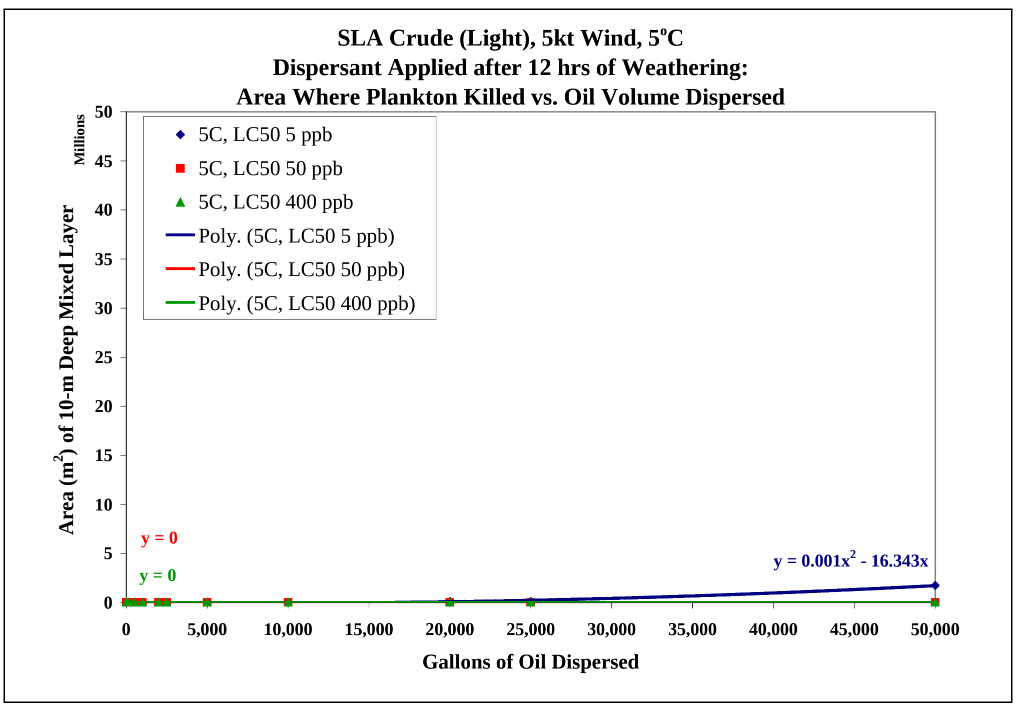

Figure 4.17. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed, for South Louisiana crude under 5 kt winds and 5°C. The area of impact is that where a lethal dose would affect plankton for each LC50.

Across all temperatures, the impact to aquatic biota increases with volume of oil dispersed, and that the rate of change of impact increases with increasing oil volume. The effect of temperature is strong because both uptake by biota and toxicity are functions of temperature. There is also a large variation in response with sensitivity to oil hydrocarbons, i.e., within the range of LC50s describing 95% of species tested (French McCay, 2002). Note that for the same concentrations (subsurface plume dynamics) the impact to aquatic biota can be negligible for insensitive species (LC50 400 ppb) and relatively large for sensitive species (LC50 5 ppb), particularly at higher temperatures (Figure 4.15).

The difference in toxicity to the most sensitive species at the highest temperatures between oil types is small (Figure 4.18). The lighter oil (SLA) creates a slightly larger impact area at higher volumes of dispersed product because of its lower viscosity which results in smaller entrained droplets and therefore higher dissolution rates. The time before chemical dispersant is applied has a noticeable affect on the area of impact (Figure 4.19). If chemical dispersant is applied 24 hours after the spill there is a much smaller area of impact; this is due to the loss of toxic components during evaporation at the surface before the product becomes entrained in the water column.

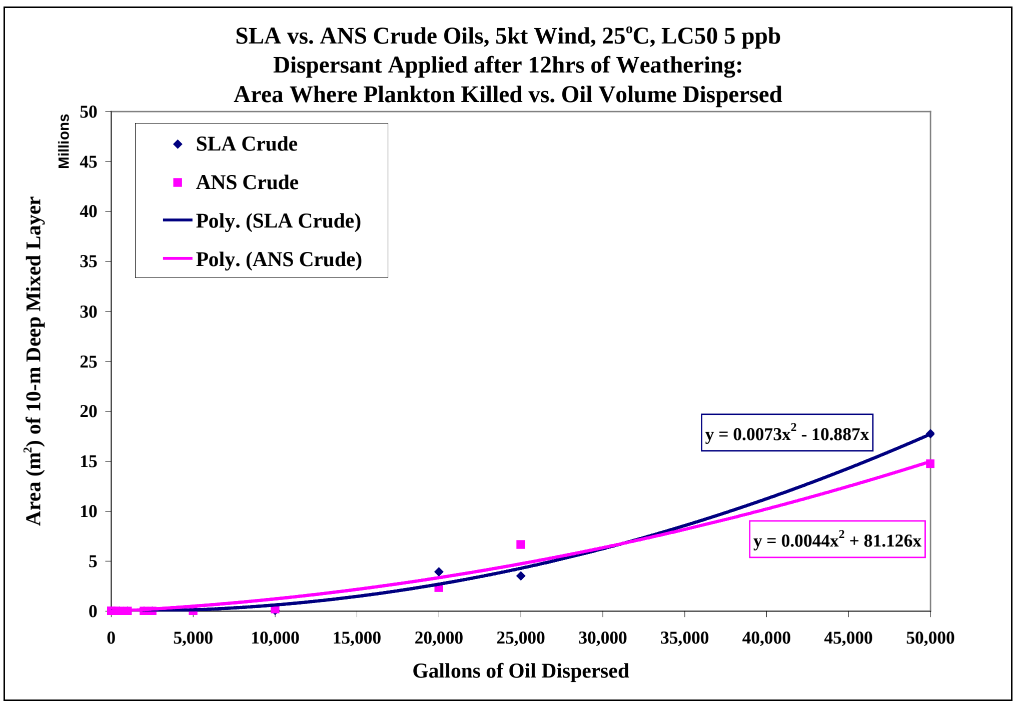

Figure 4.18. Polynomial curve fit to area impacted versus volume of oil not dispersed, for South Louisiana and Alaska North Slope crude oils under 5 kt winds. The area of impact is that where a lethal dose would affect sensitive species (LC50 5ppb) at 25ºC.

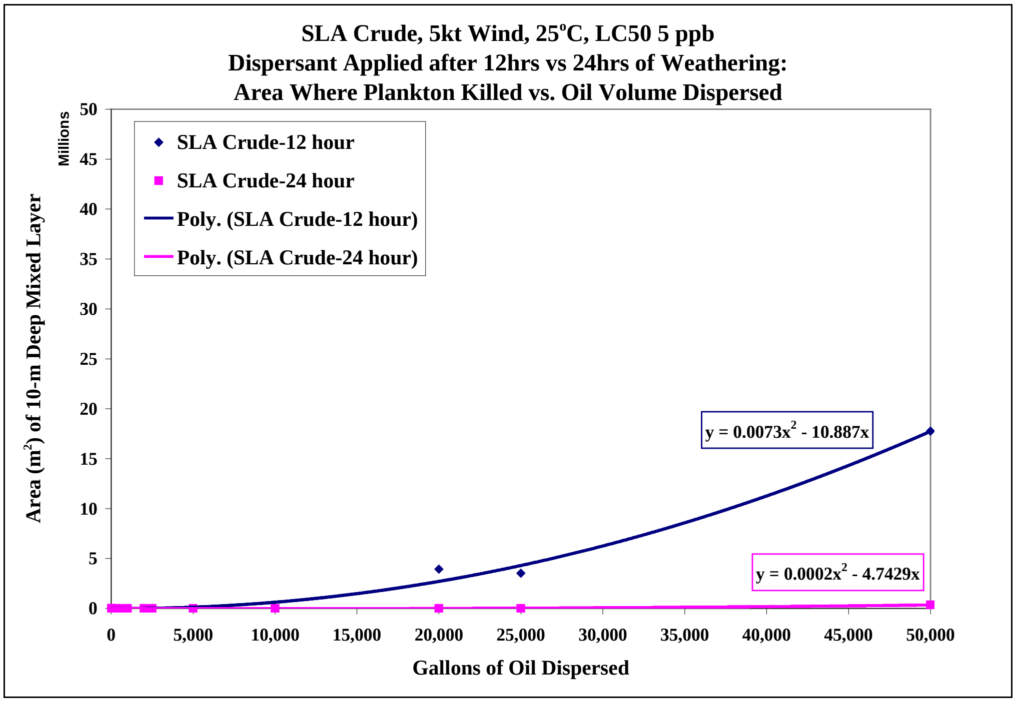

Figure 4.19. Polynomial curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude under 5 kt winds after 12 and 24 hours of weathering. The area of impact is that where a lethal dose would affect sensitive species (LC50 5ppb) at 25°C.

Injuries to fish and invertebrates are proportional to the area (or volume) of impact. An example of impact using Atlantic Coast fish and invertebrate density data shows that at 25ºC there is a large effect of species sensitivity (Figure 4.20). The most sensitive species show a steadily increasing impact as volume of oil dispersed increases, whereas average species have an overall much lower impact and rate of increase that is also much smaller.

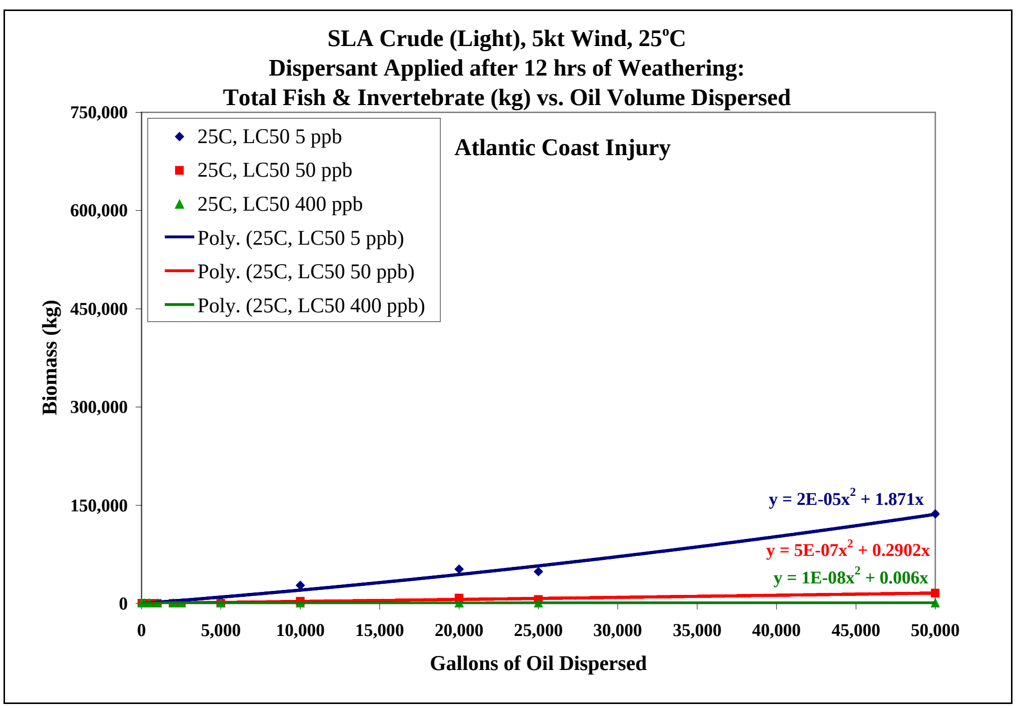

Figure 4.20. Polynomial curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude under 5 kt winds and 25ºC. The area of impact is that where a lethal dose would affect plankton for each LC50.

4.1.2.2 Light Oil at High Winds

Figures 4.21-4.23 show the area (of a 10-m deep mixed layer) where water column biota (e.g., plankton), if present, would be exposed to a lethal dose of dissolved aromatic hydrocarbons as a function of oil volume chemically dispersed into the water at warm, moderate, and cool water temperatures under 15 knots of wind. Across all temperatures, the impact to aquatic biota increases with volume of oil dispersed, and that the rate of change of impact increases with increasing oil volume. Insensitive species are still not likely to be impacted at moderate and cool temperatures; however average and sensitive species have the potential to be considerably impacted at these temperatures as the high wind speed entrains the oil before evaporation has reduced the toxicity.

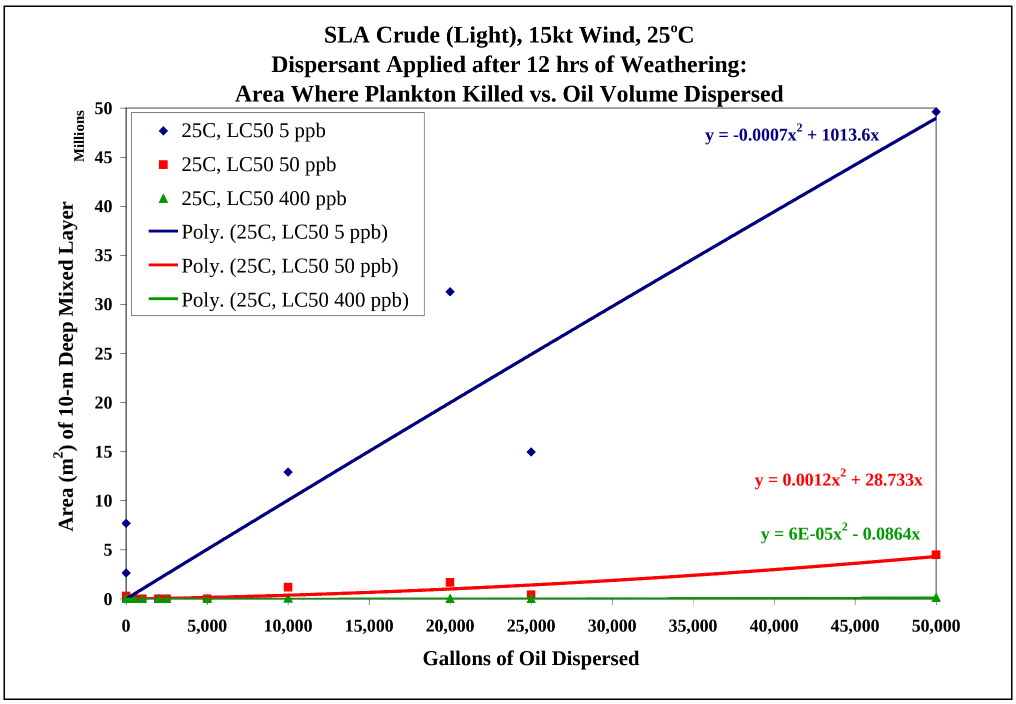

Figure 4.21. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed, for South Louisiana crude under 15 kt winds and 25ºC. The area of impact is that where a lethal dose would affect plankton for each LC50.

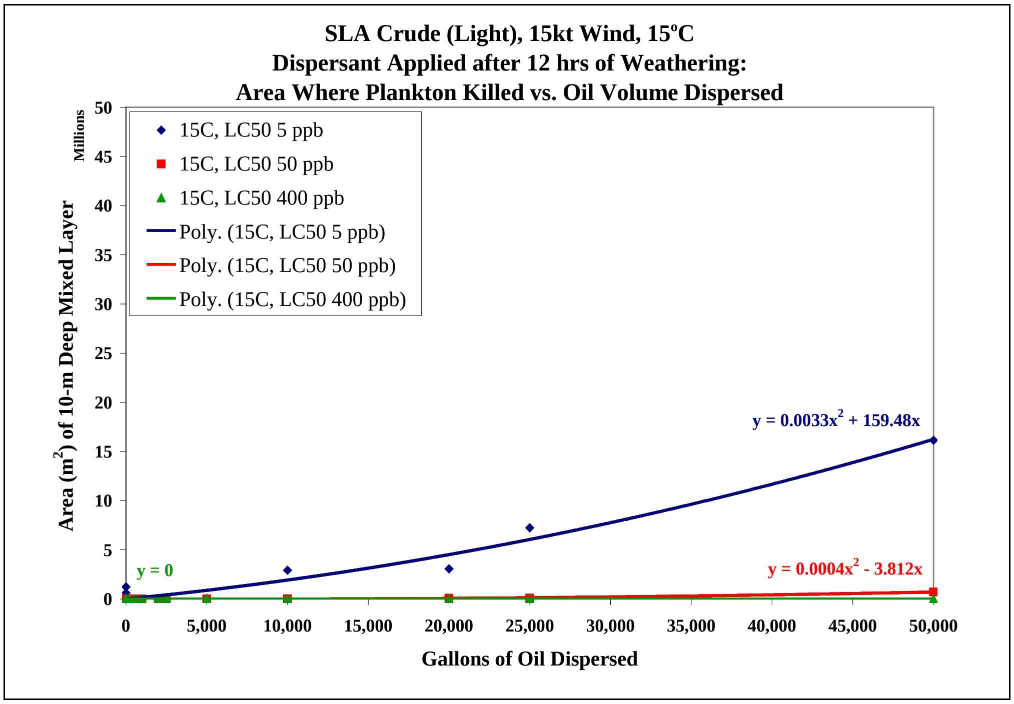

Figure 4.22. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed, for South Louisiana crude under 15 kt winds and 15°C. The area of impact is that where a lethal dose would affect plankton for each LC50.

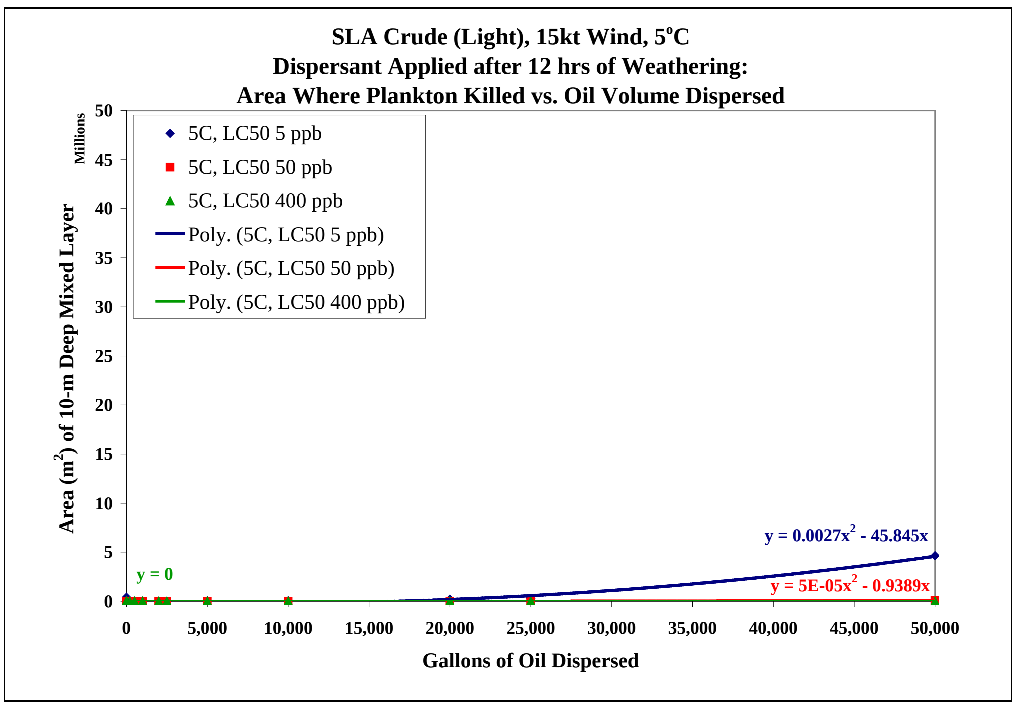

Figure 4.23. Polynomial curve fit to area of a 10-m deep mixed layer impacted versus volume of oil dispersed, for South Louisiana crude under 15 kt winds and 5°C. The area of impact is that where a lethal dose would affect plankton for each LC50.

The difference in toxicity to the most sensitive species at the highest temperatures between oil types is noticeable (Figure 4.24). This is because the lighter, less viscous oil (SLA) is more easily entrained in the water, resulting in a larger volume and area of toxicity. The apparent decrease in area of impact for the heavier oil (ANS) is a function of the viscosity of the oil; there is only a finite amount of oil that can be entrained when emulsification and the viscosity increase of the oil are considered (as it is in the model). Even though natural dispersion and entrainment increase the area of impact as compared to impacts at light wind speeds, there is a noticeable reduction in impact if the oil is dispersed after 24 instead of 12 hours (Figures 4.19 & 4.25).

An example of impact using Atlantic Coast density data shows that at 25ºC there is a large effect of species sensitivity (Figure 4.26). By comparison with the impact at 5 knot winds (Figure 4.20), higher wind speed increases the impact to sensitive species more than less sensitive species.

