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Some Thoughts on Estimating Change to Arctic Cod Populations from Hypothetical Oil Spills in the Eastern Alaska Beaufort Sea

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Running Header: Effects of oil spills on Arctic cod

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ABSTRACT

We describe a fecundity-hindcast model that incorporates Arctic cod *Boreogadus saida* acute toxicity data, field studies of Arctic cod larval distribution and abundance, natural mortality estimates for Arctic cod eggs and larvae, and an oil spill fate model in Alaska Beaufort Sea. Three orders of magnitude of spill events (1,000 tons, 10,000 tons, 100,000 tons) were evaluated for both physically and chemically dispersed oil. Using worst-case assumptions in our model, a 100,000-ton spill of crude oil treated with dispersants resulted in 266 million m$^3$ of water that exceeded our acute toxicity threshold, compared to a volume of 71 million m$^3$ for a 100,000-ton spill not treated with dispersants, and resulted in exposure of about 2 million Arctic cod larvae remaining from an initial 87 million eggs. This represents the reproductive output of about 7,300 adult females. Adult Arctic cod populations in the Alaska Beaufort number in the 10s to 100s of millions. The results show that even with an order of magnitude variation in exposure, the effect of dispersing a large oil spill on the regional cod population is expected to be insignificant (~0.7%). The recent hiatus in Arctic oil and gas development affords an opportunity to acquire additional data to further strengthen this conclusion.

**Key Words:** Alaska, Beaufort Sea, Arctic cod, oil spill impacts, natural mortality rates, ichthyoplankton, *Boreogadus saida.*
INTRODUCTION

Prior to 2015, the high price of oil resulted in an increase in exploration for oil and gas in the Beaufort and Chukchi seas of northern Alaska. In addition, exploration expanded into offshore areas outside the coastal margin where most previous oil and gas development had occurred. Licenses to operate in these regions require industry to develop adequate oil spill response capabilities, which usually include dispersants as an important response option for large offshore oil spills (NRC 2005). Dispersants reduce the surface tension of oil to allow formation of small droplets after a surface slick is subjected to wave energy or a subsea jet of oil is released into the water with high energy. This results in small droplets that are entrained in the water column and subjected to microbial biodegradation.

NewFields (2008) convened a panel of experts to identify critical gaps in knowledge regarding the use of dispersants in the Beaufort and Chukchi seas. The panel concluded that data on the relative toxicity of crude oil and dispersed oil to pelagic and epipelagic organisms in the Arctic were limited, and that additional toxicity data based on Arctic organisms tested under Arctic conditions were needed. This led to a toxicity research program as reported by Gardiner et al. (2013). The acute toxicity of physically and chemically dispersed crude oil was evaluated for three Arctic species—the copepod *Calanus glacialis*, juvenile Arctic cod *Boreogadus saida*, and larval sculpin *Myxoxcephalus* sp. All were tested under conditions representative of the Beaufort and Chukchi seas during the ice-free season. The ice-free season is relevant because it is when exploratory drilling will occur in the Arctic.

Toxicity data alone provide little insight into the environmental risk of an oil spill. However, toxicity data combined with the magnitude of a hypothetical spill, the abundance and distribution
of organisms exposed to the spill, and key vital development rates of the exposed organisms could be used to evaluate the effects of a hypothetical spill. However, the necessary data are seldom available, especially for most organisms characteristic of the Arctic region.

The motivation for this paper is to provide a demonstration of how the measured toxicity data for late-stage larvae and early juvenile stage Arctic cod combined with limited data on their abundance and distribution can be used to estimate the effects of hypothetical oil spills occurring on the central Beaufort Sea shelf during the ice-free season. Arctic cod exhibit a circumpolar distribution and are the most widespread and abundant fish species in the Chukchi and Beaufort seas (Morrow 1980; Lowry and Frost 1981; Parker-Stetter et al. 2011; Mecklenburg et al. 2011). Throughout its range it plays a central role in Arctic food webs by channeling a major fraction of the energy flow from plankton to other vertebrates, namely seabirds, marine mammals, and some fish (Bradstreet and Cross 1982; Craig et al. 1982; Bradstreet et al. 1986; Crawford and Jorgenson 1996). In all respects, it is a key species in Arctic ecosystems.

For fish such as Arctic cod, the planktonic life stages (eggs, larvae, early juveniles) are generally considered the most susceptible to oil spill effects because they have low mobility, restricted horizontal distribution, and shallow vertical distribution as compared to adults.

The general approach we used was to first measure the distribution and density of early-stage Arctic cod across the Beaufort Sea shelf during the ice-free season. The next step was to define oil spill scenarios describing the location of the spills, the meteorologic and oceanographic (metocean) conditions, the type of oil spilled, and the application of dispersants. Oil spill models were then used to determine the volume of water having oil constituent concentrations at or exceeding the 96-hour acute toxicity thresholds (concentrations lethal to 50% of the organisms,
called LC$_{50}$) determined by Gardiner et al. (2013). All larval Arctic cod that occurred within this volume of water were assumed to be lost to the system. This assumption provides a worst-case estimate of potential losses because the thresholds we chose resulted in lab-based mortality to only 50% of the organisms tested, but only after 96 hours of exposure. In contrast, we assumed 100% mortality after only 1 hour exposure to the toxicity thresholds that we used in this study.

The estimated losses were translated to egg equivalents using the fecundity-hindcasting approach described by Gallaway et al. (2007). Expressing the larval losses as egg equivalents enables the larval losses to be placed into a context of the number of females that would be required to