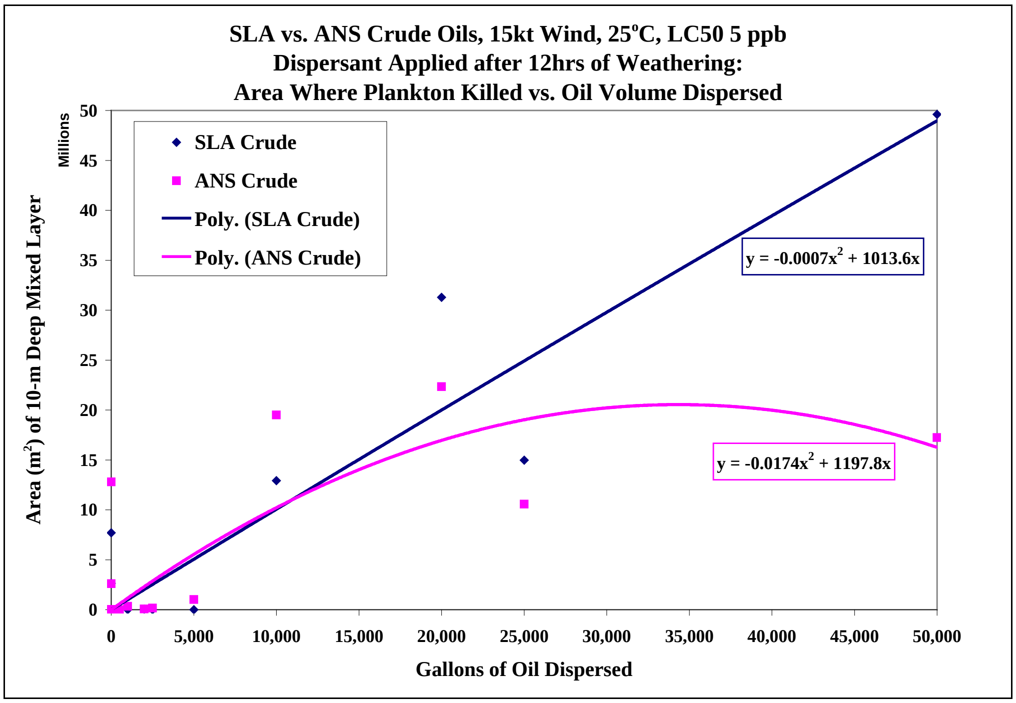

Figure 4.24. Polynomial curve fit to area impacted versus volume of oil not dispersed, for Alaska North Slope and South Louisiana crude oils under 15 kt winds. The area of impact is that where a lethal dose would affect sensitive species (LC50 5ppb) at 25ºC.

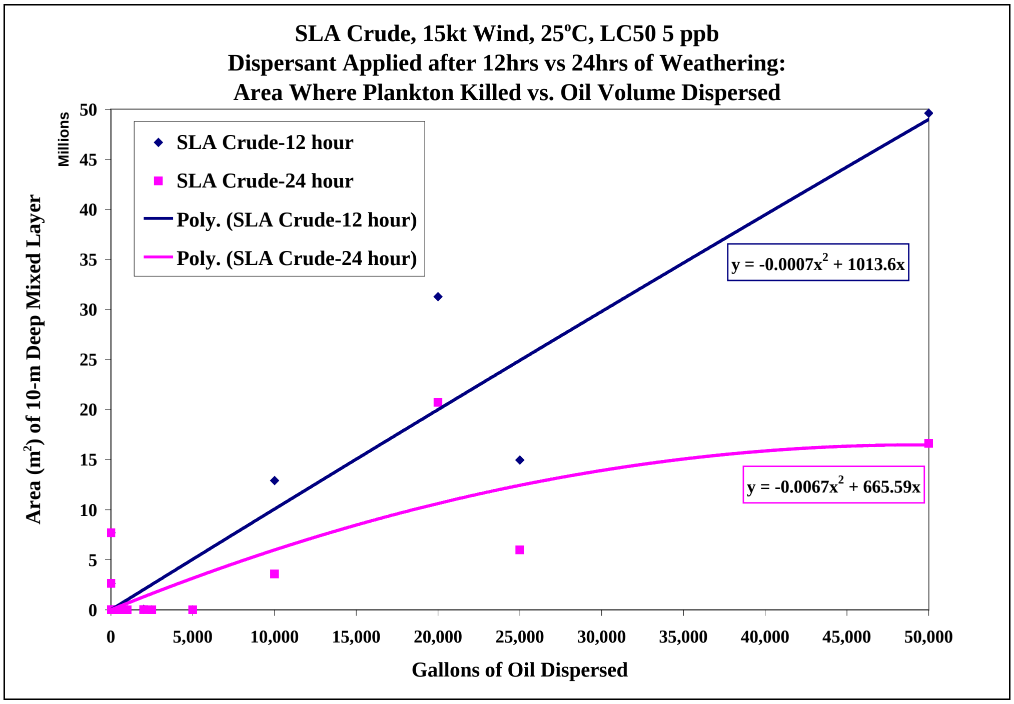

Figure 4.25. Polynomial curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude under 15 kt winds after 12 and 24 hours of weathering. The area of impact is that where a lethal dose would affect sensitive species (LC50 5ppb) at 25ºC.

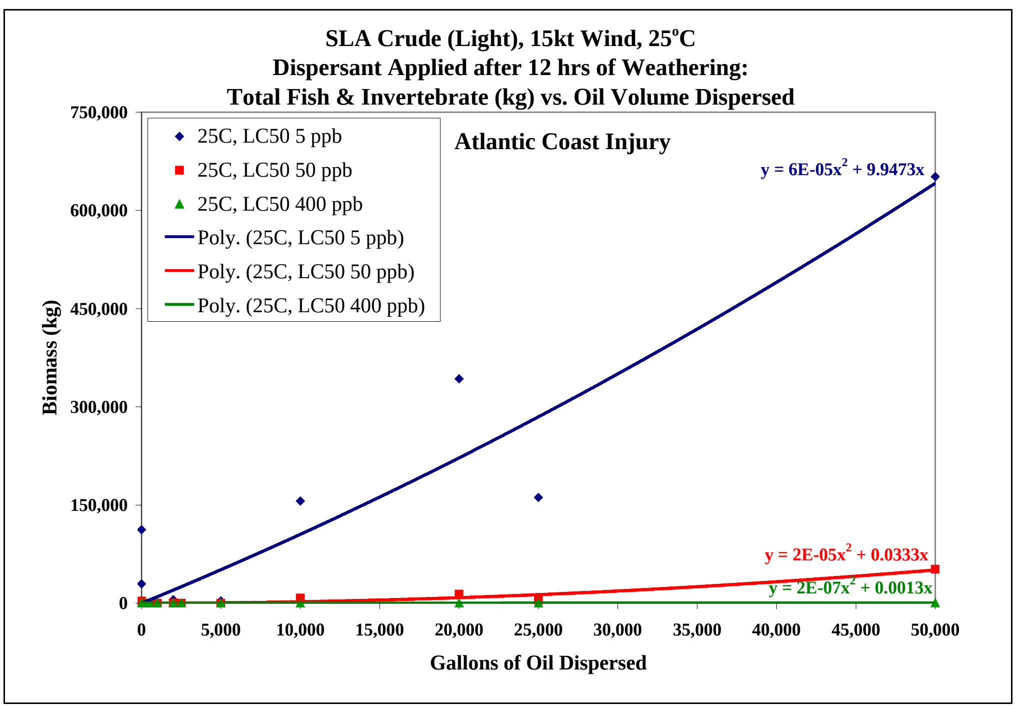

Figure 4.26. Polynomial curve fit to area impacted versus volume of oil not dispersed, for South Louisiana crude under 15 kt winds and 25ºC. The area of impact is that where a lethal dose would affect plankton for each LC50.

4.1.3 Impact Tradeoffs: Wildlife versus Water Column Biota

In order to examine the tradeoffs between impacts to wildlife and water column biota (e.g., plankton), comparisons were made between the equivalent areas where 100% mortality would occur. Presented here are the results for spills of 100,000 gal of the SLA crude. These and comparisons for 50,000 gal spills for both oils can be found in Appendix A and the OSIG Field Guide. Comparisons for spills of <50,000 gal are not presented as they produced minimal impacts on water column organisms of average sensitivity to PAHs regardless of dispersant effectiveness assumed or environmental conditions (i.e., volumes impacted by < 5,000 gal of entrained oil were not measurable for species of average sensitivity).

In light winds (5 knots) and high water temperatures (20-30º C), a spill of 100,000 gal that is not dispersed impacts close to 1,800 km^2 for wildlife and does not measurably impact the water column (Figure 4.27). If 20% of the slick is dispersed after 12 hours of weathering, the area of impact to wildlife (caused by all the oil before 12 hrs and the remaining 80% of the oil after 12 hours) is reduced to 1,550 km^2 and increased to 0.05 km^2 for plankton. At 50% dispersal, area of impact for wildlife had been reduced by half of the original impact while plankton has increased by two orders of magnitude to about 1.2 km^2. If the oil is left to weather until 24 hours after the spill before the dispersant application, the impact to wildlife is slightly lower (because the oil remaining after dispersal of a certain percentage has slightly less volume due to the higher loss to evaporation), while there are ~zero impacts to the water column biota (of average sensitivity to PAHs), regardless of percentage dispersed.

In cooler waters the impact to wildlife remains similar while impact to the water column biota is reduced from 1.2 km^2 at high water temperatures (20-30º C; Figure 4.27) to 0.14 km^2 at moderate temperatures (10-20º C; Figure 4.28) and ~zero at low temperatures (0-10º C; Figure 4.29).

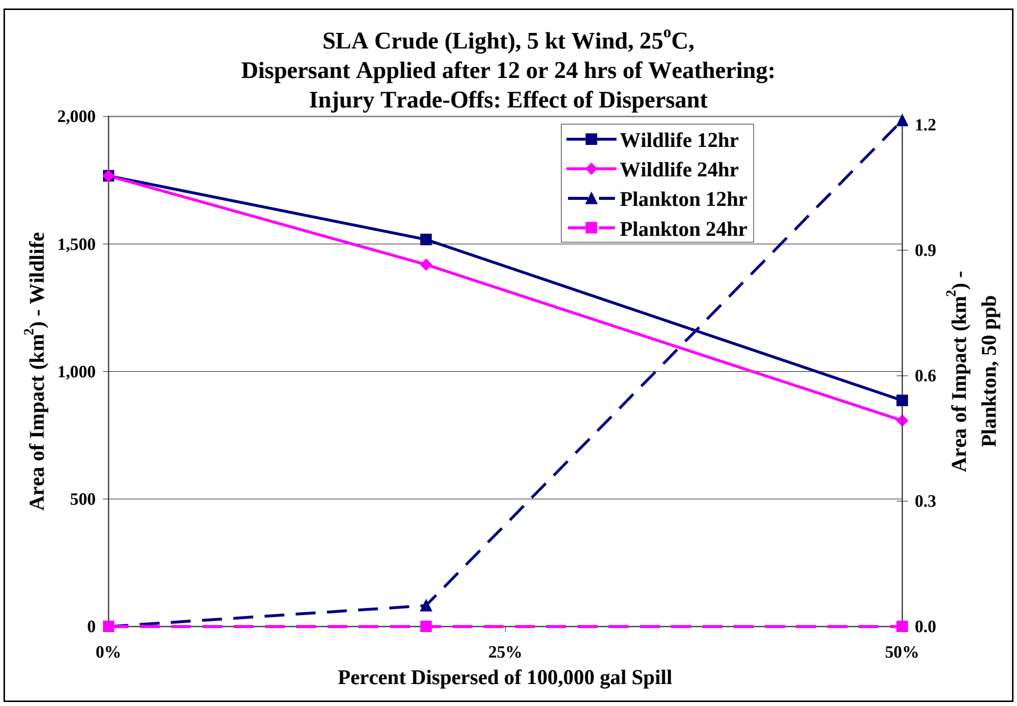

Figure 4.27. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 25º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

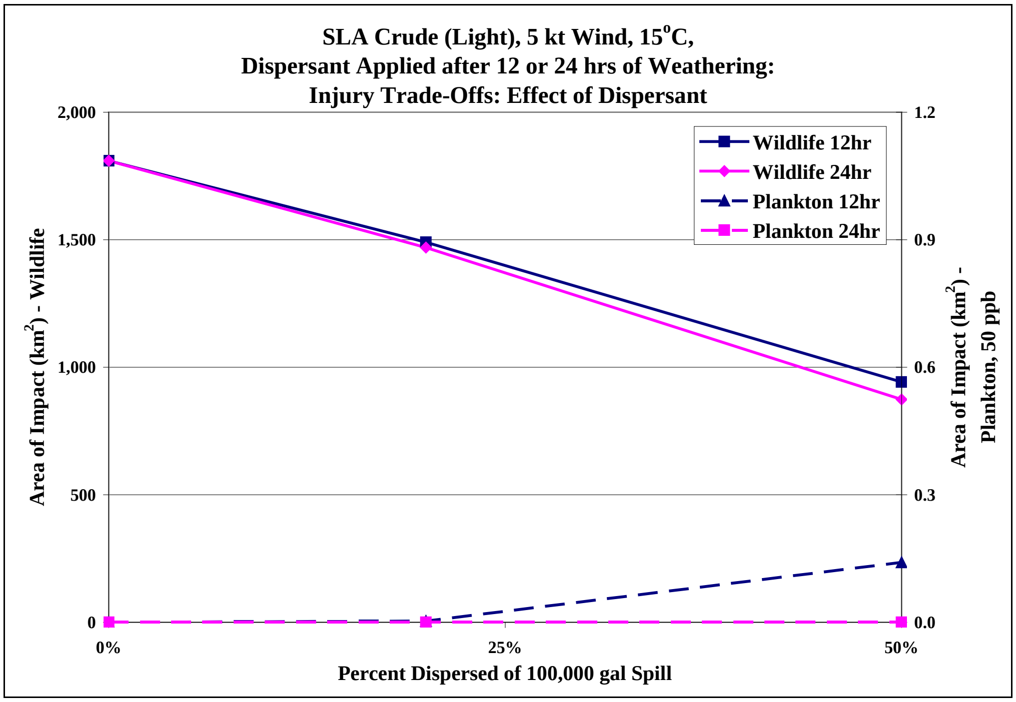

Figure 4.28. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 15° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

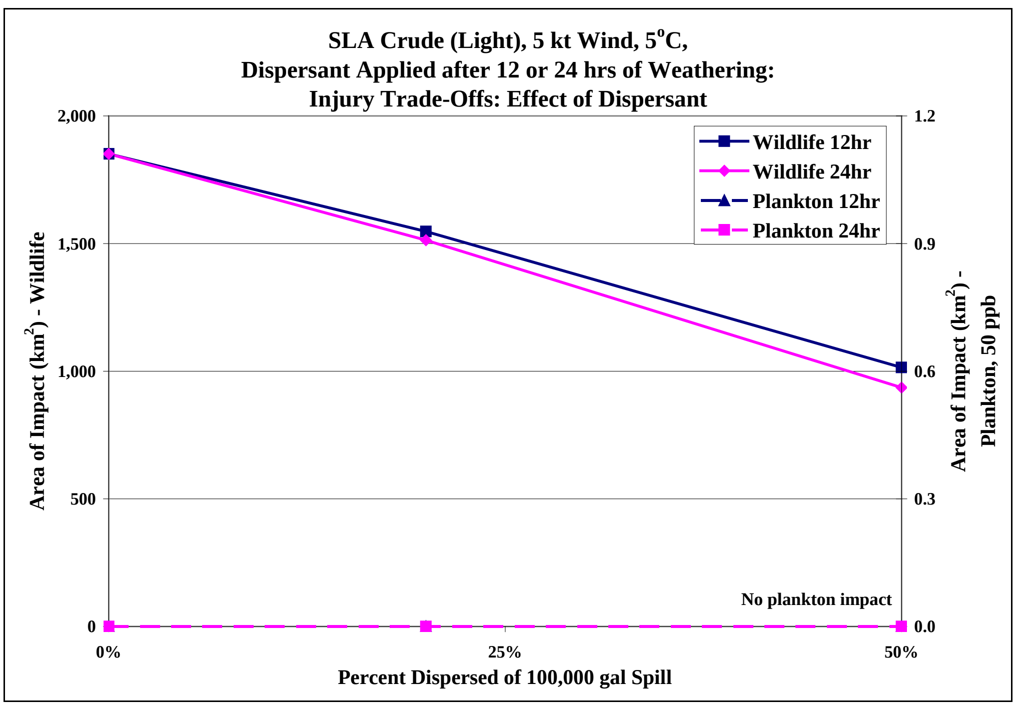

Figure 4.29. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 5° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

At higher wind speeds natural dispersion and evaporation change the relationships between impacts (Figures 4.30 to 4.32). Surface area swept is much lower at all temperature conditions under the higher winds than the low winds (compare Figures 4.30 – 4.32 to Figures 4.27 – 4.29) because natural entrainment disperses the oil. Evaporation rate is also considerably higher at 15 kts than at 5 kts, and this effect is stronger at higher temperatures. Thus, the surface area where wildlife would be oiled is much less in warmer temperatures than cooler ones (compare Figures 4.30 & 4.32). At high water temperatures, dispersing 50% of the surface slick after 12 hours of weathering reduces the impact area from 340 to 150 km^2; however, there is a large increase in area of impact for plankton. Natural dispersion impacts 0.3 km^2 while additional chemical dispersal of 50% increases the area of impact to 4.5 km^2. At cooler temperatures the impact to plankton is not as high (note different plankton impact scale on Figure 4.30). Increasing the weathering time before dispersant is applied also reduces the impact to plankton. The water column impact is very small for all volumes dispersed under cool temperatures (5° C), particularly after 24 hours of weathering.

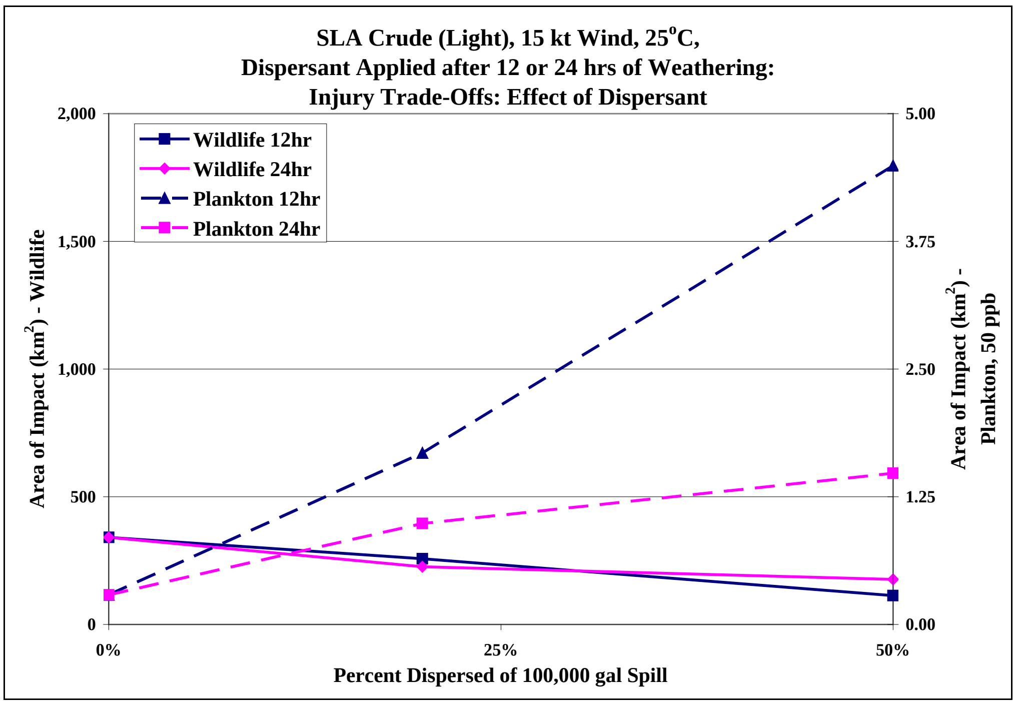

Figure 4.30. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds and 25º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

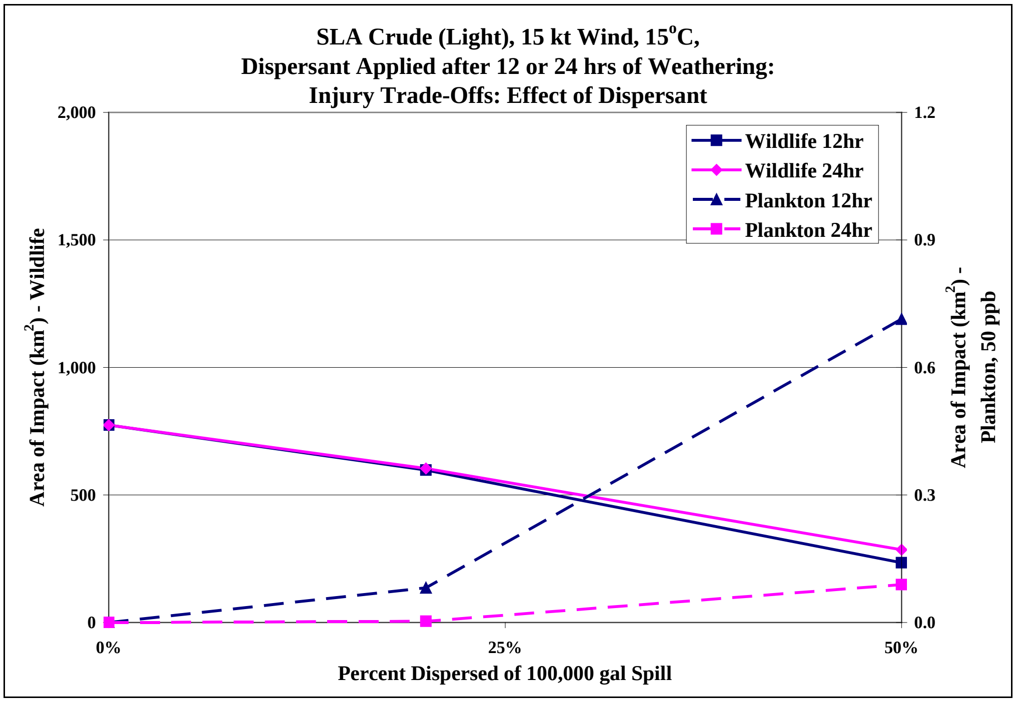

Figure 4.31. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds and 15° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

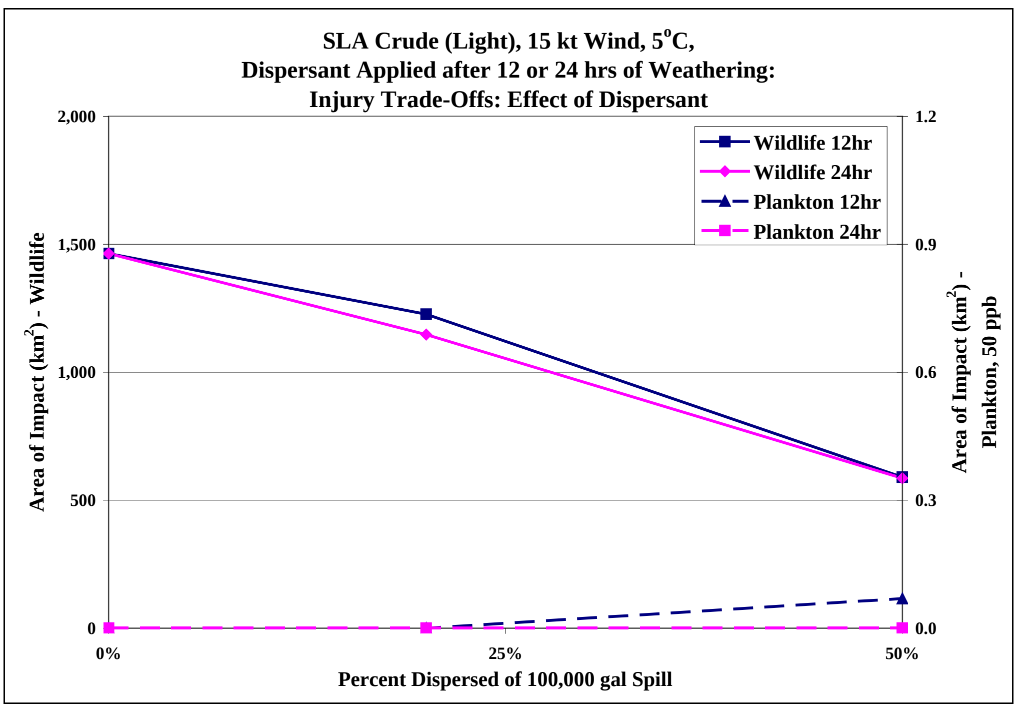

Figure 4.32. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds in 5° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

4.1.4 Sensitivity Analysis

The sensitivity analysis to quantify the potential difference in impacts due to uncertainty in the horizontal dispersion coefficient (the model input assumption with the largest potential effect on the results for a given temperature, weathering state, oil volume, and oil type) was performed for light oil spilled at moderate temperatures without chemical dispersion (Table 4.1). The results show that at the light wind speed there is no measurable impact to the water column and impact to the area of 100% mortality for wildlife varies only slightly, on the order of less than 0.1 km^2. At the higher wind speed the results are more variable with differences ranging upwards of 10 km^2. However, even the largest variation only alters the area of impact by 10%. Thus, within the range of potential values for the horizontal dispersion coefficient, which was the range tested, the uncertainty is up to 10% at higher wind speeds. Figures 4.33 and 4.34 show this information graphically.

Table 4.1. Horizontal dispersion coefficient sensitivity analysis results for impact to wildlife and plankton (sensitive species, LC50 5 ppb). All runs used light crude oil (SLA), moderate temperatures (15° C) and no chemical dispersion (0%).

			Wildlife	Plankton - 5 ppb
Wind (knots)	Oil Spilled (gal)	Horizontal Dispersion Coefficient (m^2/s)	Equivalent Area of 100% Mortality of Birds by Oil (km^2)	Equivalent Area of 100% Mortality of Plankton by Oil (km^2)
5	1,000	0.5	80.98	0
		1	80.98	0
		10	80.98	0
	5,000	0.5	241.5	0
		1	241.5	0
		10	241.4	0
	10,000	0.5	386.2	0
		1	386.2	0
		10	386.2	0
	50,000	0.5	1,145	0
		1	1,145	0
		10	1,145	0
	100,000	0.5	1,828	0
		1	1,828	0
		10	1,827	0
15	1,000	1	5.67	0
		10	7.42	0
		50	9.44	0
	5,000	1	31.20	0
		10	31.90	0
		50	31.46	0
	10,000	1	62.55	0
		10	70.39	0
		50	74.23	0
	50,000	1	357.0	0.624
		10	400.7	0.006

		50	414.4	0
	100,000	1	782.0	1.237
		10	811.9	0.011
		50	789.1	0.262

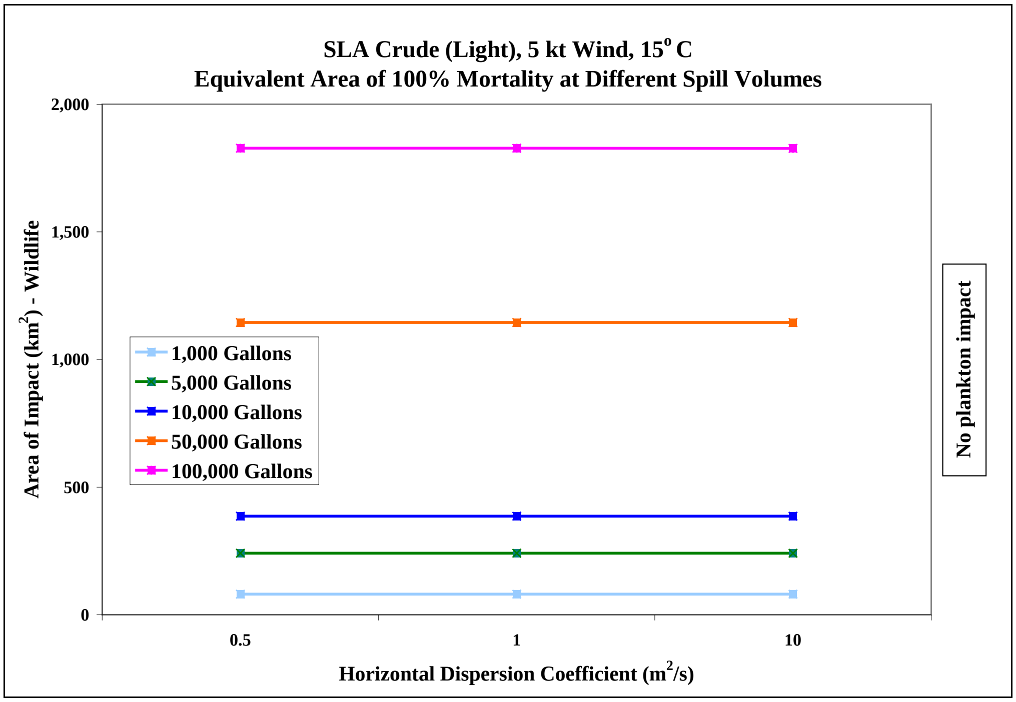

Figure 4.33. Area impacted versus Horizontal Dispersion Coefficients for spills of varying sizes of South Louisiana crude for 5 kt winds and 15º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and plankton in the water column (right axis – no impact), if present.

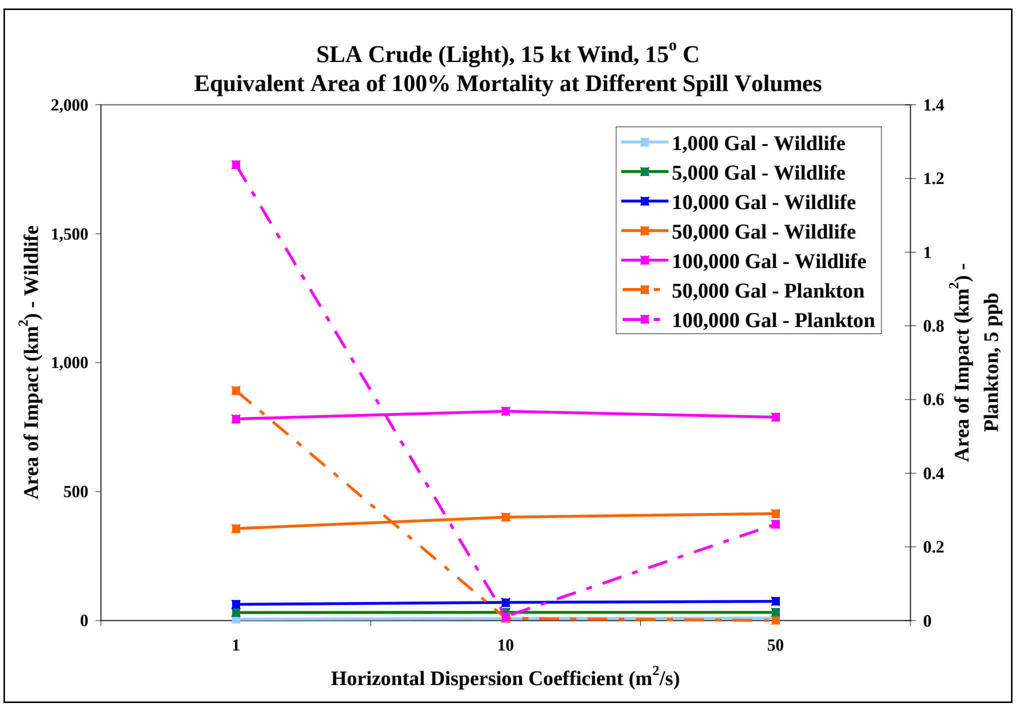

Figure 4.34. Area impacted versus Horizontal Dispersion Coefficients for spills of varying sizes of South Louisiana crude for 15 kt winds and 15º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and sensitive species (LC50 5 ppb) in the water column (right axis), if present. (No impact to plankton of other sensitivities or smaller spill sizes than those shown).

4.1.5 Example Biological Impact Results

The biological impacts estimated for 100,000 spills in 5 kts of wind, assuming no dispersant, 20% of the oil dispersed, and 50% of the oil dispersed at 12 hours (a worst case) after the release are summarized in Appendix B. These example results are those for the closest spring-season temperature in each location and the oil type more likely to be spilled (i.e., ANS crude on the Pacific and Alaskan coasts and SLA crude on the Atlantic and Gulf of Mexico coasts. The LC50 for the average species in the water column (50 ppb) is assumed, as in any location one would expect a mix of species of varying sensitivity, averaging about this level. This data provides an indication of the species included in the analysis for each of the 6 biological data sets representing various coastal regions of the US, as well as the magnitude of the impacts by species group. Note that for the fish and invertebrates listed, impacts may include direct exposure to early life history stages that are planktonic, and/or older age classes of individuals that could be present in surface waters.

For example, if a 100,000 gal SLA crude oil spill off Louisiana and Texas were left untreated, on the order of 4,000 birds and turtles would be oiled, including ~1,800 gulls, ~600 terns, ~780 pelicans, ~680 cormorants, and ~15 sea turtles (Table B.3). The fish and invertebrate injury for this scenario is a minor 7 kg (Table B.4). Dispersing 20,000 gal or 50,000 gal of the oil at 12 hours after the spill reduces the wildlife impact to ~3,400 and ~2,000 animals, respectively (Table B.3). However, the tradeoff is an increased impact of 43 and 108 metric tones (MT, 1 MT = 1,000 kg = 2,205 lbs) of fish and invertebrates, respectively for 20,000 or 50,000 gal of oil dispersed in a single location (Table B.4).

In reality it would be logistically difficult to disperse 20,000 or 50,000 gal of oil in one location via a single sortie of an airplane (or via ship application). If only up to 5,000 gal of oil were dispersed in one location, the fish and invertebrate impacts for the average species become non-measurable (~0 in the model results) – the first dispersed-oil volume level with impacts >0 being at 10,000 gal. (These thresholds are evident in the compiled results for the entire modeling matrix; see section 4.2.2.) If the dispersed oil volume was 500 gal or less (at one location and time), even sensitive species would not be expected to be adversely affected. These thresholds are applicable to dispersed oil in any of the regions modeled and under all conditions tested. Of course, dispersing only a smaller portion of the oil implies less savings of wildlife (and potentially shoreline) impacts. If the dispersant applications are spread out over wide areas or over time, such that each localized application does not exceed 500 gal (to protect all species) or 5,000 gal (to protect the average species) of oil dispersed, water column impacts can be held low while still accomplishing a reduction of impacts due to the floating oil.

If a 100,000 gal spill of ANS crude in Prince William Sound in spring (away from land) were left untreated, on the order of 19,000 birds and mammals would be oiled, including ~12,000 seabirds (mostly alcids), ~4,500 waterfowl (various sea and bay ducks), and ~2,300 sea otters. This wildlife impact would be reduced to ~16,000 animals if 20% of the oil is dispersed, and 10,000 animals oiled if 50% of the oil is dispersed at 12 hours after the release (Table B.9). The fish and invertebrate injury (assuming average sensitivity) for this scenario is 2 kg if no dispersant is applied, versus 2 MT if 20,000 gal are dispersed and 26 MT if 50,000 gal of oil are dispersed in a single application and location (Table B.10). Since temperatures in Alaska do not exceed 15^{o} C in open marine waters, if the dispersed oil volume into open waters were 1,000 gal or less (at one location and time), even sensitive species would not be expected to be adversely affected; average species would not be significantly affected if the dispersed oil volume is below 10,000 gal in one location.

Similar comparisons can be made using the other tables in Appendix B, or other model results, as described in Section 4.2.3. For example, if oil is weathered for 24 hours before it is dispersed, water column impacts are expected to be substantially lower. Results for the 15-knot wind scenarios are someone more complex, as both natural and dispersant-induced entrainment are included in the modeling. Note that typically water column impacts are lower at the higher wind speeds because of faster dilution rates.

4.2 Complete Model Results

Complete model results are available in the digital appendices to this report. Below describes where to find and how to read this information.

4.2.1 Mass Balance over Time

The mass balance of oil over time is available in tabular and graphic forms. This information shows where the oil has moved (surface, mixed layer, air, etc.) over the timeline of the spill. There are eight (8) Microsoft Excel files that hold all of these results: each combination of oil, wind speed, and weathering time has a file. These files can be found in the digital folder labeled "Fates Results".

Within each file are 45 table and chart tabs for each of the spill volume and dispersed volume combinations. Each table tab is named using the same convention marking the oil type used (ANSC or SLAC), the wind speed (5kt or 15kt), the water temperature (5ºC, 15ºC, 25ºC), the spill volume (1k, 5k, 10k, 50k, 100k where the k indicates thousands of gallons spilled), and the percent dispersed (0, 20, 50). Each chart tab is named the same as the table tab with "-CHT" at the end. For example, Table 4.2 can be found in the "ANSC5kt12hr-WTHfiles.xls" on the "ANSC-5kt5C-1k0" tab. Figure 4.35 can be found in the same excel file on the "ANSC-5kt5C-1k0-CHT" tab.

Table 4.2. Mass balance over time for a spill of 1,000 gal of Alaska North Slope crude at 5 kt winds, 5ºC with no chemical dispersion (ANSC-5kt-5C-1k0). Full table can be found in "ANSC5kt12hr-WTHfiles.xls."

Time-hr	% of oil floating	% volatilized	% in surface mixed layer	% below surface mixed layer	% Ashore	% degraded	% low MW arom. floating oil	% low MW arom. dispersed oil	% low MW arom. dissolved
0.25	97.48	2.51	0.006	0	0	0.010	91.52	0.0005	0.133
0.50	95.46	4.51	0.012	0	0	0.020	84.75	0.0009	0.257
0.75	93.54	6.42	0.017	0	0	0.030	78.33	0.0011	0.372
1	91.73	8.21	0.021	0	0	0.040	72.31	0.0012	0.477
2	85.70	14.19	0.035	0	0	0.076	52.53	0.0012	0.797
3	81.60	18.25	0.042	0	0	0.111	39.52	0.0010	0.979
4	79.04	20.77	0.046	0	0	0.144	31.86	0.0008	1.065
5	77.50	22.28	0.047	0	0	0.177	27.70	0.0007	1.096
6	76.55	23.20	0.047	0	0	0.209	25.54	0.0006	1.101
7	75.90	23.81	0.047	0	0	0.240	24.41	0.0005	1.095
…	…	…	…	…	…	…	…	…	…
720	42.85	40.99	0.033	0.0021	0	16.13	4.20	0	0.759

Time-hr = hours after instantaneous spill; % of oil floating = percent of oil floating on water surface; % volatilized = percent of oil volatilized; % in surface mixed layer = percent of oil in the 10m mixed layer; % below surface mixed layer = percent of oil below the 10m mixed layer; % ashore = percent of oil to reach shore; % degraded = percent of oil that has undergone chemical (photo-) or biological degradation; % low MW arom. floating oil = percent of the original 1- to 3- ring aromatics remaining in floating oil; % low MW arom. dispersed oil = percent of the original 1- to 3- ring aromatics in the dispersed oil droplets; % low MW arom. dissolved oil = percent of the original 1- to 3- ring aromatics that has dissolved into the water.

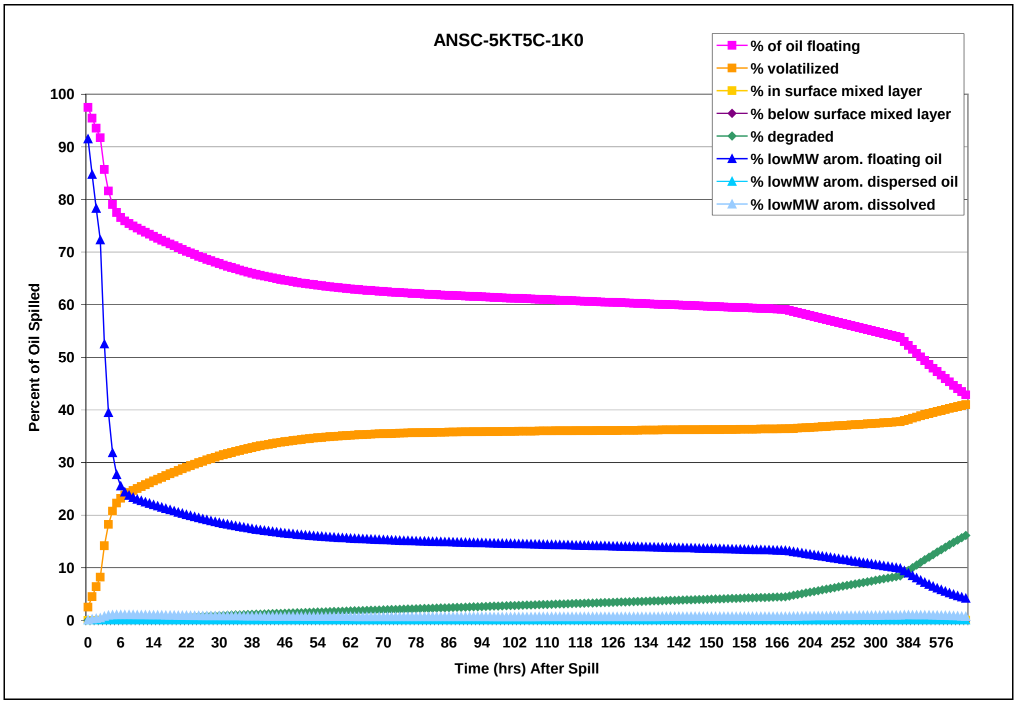

Figure 4.35. Mass balance over time for a spill of 1,000 gal of Alaska North Slope crude at 5 kt winds, 5ºC with no chemical dispersion (ANSC-5kt-5C-1k0-CHT). Chart can be found in "ANSC5kt12hr-WTHfiles.xls." Legend information is the same as those listed for Table 4.1.

4.2.2 Impact Area: Wildlife and Water Column

Complete results for area of impact for both wildlife and water column can be found in Microsoft Excel files. These files can be found in the digital folder labeled "Impact Spreadsheets". Each of the subfolders labeled with a biological database name contains eight (8) files that include each combination of oil, wind speed, and weathering time. The reader will find the charts most useful for evaluating trends with increasing oil volume, comparing implications of assumed inputs. Comparison of the model results on the "Data Tabs" (see below) is helpful when evaluating tradeoffs and comparisons not included in the charts provided.

Each file has the same format:

- Wildlife Impact Chart Tabs
    - "Wild km2-spilled" is a chart of gallons of oil spilled versus the area (km^2) of impact for wildlife.
    - "Wild km2-not disp" is a chart of gallons of oil not dispersed versus the area (km^2) of impact for wildlife.
    - "Wild-not disp (power-km2)" is a chart of gallons of oil not dispersed versus the area (km^2) of impact for wildlife fitted with a power curve.
    - "Wild km2-not disp 25C" is a chart of gallons of oil not dispersed versus the area (km^2) of impact for wildlife at 25º C fitted with a power curve.
    - "Wild km2-not disp 15C" is a chart of gallons of oil not dispersed versus the area (km^2) of impact for wildlife at 15º C fitted with a power curve.

- “Wild km2-not disp 5C” is a chart of gallons of oil not dispersed versus the area (km^2) of impact for wildlife at 5º C fitted with a power curve.
- “Wild#-not disp” is a chart of gallons of oil not dispersed versus number of birds oiled. (This chart differs between the different biological regions.)
- “Wild-not disp (power #)” is a chart of gallons of oil not dispersed versus number of birds oiled, fitted with a power curve. (This chart differs between the different biological regions.)

- Data Tabs
  - “Regr-Summary” tab contains the regressions created for each temperature and LC50;
  - “wild” tab contains the raw data, i.e., the actual model results, for wildlife impacts; and
  - “fish-tab” tab contains the raw data, i.e., the actual model results, for water column impacts.
- Water Column Impact Chart Tabs
  - “Plank-disp (25C-poly m2)” is a chart of gallons of oil dispersed versus the area (m^2) of impact for plankton assuming a 10-m deep mixed layer at 25º C, fitted with second order polynomial curves for each LC50 (5, 50, 400 ppb)
  - “Plank-disp (15C-poly m2)” is a chart of gallons of oil dispersed versus the area (m^2) of impact for plankton assuming a 10-m deep mixed layer at 15º C, fitted with second order polynomial curves for each LC50 (5, 50, 400 ppb)
  - “Plank-disp (5C-poly m2)” is a chart of gallons of oil dispersed versus the area (m^2) of impact for plankton assuming a 10-m deep mixed layer at 5º C, fitted with second order polynomial curves for each LC50 (5, 50, 400 ppb)
  - “Plank-disp (25c-poly) (kg)” is a chart of gallons of oil dispersed versus the total volume of biomass (kg) of impact for plankton assuming a 10-m deep mixed layer at 25º C, fitted with second order polynomial curves for each LC50 (5, 50, 400 ppb). (This chart differs between the different biological regions.)
  - “Plank-disp (15c-poly) (kg)” is a chart of gallons of oil dispersed versus the total volume of biomass (kg) of impact for plankton assuming a 10-m deep mixed layer at 15º C, fitted with second order polynomial curves for each LC50 (5, 50, 400 ppb). (This chart differs between the different biological regions.)
  - “Plank-disp (5c-poly) (kg)” is a chart of gallons of oil dispersed versus the total volume of biomass (kg) of impact for plankton assuming a 10-m deep mixed layer at 5º C, fitted with second order polynomial curves for each LC50 (5, 50, 400 ppb). (This chart differs between the different biological regions.)

4.2.3 Species Impacts

Tabular data listing all species calculated as impacted are contained in a series of digital subfolders under the main folder “Biological Results”. Each of the subfolders labeled with a biological database name contains two subfolders indicating the hours of weathering before dispersant application, and under those three subfolders indicating the LC50 assumed for water column biota. There are two files in each LC50 subfolder: one for wildlife impacts (with extension = WLD) and one for impacts to water column biota, i.e., fish and invertebrates (with extension = FSH). Both files are text files that can be opened with a text editor such as WordPad. Example results for 100,000 gal spills are provided in Appendix B.

4.2.4 Quality Control

Ms. Eileen Graham performed the modeling and regression analysis under the direction of the PI, Dr. French McCay. A complete review of all modeling results was performed by the PI. After the entire report was written, the software prepared, and the data files assembled, the deliverables were carefully reviewed by Ms Melanie Schroeder of ASA as an additional quality control step. The technical reviewers also evaluated the results and provided review comments.

4.3 Use of the OSIG Calculator

The OSIG Calculator is designed to allow the user to enter two scenarios and compare the results to assist in the decision making process. The calculator is designed in Microsoft Excel to allow easy distribution and use. There are two tabs for the user to consider.

The first tab ("InputGuide", Figure 4.36) is where scenario parameters are entered. This tab allows the user to choose spill conditions that best describe their situation and manipulate spill volume and dispersed volume between 1,000 and 100,000 gal. Spill conditions requiring user choice are oil type (light, mid/heavy), wind speed (light, moderate), weathering of spilled oil before dispersant is assumed applied (12 hours, 24 hours), water temperature (cool, moderate, warm), mixed layer depth (default: 10m, any number allowed), spill volume (any value between 1,000 and 100,000 gal), dispersed volume (any value ≤ spill volume *OR* a percentage between 0 and 100), and biological data (six biological regions from the coastal US). The calculator takes the parameters chosen by the user and uses the modeled regressions to interpolate spill volumes that were not included in the matrix of runs. Note that the regressions were developed based on the volume of oil dispersed and not dispersed. Thus, the wildlife regression is the same if 50% of 20,000 gal or 100% of 10,000 gal is dispersed; however, in these two situations the volume dispersed changes from 0 to 10,000 gal, which yield different results in the water column impact.

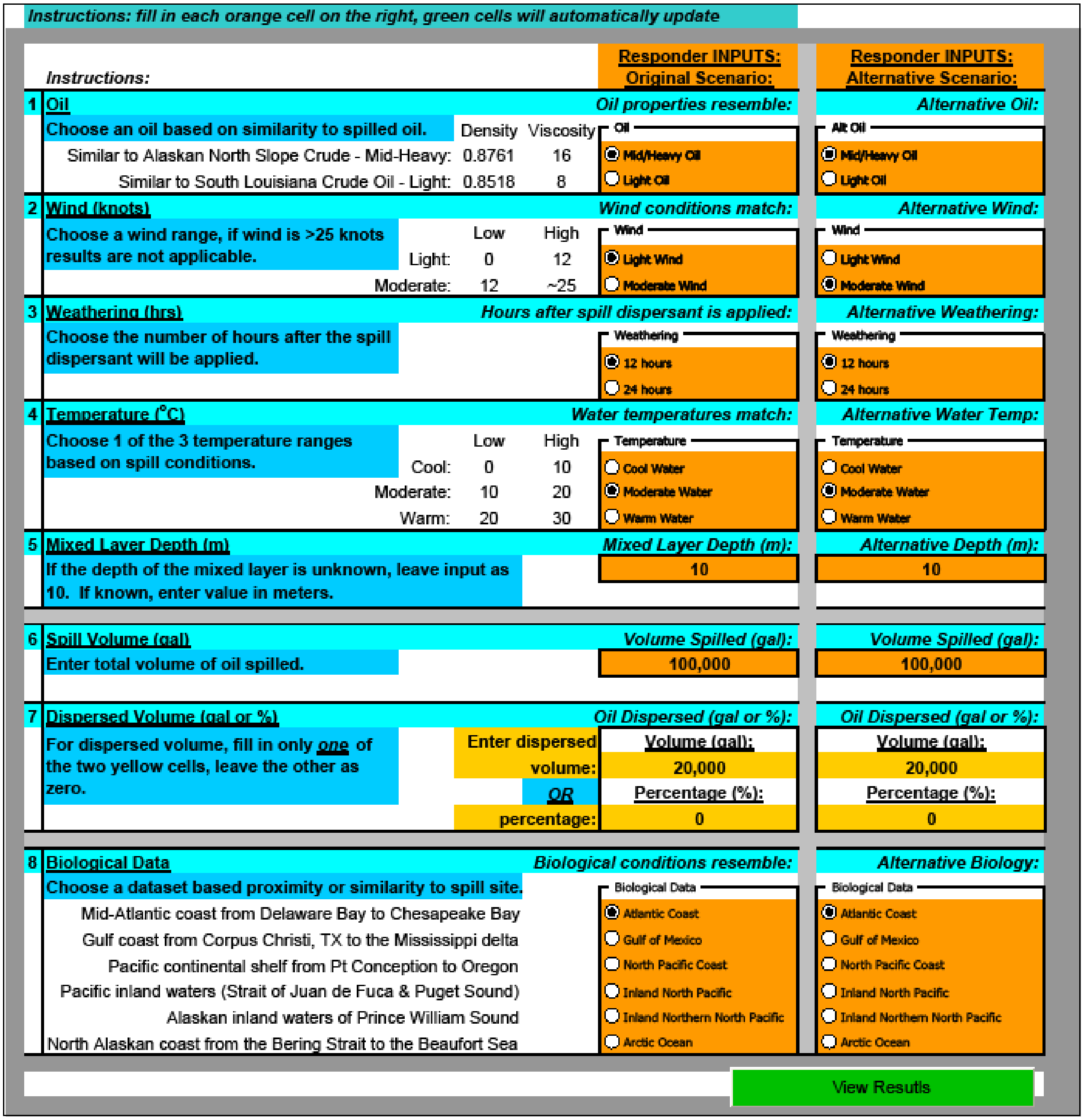

Figure 4.36. "InputGuide" tab of the OSIG Calculator.

When all parameters have been chosen for one, or both (original and alternative columns), of the scenarios the user can then click on the green "View Results" button in the lower right corner (Figure 4.36), which takes them directly to the "ImpactReport" tab (Figure 4.37). The "ImpactReport" displays the spill conditions modeled to generate the results and impact to wildlife, and fish and invertebrates, for two scenarios. To record the results, the user can elect to print the page using the button in the bottom right corner. If another set of scenarios is preferred, the button on the top right corner will take the user back to the "InputGuide" tab.

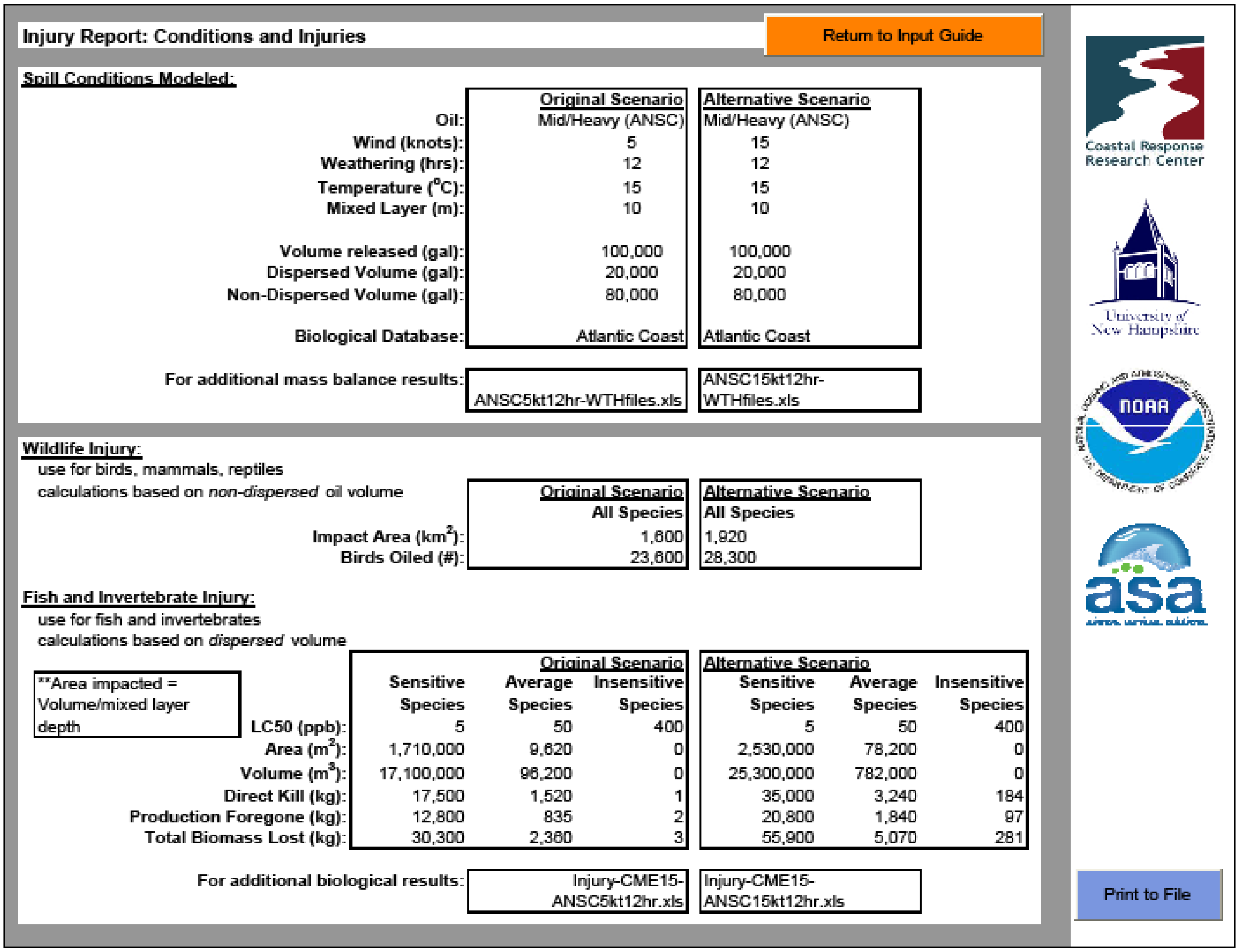

Figure 4.37. "ImpactReport" tab of the OSIG Calculator.

The guide reports several impact indices for wildlife and water column biota (fish and invertebrates). Wildlife indices reported are area (km^2) where wildlife would be oiled and the total number of birds oiled. Fish and invertebrate indices reported are equivalent area (km^2) and volume (m^3) where 100% of organisms would be killed for each sensitivity level, direct kill (kg), production forgone (kg), and total biomass lost (kg). To calculate number and biomass impact results, the calculator uses one of six biological databases. However if a more specific biological data is available results can be tailored because injuries are proportional to area or volume impacted. In order to determine impact, simply multiply the area (km^2, m^2) or volume (m^3) impact results by known biological abundances to generate a more specific impact.

5.0 Discussion and Importance to Oil Spill Response/Restoration

The proposed research addresses the major priority area identified by Coastal Response Research Center (CRRC) in their 2008 RFP: "Biologically/Ecologically-Driven Spill Response" regarding the timing and nature of tradeoff decision points in the context of response activities and expected level of resource injury. Following an oil spill, there is a theoretical point at which continued response activities do not provide a measurable benefit to the environment or lead to quicker recovery periods. Decision makers must rapidly consider various response options and their relation to the expected improvement, degradation and eventual recovery and restoration of the environment.

Dispersants are a “tool” in the responder’s “toolbox” that should be considered among other options for how to best respond to a spill. Many areas off the US coast have been designated as “Pre-approval Zones” for dispersant application to floating oil during oil spill response, but in these and other areas the “Go” decision to apply dispersants remains controversial because of uncertainty about efficacy and tradeoffs of impact caused by floating versus dispersed oil (NRC 1989, 2005; Lunel et al., 1997a,b; S.L. Ross, 1997; Trudel, 1998; Fingas and Ka’aihue, 2004). With respect to impacts, an effective application of dispersant would reduce injuries to wildlife (e.g. seabirds, furred marine mammals) and shoreline habitats, but with the potential tradeoff that the dispersed oil may cause impacts to water column organisms. This OSIG tool should be helpful to response advisors and decision makers in providing quantitative impact estimates for typical open water situations where dispersants might be applied on oil. The guidance includes water volume adversely affected (with respect to toxicity to aquatic biota) by dispersed oil and dissolved hydrocarbons, the surface area impacted by floating oil, and estimated impacts for biological densities typical of representative offshore locations around the US coast. Users of the tool may evaluate tradeoffs of dispersant use, as well as plan monitoring activities for response effectiveness and natural resource damage assessment (NRDA).

Based on the results of the model matrix, the range of volumes where dispersant would be applied (1,000 – 100,000 gal) with the 3 percent efficiencies (0%, 20%, 50%) provided useful modeling results for guidance. The highest potential oil volume that could be treated with dispersant *at a given location* would be that amount of oil that could be dispersed by a single sortie of a C-130 airplane: 100,000 gal (379 m^3) of oil. Thus, to a limited extent (i.e., to several hundreds of thousands of gallons of floating oil), higher volumes of potentially-treated oil than 100,000 gal need not be run, as the affected areas would of necessity be separated in space and time and the impacts of each treated oil volume would be additive.

Impacts for dispersed oil volumes up to 5,000 gal (19 m^3) were below the level detectable in these simulations for water column biota of average sensitivity. For sensitive water column species, this threshold was 500 gal (2 m^3). Thus, as a general conclusion, the tradeoff with respect to wildlife versus water column biota is in favor of dispersant use for oil volumes < 500 gal, while remaining protective of all species. Dispersing more than 500 gal of oil in a single location during a short period of time (<1 hour) could have impacts on some biota in the surface mixed layer, depending on winds, degree of current shear, weathering state, temperature, and sensitivity of the aquatic biota exposed (i.e., toxicity). However, the volume and area of surface water where water column biota would be affected would be much less than the area affected by floating oil thick enough to impact wildlife. Furthermore, the model results showed that dispersant application on spills of <5,000 gal (19 m^3) produced non-measurable impacts on water column organisms of *average* sensitivity to dissolved PAHs, regardless of dispersant effectiveness assumed or environmental conditions. Thus, if the dispersant applications are spread out over wide areas or over time, such that each localized application does not exceed 500 gal (to protect all species) or 5,000 gal (to protect the average species) of oil dispersed, water column impacts can be held low while still accomplishing a reduction of impacts due to the floating oil.

In an actual incident, the prevailing balance between the potential benefits and risks of dispersant use will depend on several factors. If the spilled oil is removed from the water surface by being dispersed into the water column, the benefit to some resources (for example, sea ducks) on the water surface must be balanced against the potential risk to other resources (for example, fish larvae) in the water column. It must first be established whether such resources are present or absent in the area that will be affected by the spilled oil. The second consideration would be to estimate exposure and direct effects that would occur in the location of the spilled oil and the prevailing conditions. Finally, long-term effects should be considered. Populations of long-lived species such as birds and marine mammals typically recover much slower from the impact of an oil spill than populations of species with a higher turnover rate such as zooplankton. In addition, the potential for long-term effects in intertidal areas that might be exposed to oil needs to be weighed in the balance.

Finally, we expect that the research and lessons learned from this effort will contribute to national and international efforts aimed at developing decision-support tools, and provide needed information related to spill response, specifically with respect to dispersant use. This project specifically addresses several CRRC goals, including fostering integrative approaches to spill response and assessment, improving oil-spill operational and response activities, and generating information for educational opportunities and public outreach regarding dispersant use and potential impacts.

6.0 Technology Transfer

The audience for this guidance and dispersant usage tool includes anyone involved with spill response, such as decision makers and scientific support, as well as those evaluating the impact of oil spills. This includes federal and state authorities and technical personnel, oil spill response organizations, oil companies, oil shippers, technical consultants to these groups, and non-governmental organizations. In addition, the guidance is useful internationally, both where dispersant application is being considered and where oil spill impacts are simply being evaluated.

The four deliverables for this project are:

- A report describing the approach, assumptions and results of the modeling and guidance development;
- A field guide in PDF format;
- A calculator in spreadsheet format that will facilitate interpolations; and
- A manuscript for publication (in preparation, based on this report).

The report and guidance will be disseminated on the CRRC website, as for all CRRC projects. In addition, ASA will provide and support the guidance on its website, including free access to the report, the field guide, and the calculator in spreadsheet format that will facilitate interpolations. Hosting by two Internet sites will allow download by anyone who may want to use the information, including from field locations during the response phase. The only requirement would be a computer or hand-held device connected to the internet.

Dr. French-McCay has presented the study results twice at Center-sponsored workshops at the Clean Gulf Conference (in San Antonio, TX during October 2008 and in New Orleans in November 2009). Finally, the development of and information in the guide will be summarized in a manuscript for publication, as a paper submitted to the 2010 AMOP Proceedings, as well as to the 2011 International Oil Spill Conference.

The report and OSIG calculator has not yet been released and distributed to to the targeted audience. However, we expect to present it at trade shows, conferences and workshops, in addition to its being available via the Internet.

7.0 Achievement and Dissemination

The following presentations have been made, and the Power Point slide shows have been submitted to CRRC.

- A presentation was presented at the Annual CRRC Science Advisory Panel meeting in on 29 May 2008. CRRC has a copy of the power point file used for this presentation.
- Dr. French McCay presented the research project approach and preliminary results at the Clean Gulf Conference in San Antonio, TX, on 28 October 2008 (about 50 participants).
- Dr. French McCay presented the research project approach and preliminary results at the Clean Gulf Conference in New Orleans, LA, on 17 November 2008 (about 70 participants).

The 2010 AMOP paper, as well as any follow-on work, will be provided to CRRC when prepared.

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Appendix A. Impact Tradeoffs – Wildlife versus Water Column Biota

In order to examine the tradeoffs between impacts to wildlife and water column biota (e.g., plankton), comparisons were made between the equivalent areas where 100% mortality would occur. Results for 100,000 gallon and 50,000 gallon spills are presented here. Comparisons for spills of smaller sizes are not shown as they produced minimal impacts on water column organisms of average sensitivity to PAHs regardless of dispersant effectiveness assumed or environmental conditions (i.e., volumes impacted by < 25,000 gal of entrained oil were not measurable for species of average sensitivity). In those cases, impacts to wildlife and shorelines should be the main concern.

A.1 South Louisiana (Light) Crude Oil

A.1.1 100,000 Gallon Spills

At light winds (5 knots) and high water temperatures (20-30º C) a spill of 100,000 gallons that is not dispersed impacts close to 1,800 km^2 for wildlife and does not measurably impact the water column (Figure A.1). If 20% of the slick is dispersed after 12 hours of weathering, the area of impact to wildlife (caused by all the oil before 12 hrs and the remaining 80% of the oil after 12 hours) is reduced to 1,550 km^2 and increased to 0.05 km^2 for plankton. At 50% dispersal, area of impact for wildlife is reduced by half of the original impact area while plankton has increased by two orders of magnitude to about 1.2 km^2. If the oil is left to weather until 24 hours after the spill, the impact to wildlife is slightly lower (because the oil remaining after dispersal of a certain percentage has slightly less volume due to the higher loss to evaporation), while there are ~zero impacts to the water column biota (of average sensitivity to PAHs), regardless of percentage dispersed.

In cooler waters the impact to wildlife remains similar while impact to plankton is reduced from 1.2 km^2 at high water temperatures (20-30º C; Figure A.1) to 0.14 at moderate temperatures (10-20º C; Figure A.2) and zero at low temperatures (0-10º C; Figure A.3).

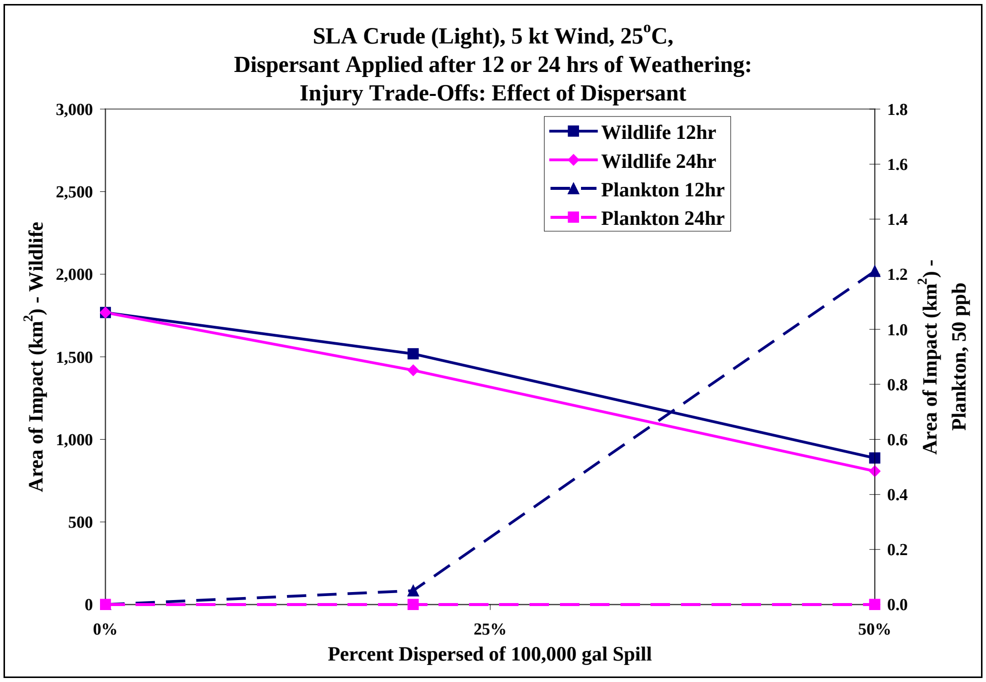


Figure A.1. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 25º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

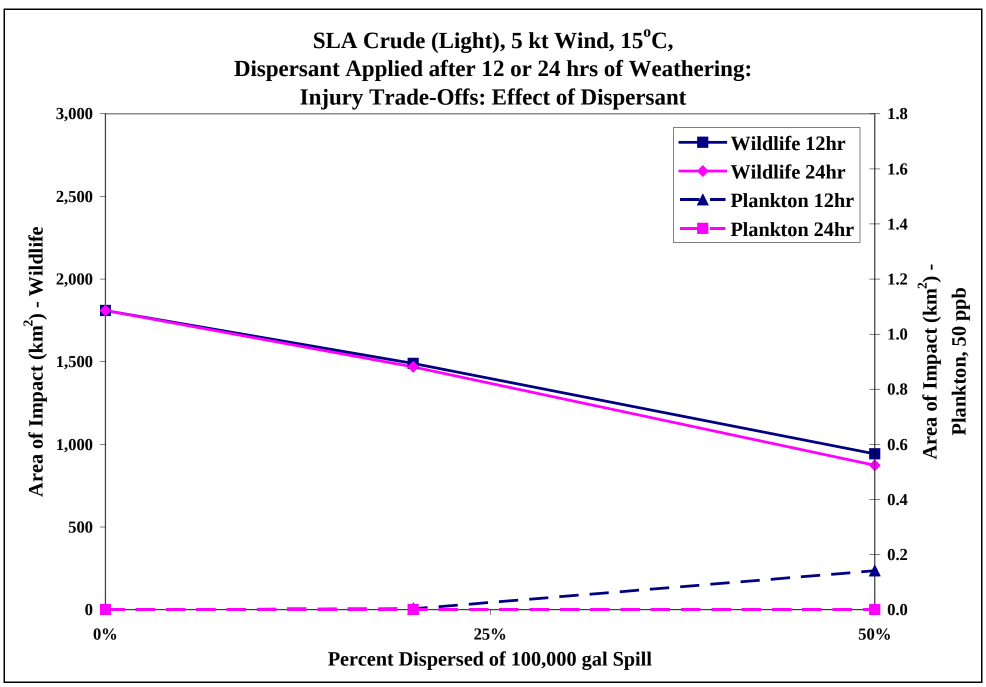


Figure A.2. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 15º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

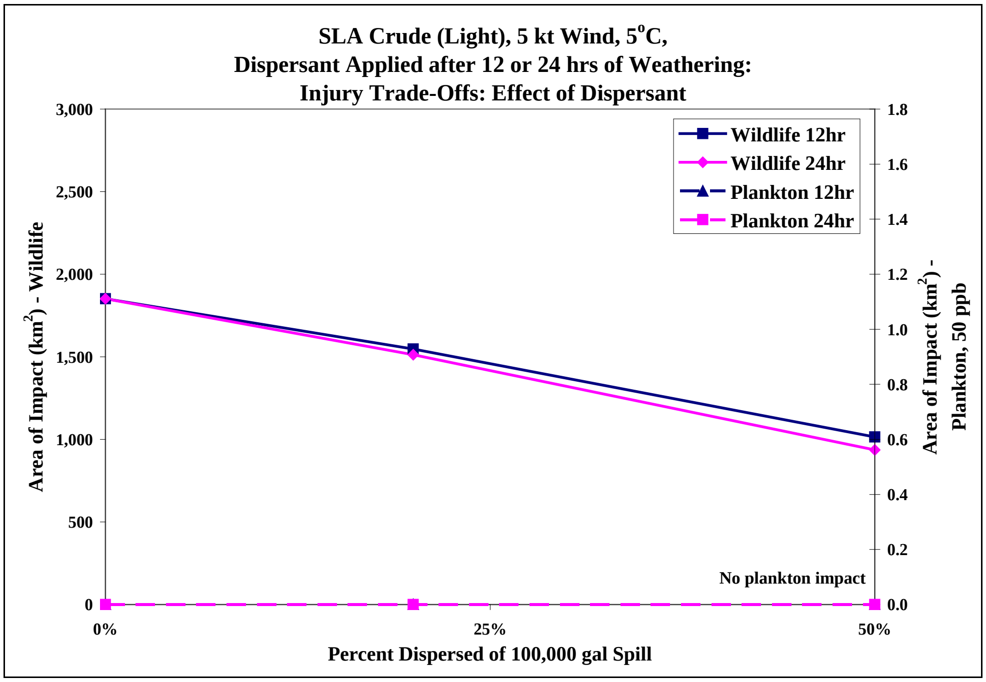


Figure A.3. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 5° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

At higher wind speeds natural dispersion and evaporation change the relationships between impacts (Figures A.4 to A.6). Surface area swept is much lower at all temperature conditions under the higher winds than the low winds (compare Figures A.4 – A.6 to Figures A.1 – A.3) because natural entrainment disperses the oil. Evaporation rate is also considerably higher at 15 kts than at 5 kts, and this effect is stronger at higher temperatures. Thus, the surface area where wildlife would be oiled is much less in warmer temperatures than cooler ones (compare Figures A.4 & A.6). At high water temperatures, dispersing 50% of the surface slick after 12 hours of weathering reduces the impact area from 340 to 150 km^2 (Figure A.4); however, there is a large increase in area of impact for plankton. Natural dispersion impacts 0.3 km^2 while additional chemical dispersal of 50% increases the area of impact to 4.5 km^2. At cooler temperatures the impact to plankton is not as high (note different plankton impact scale on Figure A.4). Increasing the weathering time before dispersant is applied also reduces the impact to plankton. The water column impact is very small for all volumes dispersed under cool temperatures (5° C), particularly after 24 hours of weathering (Figure A.6).

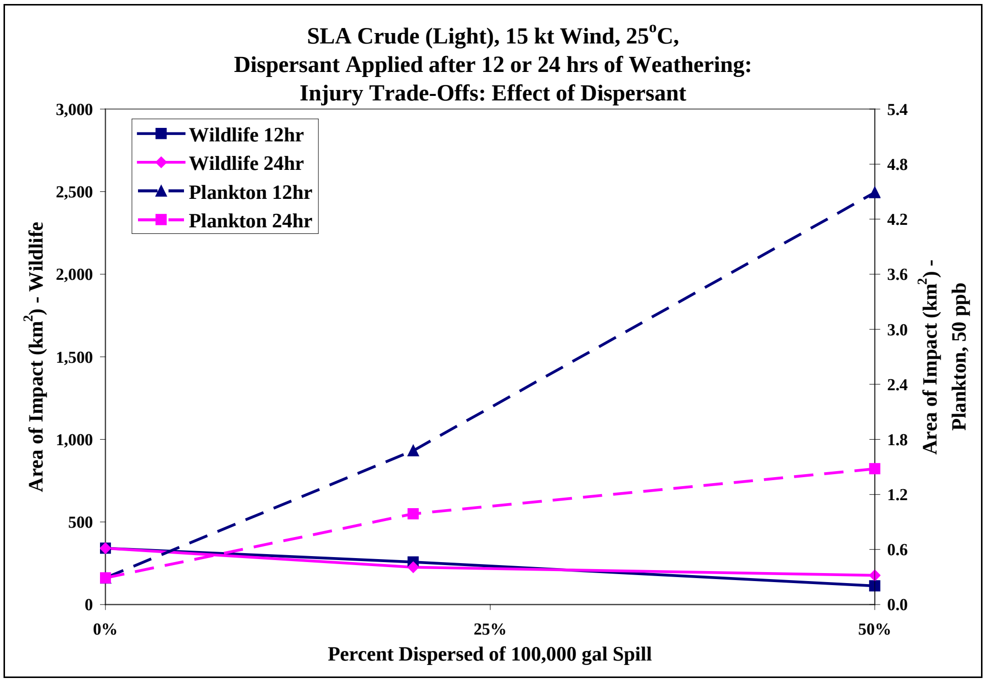


Figure A.4. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds and 25° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

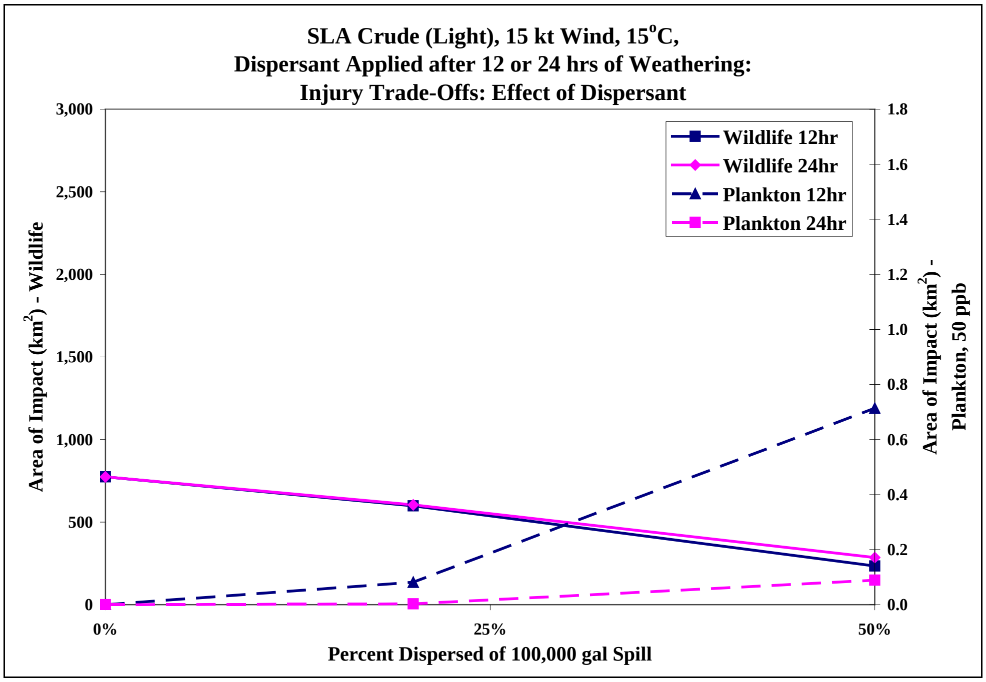


Figure A.5. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds and 15° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

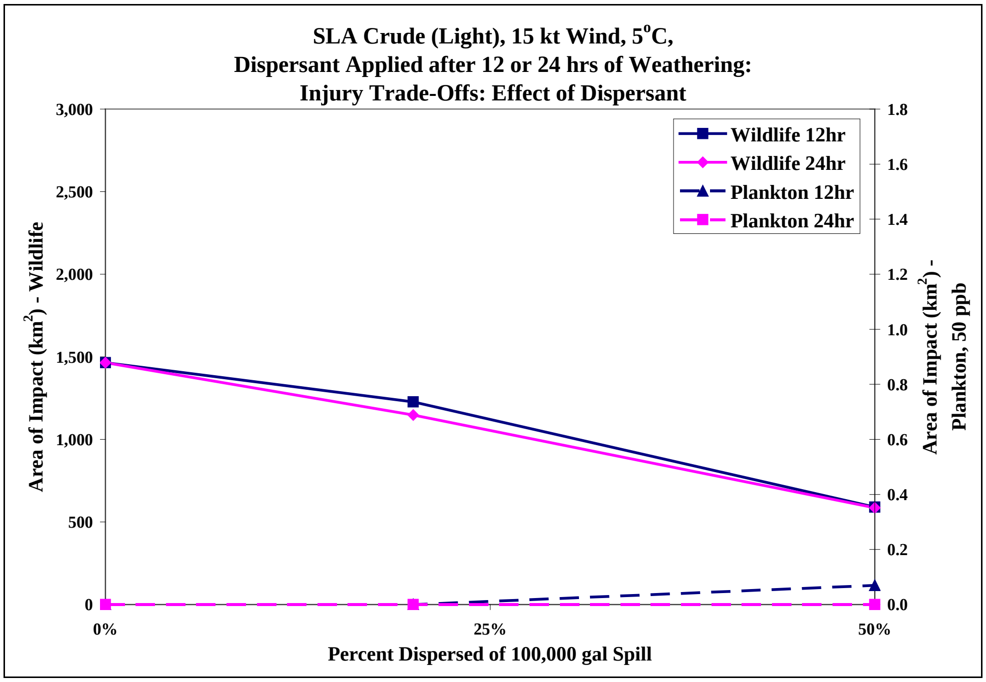


Figure A.6. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds in 5º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

A.1.2 50,000 Gallon Spills

Spills of smaller volumes of oil show similar patterns and lower overall areas of impact. In light wind, high temperatures and with no dispersant the area of impact for wildlife is about 1,800 km^2 for a 100,000 gallon spill (Figure A.1) but only 1,100 km^2 for a 50,000 gallon spill (Figure A.7). For plankton, reducing the spill volume by half results in a two orders of magnitude reduction in area of impact; from 1.2 km^2 (Figure A.1) to 0.05 km^2 (Figure A.7). At lower temperatures, wildlife impacts remain similar and plankton show no measurable impacts (Figures A.8 & A.9).

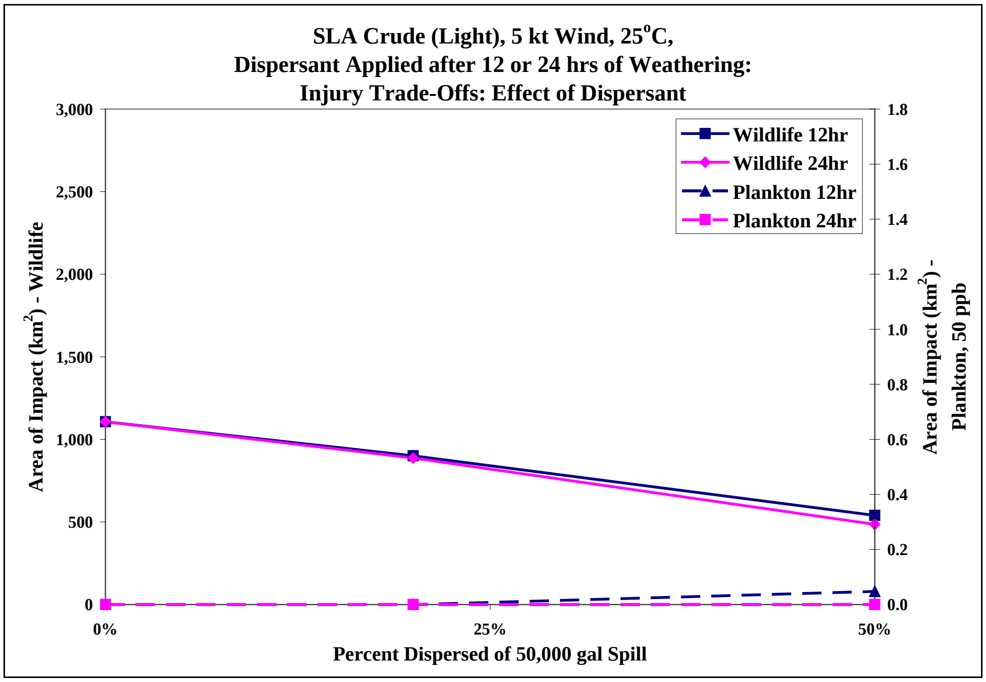


Figure A.7. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 25º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

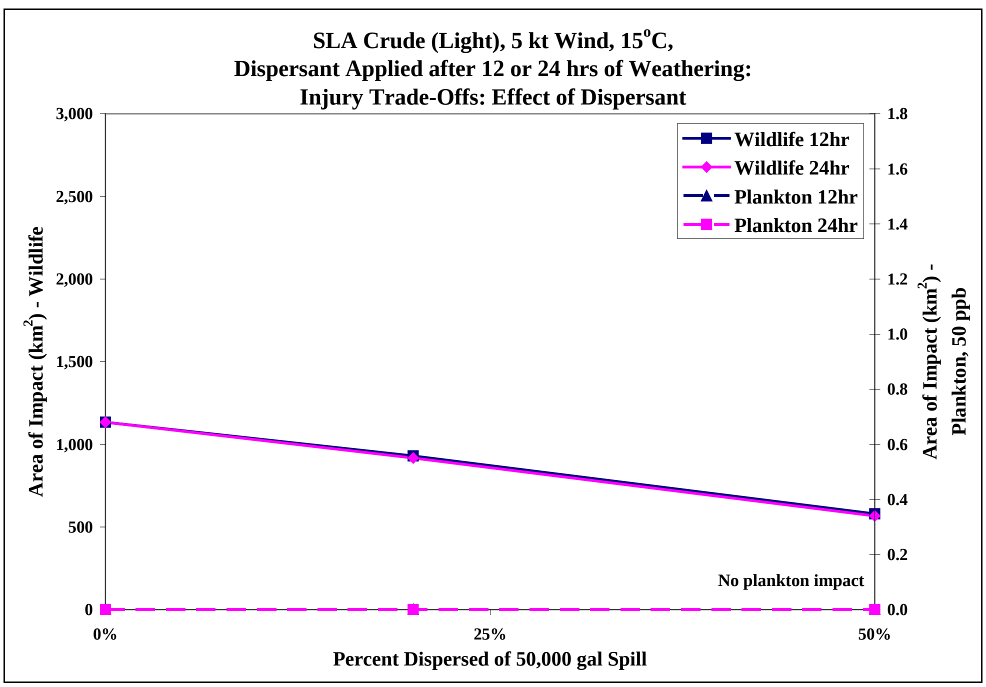


Figure A.8. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 15º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

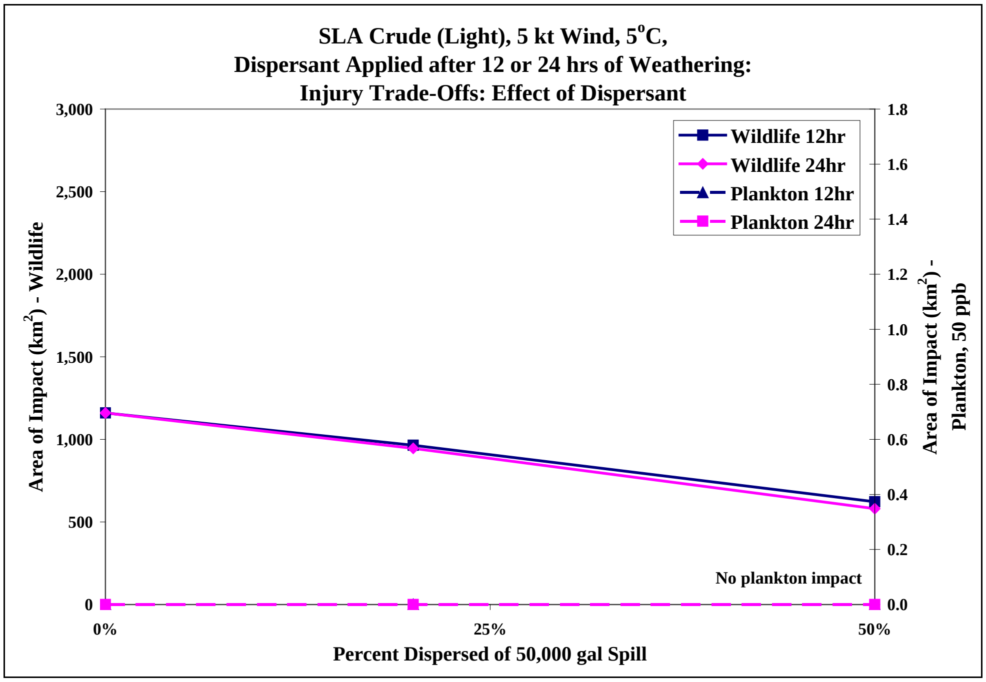


Figure A.9. Area impacted versus percent dispersed for South Louisiana crude under 5 kt winds and 5° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

For smaller spills in high wind, the relationship remains similar for wildlife and plankton as compared with spills of larger volumes. Wildlife impacts increase at cooler temperatures due to reduced evaporation while plankton impacts are higher in warm temperatures and negligible at cooler temperatures (Figures A.10-A.12).

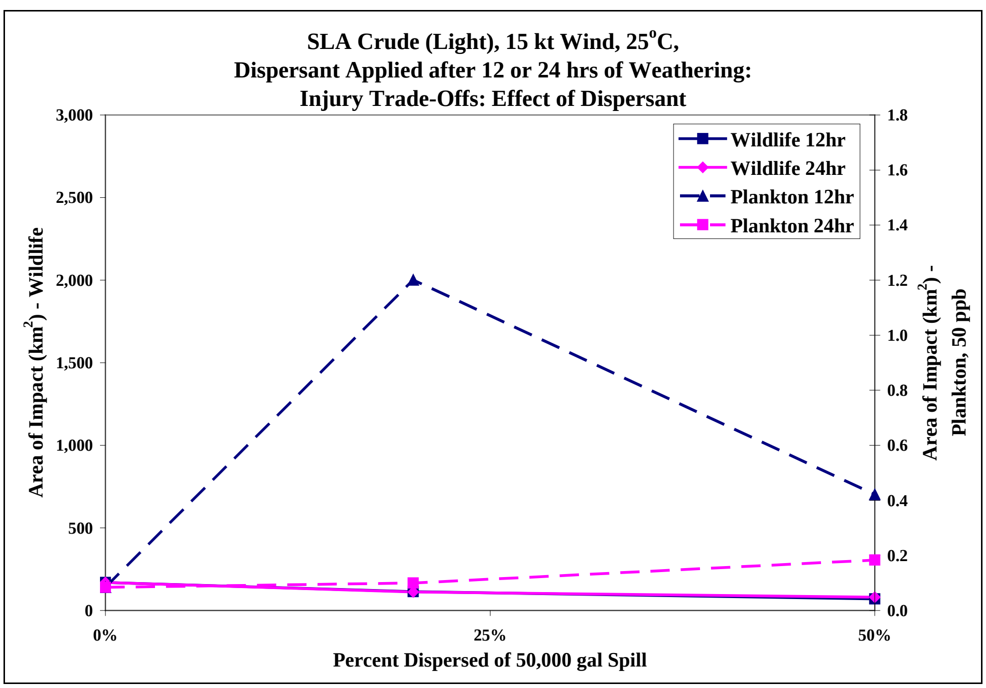


Figure A.10. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds and 25° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

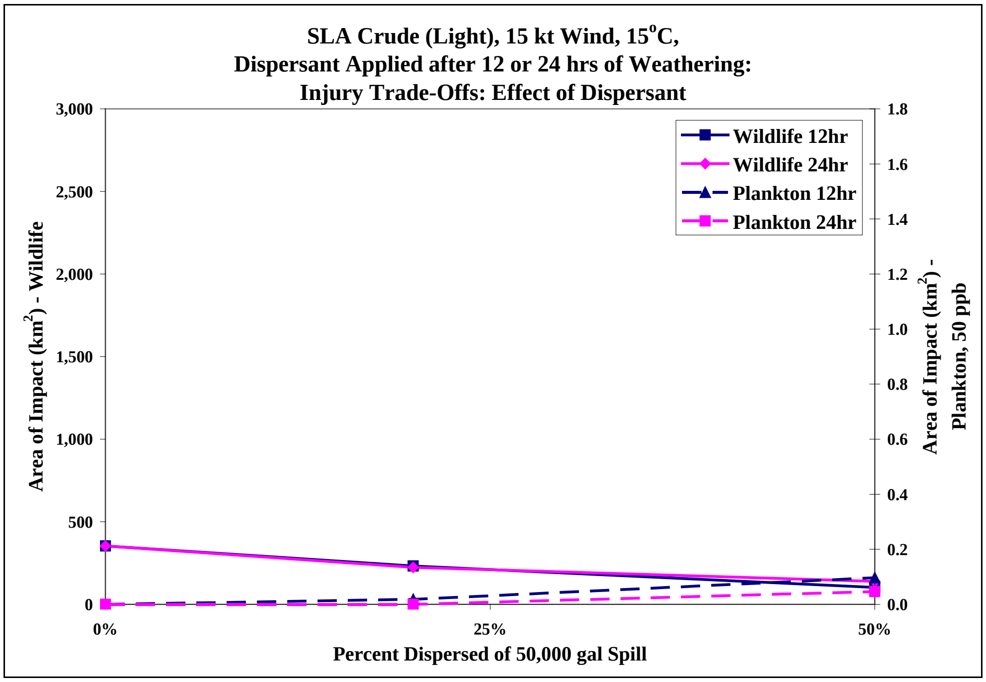


Figure A.11. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds and 15º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

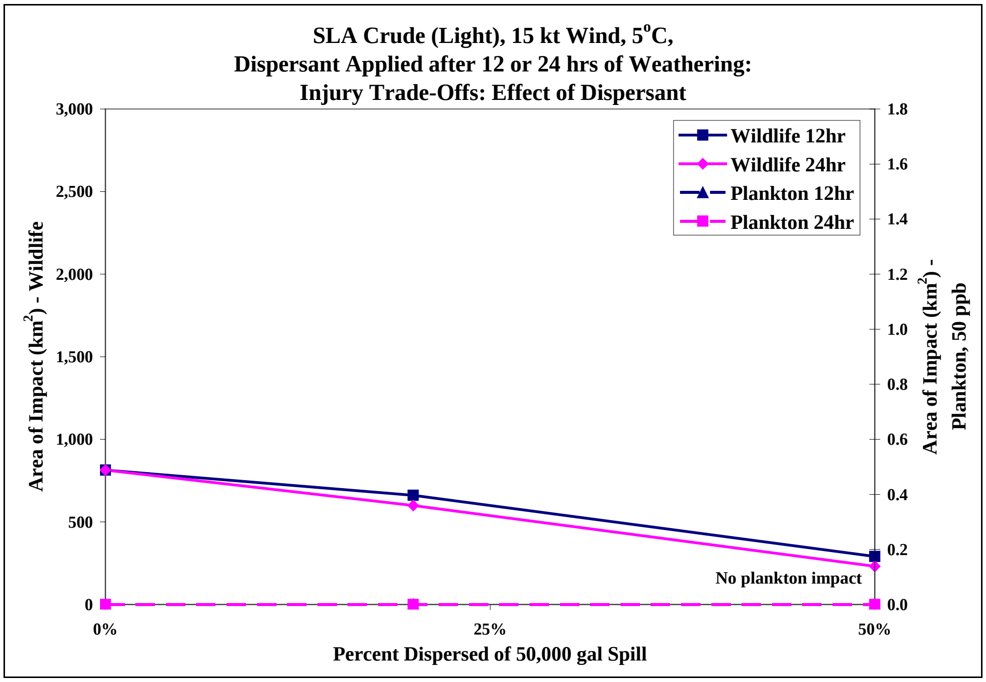


Figure A.12. Area impacted versus percent dispersed for South Louisiana crude for 15 kt winds in 5º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

A.2 Alaskan North Slope (Mid-Heavy) Crude Oil

A.2.1 100,000 Gallon Spills

In light wind the heavier oil produces similar impact tradeoffs as those presented for the lighter oil for both wildlife and water column biota (Figures A.13-A.16). In general, wildlife impacts are reduced by increasing the percentage of dispersant applied; while water column impacts are greatly reduced by allowing the oil to weather for 24 hours before applying the dispersant. The effects of temperature on the area of impact are also similar to that of the lighter oil.

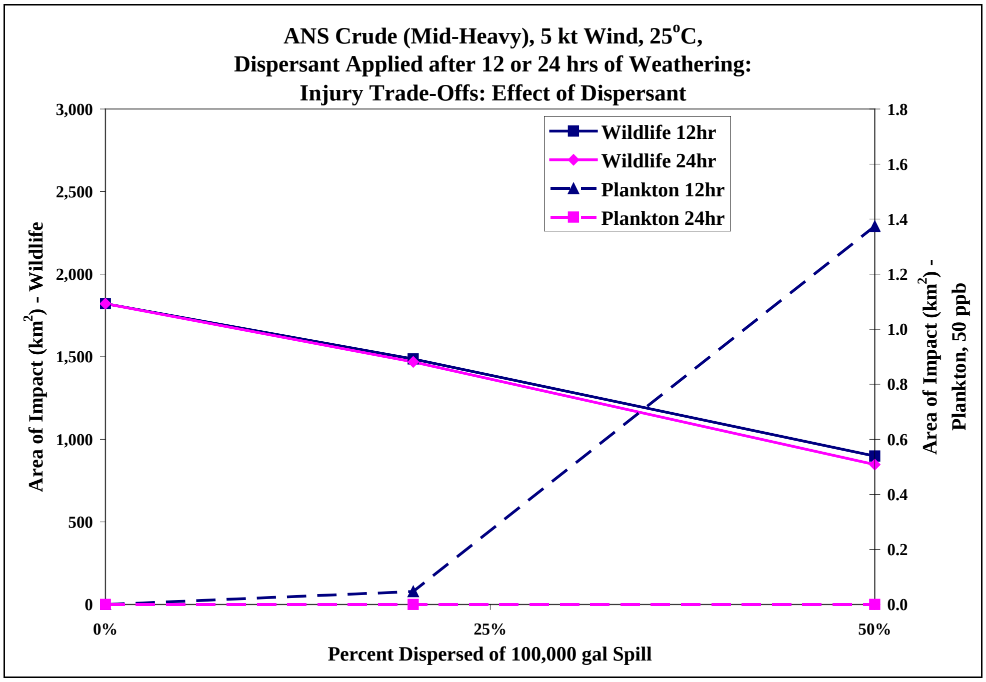


Figure A.13. Area impacted versus percent dispersed for Alaskan North Slope crude under 5 kt winds and 25° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

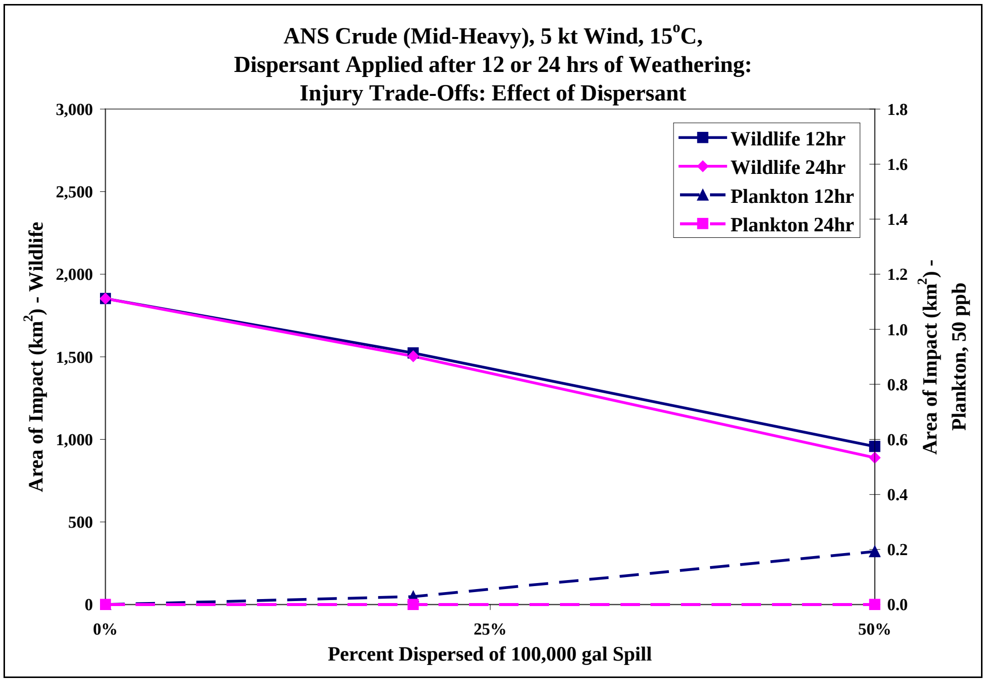


Figure A.14. Area impacted versus percent dispersed for Alaskan North Slope crude under 5 kt winds and 15º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

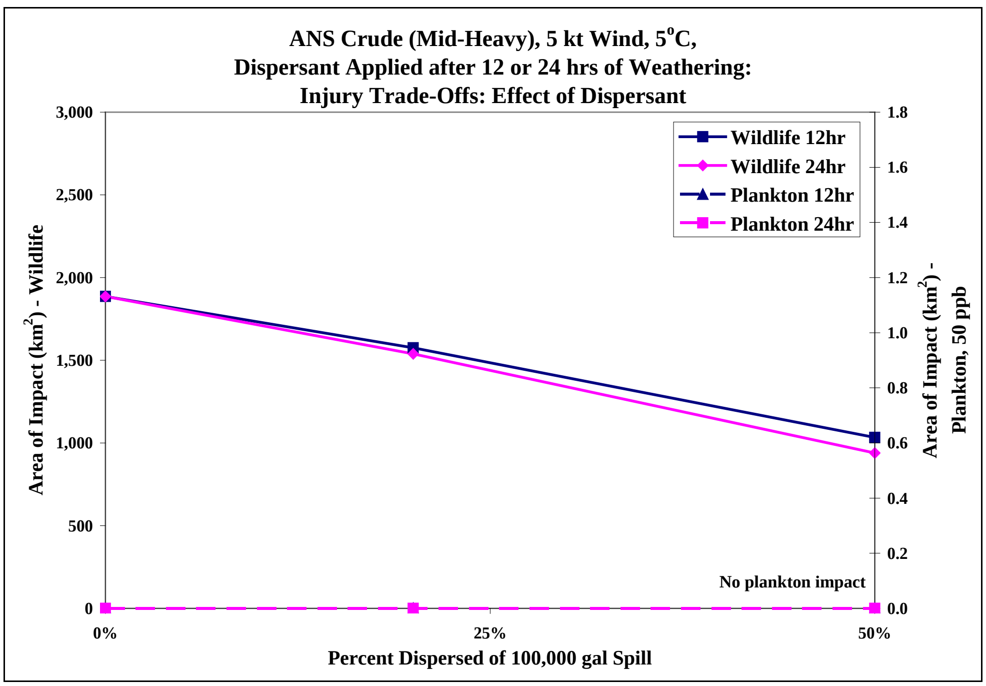


Figure A.15. Area impacted versus percent dispersed for Alaskan North Slope crude under 5 kt winds and 5º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

At higher wind speeds the effect of temperature is noticeable for both wildlife and plankton impacts. Wildlife impacts vary considerably ranging from less than 1,000 km^2 at 25º C to over 2,800 km^2 at 15º C (Figures A.16-A.18). At higher temperature, the oil evaporates more quickly, as well as being less viscous and more easily entrained by wind-driven waves, reducing the area of impact. Plankton impacts follow the general trend of smaller impacts at cooler temperatures and longer weathering times.

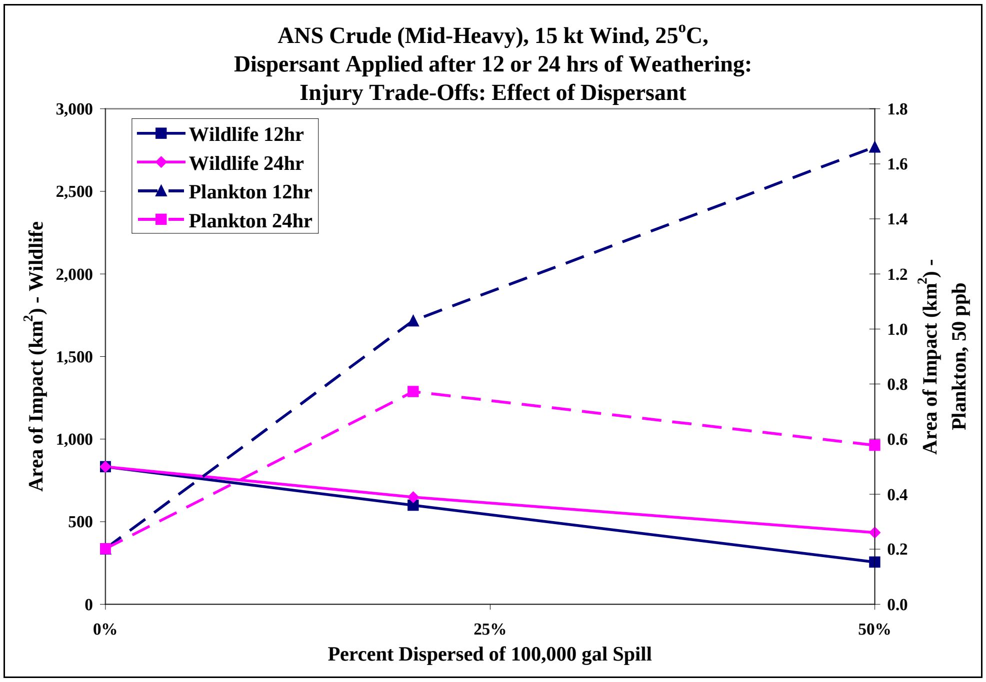


Figure A.16. Area impacted versus percent dispersed for Alaskan North Slope crude under 15 kt winds and 25º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

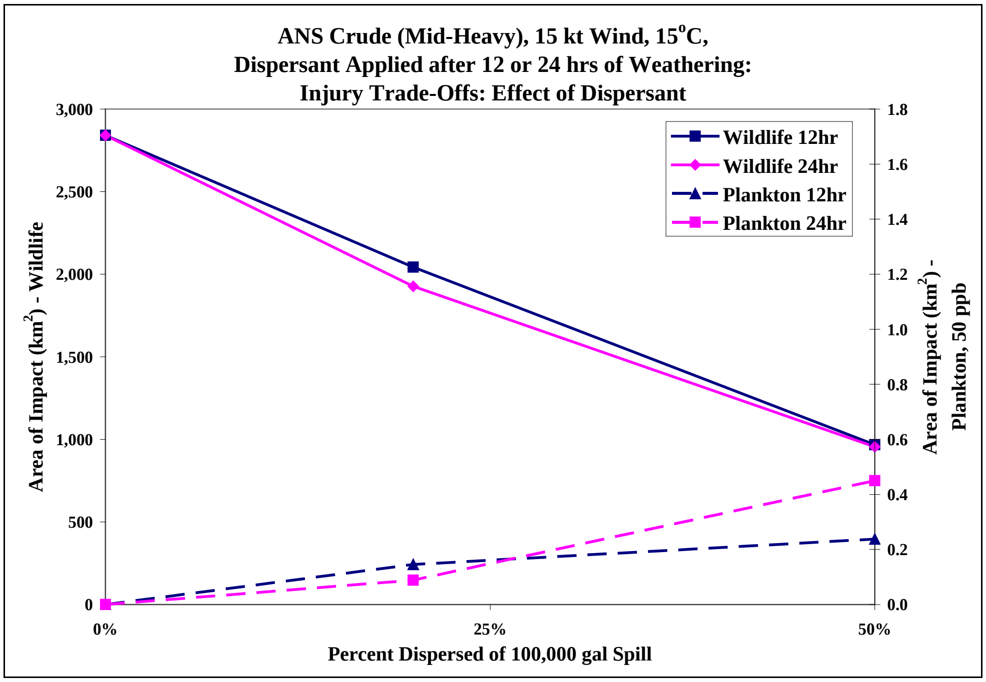


Figure A.17. Area impacted versus percent dispersed for Alaskan North Slope crude under 15 kt winds and 15° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

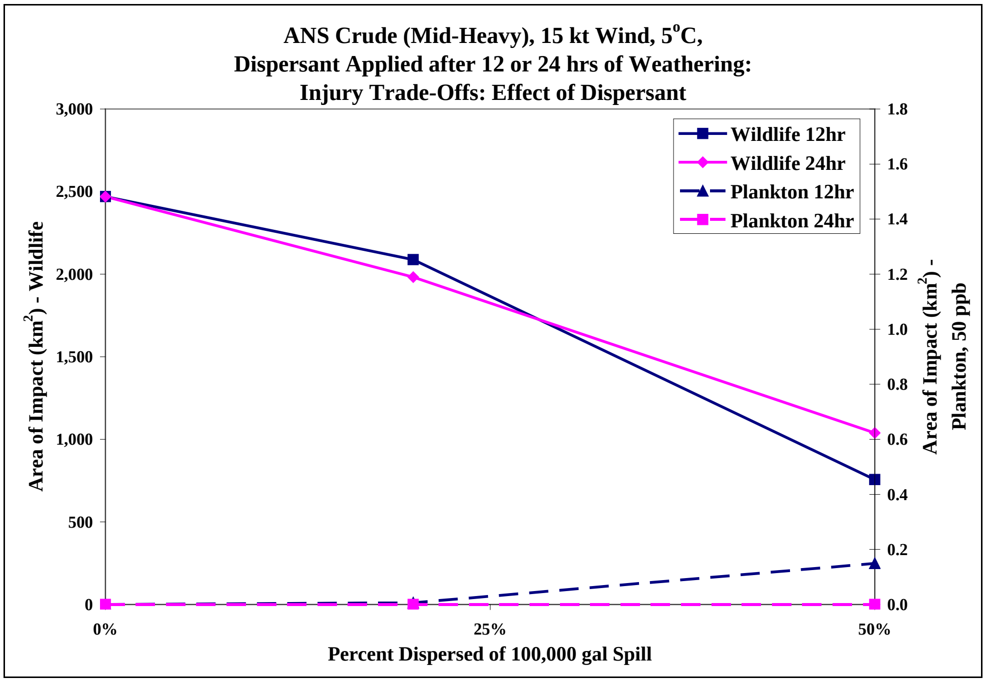


Figure A.18. Area impacted versus percent dispersed for Alaskan North Slope crude under 15 kt winds and 5° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

A.2.2 50,000 Gallon Spills

Spills of a smaller volume of the heavier oil have similar impact trends to those described for the larger spills (Figures A.19-A.24). Total impacts are reduced but not proportionally to the volume spilled.

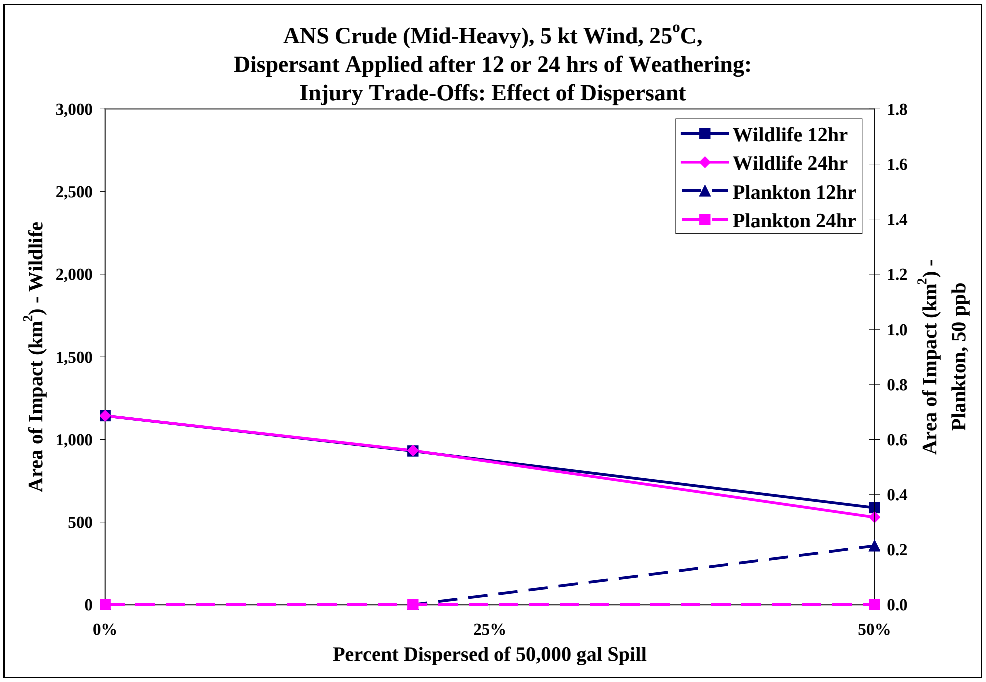


Figure A.19. Area impacted versus percent dispersed for Alaskan North Slope crude under 5 kt winds and 25° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

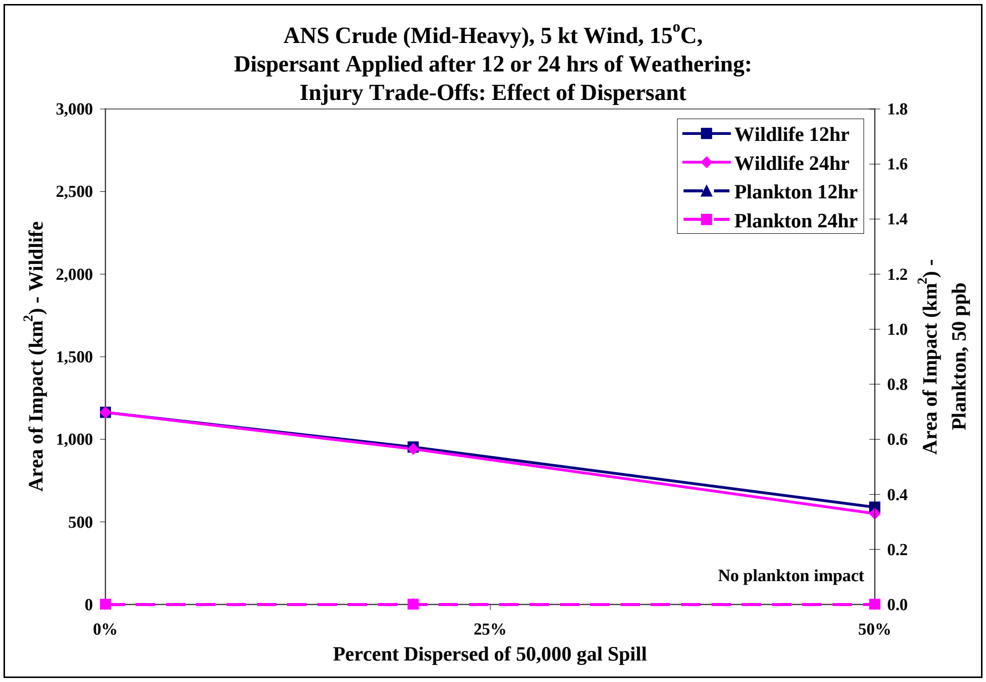


Figure A.20. Area impacted versus percent dispersed for Alaskan North Slope crude under 5 kt winds and 15° C. The swept area of impact is that where a lethal dose would affect

wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

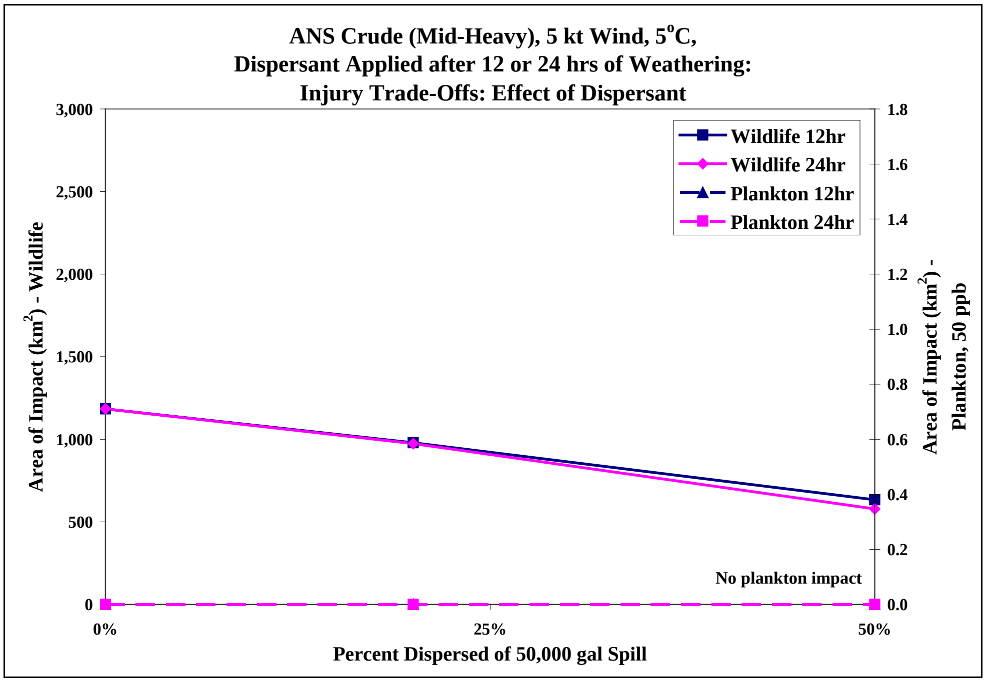
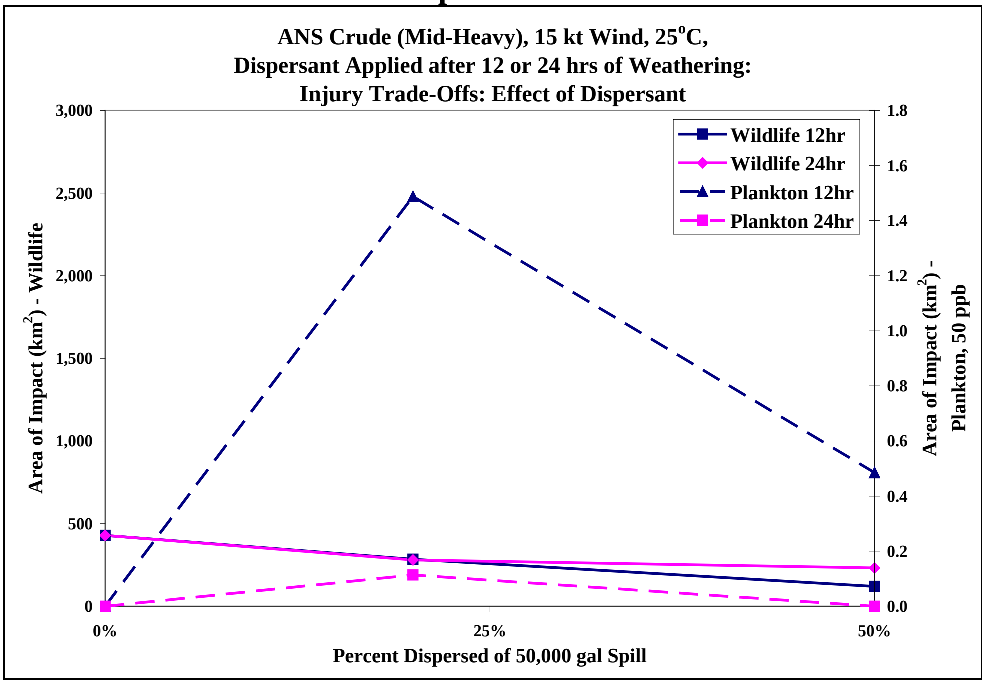


Figure A.21. Area impacted versus percent dispersed for Alaskan North Slope crude under 5 kt winds and 5° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.



**Peak in impact for Plankton at 12 hours is a result of variability in the model.

Figure A.22. Area impacted versus percent dispersed for Alaskan North Slope crude under 15 kt winds and 25° C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

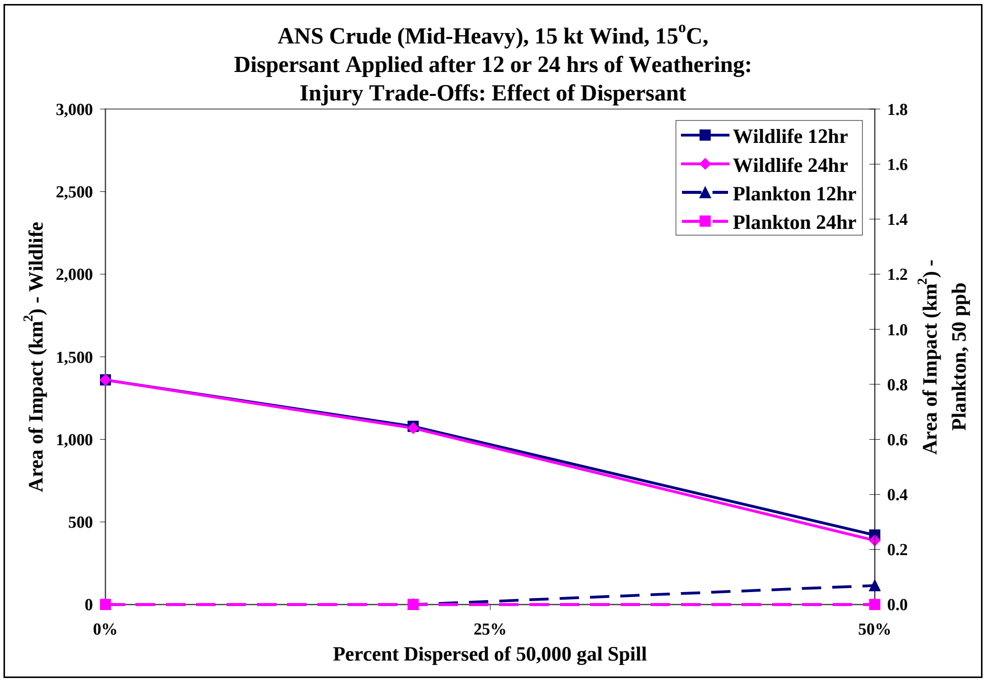


Figure A.23. Area impacted versus percent dispersed for Alaskan North Slope crude under 15 kt winds and 15º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

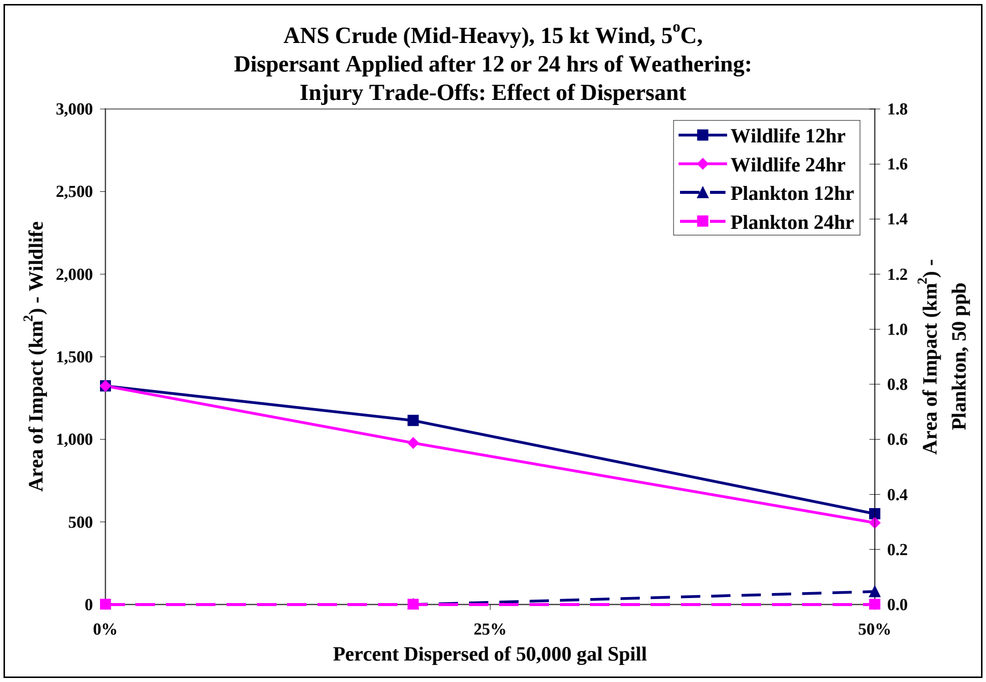


Figure A.24. Area impacted versus percent dispersed for Alaskan North Slope crude under 15 kt winds and 5º C. The swept area of impact is that where a lethal dose would affect wildlife (left axis) and average species (LC50 50 ppb) in the water column (right axis), if present.

Appendix B. Biological Impacts for 100,000 gal Spills

The biological impacts estimated for 100,000 spills in 5 kts of wind, assuming no dispersant, 20% of the oil dispersed, and 50% of the oil dispersed at 12 hours (a worst case) after the release are summarized in Tables B.1 to B.12. The LC50 for the average species (50 ppb) in the water column is assumed, as in any location one would expect a mix of species of varying sensitivity, averaging about this level. This data provides an indication of the species included in the analysis for each of the 6 biological data sets representing various coastal regions of the US, as well as the magnitude of the impacts by species group. Note that for the fish and invertebrates listed, impacts may include direct exposure to early life history stages that are planktonic, and/or older age classes of individuals that could be present in surface waters.

Table B.1. Wildlife impacts (number oiled and killed) for 100,000 gal spills in the Atlantic coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Wildlife Species	No Dispersant	20% Dispersed	50% Dispersed
Common loon	1,393.37	1,147.35	725.34
Black-leg. kittiwake	3.69	3.03	1.91
Bonapartes gull	109.76	90.23	56.88
Bridled tern	0.00	0.00	0.00
Common tern	21.71	17.85	11.25
Elegant tern	0.02	0.02	0.01
Forster's tern	12.39	10.18	6.42
Gulls, general	21.21	17.44	10.99
Herring gull	354.18	291.17	183.56
Jaegers, general	0.92	0.76	0.48
Laughing gull	16.60	13.65	8.60
Leach's storm-petrel	19.31	15.89	10.02
Least tern	10.40	8.55	5.39
Manx shearwater	0.92	0.76	0.48
Northern fulmar	46.12	37.91	23.90
Northern gannet	18.45	15.17	9.56
Parasitic jaeger	0.92	0.76	0.48
Phalaropes, general	7,328.75	6,034.75	3,815.12
Pomarine jaeger	1.84	1.52	0.96
Red phalarope	13,046.99	10,743.34	6,791.85
Red-necked phalarope	615.25	506.62	320.28
Ring-billed gull	16.60	13.65	8.60
Royal tern	18.54	15.24	9.61
Skuas	1.84	1.52	0.96
Sooty shearwater	3.69	3.03	1.91
Terns, general	13.41	11.03	6.95
Wilson's stormpetrel	3,894.67	3,203.49	2,021.36
Total	**26,971.57**	**22,204.89**	**14,032.89**
Waterfowl	1,393	1,147	725
Seabirds	25,578	21,058	13,308
Total	**26,972**	**22,205**	**14,033**

Table B.2. Fish and invertebrate impacts (number killed and biomass losses) for 100,000 gal spills in the Atlantic coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Fishery species	No Dispersant	20% Dispersed	50% Dispersed
Atlantic herring	0	0.01	0.04
Atlantic mackerel	0.17	34.07	401.59
Atlantic menhaden	0.03	5.94	74.86
Bigeye tuna	0	2.51	34.33
Bluefish	0.01	43.09	603.36
Swordfish	0	0.84	11.84
Yellowfin tuna	0	1.26	17.17
King mackerel	0	3.05	43.12
Red hake	0	3.39	47.96
Silver hake	0	2.39	33.84
Spanish mackerel	0	5.34	75.46
Spiny dogfish	0	48.42	685.66
Striped bass	0	17.50	247.40
Weakfish	0	13.02	184.10
White perch	0	0.92	12.96
Black sea bass	0.01	1.12	13.78
Spot	0	0.08	0.77
American lobster	0	0.01	0.08
Blue crab	0.03	4.94	54.89
Rock crabs, general	0.03	6.04	98.25
Long-finned squid	0	23.02	325.40
Market squid	0	34.68	490.32
Total	**0.27**	**251.64**	**3,457.18**
Total small pelagic fish	0.2	40.02	476.49
Total large pelagic fish	0.01	199.43	2,812.92
Total demersal fish	0.01	1.20	14.55
Total demersal invertebrates	0.05	10.99	153.22
Total mollusks	0	0.00	0.00

Table B.3. Wildlife impacts (number oiled and killed) for 100,000 gal spills in the Gulf of Mexico coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Wildlife Species	No Dispersant	20% Dispersed	50% Dispersed
Brown pelican	1.80	1.55	0.90
Caspian tern	13.69	11.74	6.84
Common tern	13.51	11.59	6.75
Forster's tern	133.30	114.34	66.57
Herring gull	13.51	11.59	6.75
Laughing gull	1,839.16	1,577.53	918.47
Least tern	43.23	37.08	21.59
Olivaceous cormorant	675.81	579.88	337.98
Royal tern	244.08	209.36	121.90
Sandwich tern	195.44	167.64	97.61
Terns, general	6.39	5.49	3.19
White pelican	774.57	664.39	386.83
Leatherback turtle	1.80	1.55	0.90
Loggerhead turtle	12.61	10.82	6.30
Ridley turtle	0.18	0.15	0.09
Total	**3,971.54**	**3,406.77**	**1,983.90**
Seabirds	3,955	3,392	1,975
Reptiles	15	13	7
Total	**3,972**	**3,407**	**1,984**

Table B.4. Fish and invertebrate impacts (number killed and biomass losses) for 100,000 gal spills in the Gulf of Mexico coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Fishery species	No Dispersant	20% Dispersed	50% Dispersed
Anchovies, general	0	0.04	0.12
Bay anchovy	0	1.22	17.06
Gulf butterfish	0	0.09	0.27
Harvestfish	0	0.01	0.02
Gulf menhaden	0	0.27	0.82
Spanish sardine	0	0.03	0.09
Scaled sardine	0	0.15	0.47
Thread herrings	0	0.01	0.02
Batfish	0	868.44	2,136.34
Frogfish	0	73.32	180.38
Jacks, general	0	58.54	144.01
Amberjacks = Kahala	0	6.14	16.20
Atlantic moonfish	0	149.01	366.57
Atlantic bumper	0	149.01	366.57
Scads	0	1,221.63	3,005.17
Marlin, spearfish	0	0.16	0.39
Swordfish	0	1.26	3.11
Large sharks	0	24.06	59.19
Tunas	0	0.38	0.92
Bluefin tuna	0	0.58	1.61

Yellowfin tuna	0	24.40	60.03
Bigeye tuna	0	0.19	0.46
Southern hake	0	264.73	665.08
Hakes (similar)	0	29.76	74.76
Cobia	0	2.59	6.82
King mackerel	0	9.93	24.95
Spanish mackerel	0	83.83	210.61
Sea trouts, general	0	98.39	247.18
Spotted sea trout	0	420.19	1,055.67
Sand sea trout	0	2,014.19	5,060.35
Silver sea trout	0.01	28,887.43	72,575.13
Kingfish	0	348.45	875.43
Searobins	0	844.10	2,120.68
Horned searobin	0	272.14	683.72
Bighead searobin	0	269.84	677.92
Blackfin searobin	0	1,210.80	3,041.95
Mexican searobin	0	885.62	2,224.97
Snappers, general	0	462.61	1,162.23
Red snapper	0	4,294.41	10,789.02
Red bigeye	0	123.23	309.58
Black drum	0	0.00	0.00
Spot	0.01	5.43	77.70
Brown shrimp	0	0.00	0.00
Squid, general	0	0.12	0.30
Total	**0.02**	**43,106.72**	**108,243.88**
Total small pelagic fish	0	1.81	18.87
Total large pelagic fish	0.01	43,099.49	108,147.31
Total demersal fish	0.01	5.43	77.70
Total demersal invertebrates	0	0.00	0.00
Total mollusks	0	0.00	0.00

Table B.5. Wildlife impacts (number oiled and killed) for 100,000 gal spills in the California coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Wildlife Species	No Dispersant	20% Dispersed	50% Dispersed
Grebes, general	3,000.97	2,464.95	1,546.05
Loons, general	5,566.80	4,577.66	2,876.82
Scoters	2,598.25	2,134.16	1,338.57
Albatross, general	23.89	19.62	12.29
Alcids, general	5,517.49	4,531.97	2,842.51
Auklets	1,515.97	1,245.20	781.00
Brown pelican	4.63	3.80	2.38
Common murre	4,001.51	3,286.78	2,061.52
Cormorants, general	2,107.86	1,731.36	1,085.94
Fulmars	8.22	6.75	4.23
Gulls, general	1,537.33	1,262.07	790.86
Phalaropes, general	27,476.47	22,594.28	14,199.29
Shearwaters, general	3,033.21	2,490.10	1,560.42
Storm-petrels, gen.	12.52	10.29	6.45
Terns, general	5.95	4.88	3.06
Dolphins, general	0.40	0.33	0.21
Harbor porpoise	0.66	0.54	0.34
California sea lion	2.49	2.05	1.28
Harbor seal	0.23	0.19	0.12
Northern fur seal	16.88	13.88	8.71
Northern sea lion	0.45	0.37	0.23
Sea otter	212.28	174.49	109.58
Total	**56,644.52**	**46,555.73**	**29,231.88**
Waterfowl	11,166	9,177	5,761
Seabirds	45,245	37,187	23,350
Pinnipeds (seals)	20	16	10
Other mammals	212	174	110
Total	**56,645**	**46,556**	**29,232**

Table B.6. Fish and invertebrate impacts (number killed and biomass losses) for 100,000 gal spills in the California coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Fishery species	**No Dispersant**	**20% Dispersed**	**50% Dispersed**
Delta smelt	0.02	1.19	16.51
Longfin smelt	0.02	1.18	16.48
Pacific = N. anchovy	0.54	32.59	455.10
Pacific herring	0	0.12	0.35
Pacific sardine	0.01	0.30	4.22
Pacific=chub mackere	0.06	3.76	52.41
Jack mackerel	0.02	6,675.67	12,037.51
Greenlings, general	0	70.84	132.68
Lingcod	0	1,341.92	2,497.37
Pacific whiting	0.12	30,622.11	57,066.00
Rockfish, scorpionfi	0.47	29,044.41	54,382.55
Sablefish	0.19	9,022.80	16,927.39
Steelhead trout	0	994.02	1,851.86
Thornyheads	0.42	4,437.45	8,561.17
Drums, Croakers	0.84	50.35	703.89
Dungeness crab	0.05	2.96	41.42
Market squid	0.01	17,997.68	33,494.50
Sea urchins	0.06	3.58	53.84
Total	**2.83**	**100,302.94**	**188,295.25**
Total small pelagic fish	0.65	39.14	545.07
Total large pelagic fish	1.23	100,206.89	186,951.02
Total demersal fish	0.84	50.35	703.89
Total demersal invertebrates	0.11	6.55	95.26
Total mollusks	0	0.00	0.00

Table B.7. Wildlife impacts (number oiled and killed) for 100,000 gal spills in the Pacific Northwest (Washington) coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Wildlife Species	No Dispersant	20% Dispersed	50% Dispersed
Diving ducks, gen.	3,937.12	3,233.88	2,028.34
Goldeneyes	191.14	157.00	98.47
Grebes, general	57.15	46.94	29.44
Harlequin duck	301.02	247.25	155.08
Horned grebe	456.97	375.35	235.42
Loons, general	49.46	40.67	25.56
Mergansers, gen.	661.36	543.23	340.72
Oldsquaw	467.97	384.39	241.09
Pacific loon	8,484.51	6,976.93	4,384.63
Red-necked grebe	261.47	214.77	134.71
Red-throated loon	673.02	553.43	347.80
Scaups	2,447.51	2,010.34	1,260.91
Scoters	18,501.54	15,196.86	9,531.68
Western grebe	2,691.38	2,210.66	1,386.55
Alcids, general	19.77	16.24	10.19
Ancient murrelet	4.42	3.63	2.28
Arctic tern	0.11	0.09	0.06
Bonapartes gull	698.87	573.74	359.53
Brandt's cormorant	316.38	259.87	162.99
Common murre	569.02	467.38	293.15
Common tern	1.26	1.03	0.65
Cormorants, general	832.67	683.94	428.97
Dblcrested cormorant	470.15	386.17	242.21
Glaucous-winged gull	3,261.73	2,677.71	1,677.97
Gulls, general	334.01	274.21	171.83
Marbled murrelet	292.19	240.00	150.53
Mew gull	59.50	48.85	30.61
Murres, razorbills	24.19	19.87	12.46
Parakeet auklet	2,067.46	1,698.18	1,065.12
Pelagic cormorant	889.81	730.88	458.42
Pigeon guillemot	4,933.80	4,057.13	2,549.69
Rhinoceros auklet	2,938.62	2,413.73	1,513.93
Harbor seal	5.08	4.17	2.61
Sea lions, general	1.13	0.93	0.58
Total	**56,901.80**	**46,749.45**	**29,334.21**
Waterfowl	39,182	32,192	20,200
Seabirds	17,714	14,553	9,131
Pinnipeds (seals)	6	5	3
Total	**56,902**	**46,749**	**29,334**

Table B.8. Fish and invertebrate impacts (number killed and biomass losses) for 100,000 gal spills in the Pacific Northwest (Washington) coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Fishery species	No Dispersant	20% Dispersed	50% Dispersed
Pacific herring	2.53	1,998.73	7,330.58
Chum = keta salmon	3.2	1,979.16	7,221.70
Dogfish, general	0.05	41,493.42	92,502.22
Lingcod	0	1,367.35	2,930.68
Pacific cod	0.01	6,021.29	14,032.12
Pacific halibut	0	922.24	2,053.33
Rockfish, scorpionfi	0.13	6,054.63	13,126.52
Walleye pollock	0	3,707.17	7,945.67
Geoduck	0.85	650.46	2,384.36
Sea urchins	0.04	32.78	120.36
Total	**6.8**	**64,227.24**	**149,647.55**
Total small pelagic fish	2.53	1,998.73	7,330.58
Total large pelagic fish	3.39	61,545.26	139,812.25
Total demersal fish	0	0.00	0.00
Total demersal invertebrates	0.04	32.78	120.36
Total mollusks	0.85	650.46	2,384.36

Table B.9. Wildlife impacts (number oiled and killed) for 100,000 gal spills in Prince William Sound or Alaskan Pacific coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Wildlife Species	No Dispersant	20% Dispersed	50% Dispersed
Bufflehead	157.44	131.40	86.06
Common loon	59.03	49.32	32.36
Diving ducks, gen.	8.79	7.34	4.81
Goldeneyes	1,228.30	1,025.14	671.38
Grebes, general	72.48	60.49	39.62
Harlequin duck	874.56	729.92	478.04
Horned grebe	94.49	78.86	51.65
Loons, general	132.40	110.62	72.58
Mergansers, gen.	506.67	422.87	276.95
Oldsquaw	215.08	179.51	117.56
Pacific loon	16.03	13.39	8.79
Red-necked grebe	59.12	49.34	32.32
Red-throated loon	9.43	7.88	5.17
Scaups	42.14	35.17	23.04
Scoters	900.40	751.48	492.16
Sea ducks, general	96.64	80.65	52.82
Yellow-billed loon	5.28	4.41	2.89
Alcids, general	45.70	38.14	24.98
Aleutian tern	0.78	0.65	0.43
Ancient murrelet	30.06	25.09	16.43
Arctic tern	37.30	31.12	20.36
Black-leg. kittiwake	325.47	271.50	177.65
Bonapartes gull	7.86	6.55	4.29
Caspian tern	0.08	0.06	0.04
Cassin's auklet	0.40	0.34	0.22
Common murre	2,318.88	1,935.36	1,267.50
Cormorants, general	73.69	61.50	40.28
Dblcrested cormorant	18.92	15.79	10.34
Forktail. Stormpet.	646.73	539.76	353.50
Glaucous-winged gull	255.45	213.10	139.44
Gulls, general	58.05	48.43	31.69
Herring gull	4.81	4.01	2.62
Horned puffin	51.14	42.68	27.95
Jaegers, general	1.49	1.24	0.81
Kittlitz' murrelet	130.39	108.83	71.27
Long-tailed jaeger	0.26	0.22	0.14
Marbled murrelet	1,674.30	1,397.38	915.17
Mew gull	75.07	62.63	40.98
Murrelets	3,422.96	2,856.83	1,870.99
Murres, general	812.35	678.00	444.03
Northern fulmar	0.14	0.12	0.08
Parakeet auklet	19.46	16.24	10.64
Parasitic jaeger	0.98	0.82	0.54
Pelagic cormorant	330.24	275.62	180.51
Phalaropes, general	10.00	8.35	5.48
Pigeon guillemot	642.37	536.70	352.15
Pomarine jaeger	1.89	1.58	1.03
Puffins, general	4.70	3.92	2.57

Red-faced cormorant	0.27	0.22	0.15
Red-necked phalarope	820.41	685.45	449.75
Shearwater	0.21	0.18	0.12
Storm-petrels, gen.	0.54	0.45	0.29
Terns, general	1.51	1.26	0.82
Thick-billed murre	4.03	3.36	2.20
Tufted puffin	160.73	134.14	87.85
Harbor seal	8.21	6.85	4.48
Northern sea lion	6.07	5.07	3.32
Sea otter	2,275.55	1,900.46	1,246.11
Total	**18,758.31**	**15,658.25**	**10,257.69**
Waterfowl	4,478	3,738	2,448
Seabirds	11,990	10,008	6,555
Pinnipeds (seals)	14	12	8
Other mammals	2,276	1,900	1,246
Total	**18,758**	**15,658**	**10,258**

Table B.10. Fish and invertebrate impacts (number killed and biomass losses) for 100,000 gal spills in Prince William Sound or Alaskan Pacific coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Fishery species	**No Dispersant**	**20% Dispersed**	**50% Dispersed**
Pacific herring	0.01	0.30	0.76
Smelts, general	0.00	0.20	0.62
Chinook	0.00	0.13	1.79
Chum = keta salmon	0.00	7.60	108.96
Pink salmon	0.00	27.26	390.79
Sockeye	0.00	1.42	20.30
Greenlings, general	0.18	9.03	28.65
Pacific cod	0.00	54.58	747.17
Pacific halibut	0.00	295.22	4,046.04
Rockfish, scorpionfi	0.00	906.13	12,419.98
Sablefish	0.10	215.38	2,897.22
Walleye pollock	1.34	464.41	5,650.90
Dungeness crab	0.00	0.07	0.23
King crabs	0.00	0.06	0.20
Pandalid shrimp	0.00	0.08	0.26
Tanner = snow crab	0.01	0.35	1.15
Squid, general	0.00	2.73	37.46
Total	**1.65**	**1,984.95**	**26,352.50**
Total small pelagic fish	0.01	0.49	1.37
Total large pelagic fish	1.63	1,983.88	26,349.27
Total demersal fish	0.00	0.00	0.00
Total demersal invertebrates	0.01	0.57	1.85

Table B.11. Wildlife impacts (number oiled and killed) for 100,000 gal spills in the Chukchi Sea (Arctic) coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Wildlife Species	**No Dispersant**	**20% Dispersed**	**50% Dispersed**
Black-leg. kittiwake	96.16	80.22	52.49
Crested auklet	201.33	168.03	110.05
Glaucous gull	38.46	32.09	21.00
Horned puffin	67.11	56.01	36.68
Least auklet	67.11	56.01	36.68
Murres, general	3,019.91	2,520.45	1,650.77
Northern fulmar	38.46	32.09	21.00
Parakeet auklet	67.11	56.01	36.68
Ross gull	38.46	32.09	21.00
Bearded seal	0.73	0.61	0.40
Ribbon seal	0.31	0.26	0.17
Ringed seal	0.12	0.10	0.07
Spotted seal	0.35	0.29	0.19
Walrus	0.52	0.43	0.28
Polar bear	4.30	3.59	2.35
Total	**3,640.48**	**3,038.30**	**1,989.84**
Seabirds	3,634	3,033	1,986
Pinnipeds (seals)	2.0	1.7	1.1
Other mammals	4.3	3.6	2.4
Total	**3,640**	**3,038**	**1,990**

Table B.12. Fish and invertebrate impacts (number killed and biomass losses) for 100,000 gal spills in the Chukchi Sea (Arctic) coastal area. The dispersant application is assumed to occur at 12 hours after oil release.

Fishery species	**No Dispersant**	**20% Dispersed**	**50% Dispersed**
Capelin	0	0	0
Pacific herring	0	0	0.08
Chum = keta salmon	0	1.9	27.05
Arctic cod	0	2.26	32.36
Pacific halibut	0	15.63	223.66
Saffron cod	0	54.14	774.03
Walleye pollock	0	0.72	10.34
Total	0	74.66	1067.53
Total small pelagic fish	0	0	0.08
Total large pelagic fish	0	74.66	1067.45
Total demersal fish	0	0	0
Total demersal invertebrates	0	0	0
Total mollusks	0	0	0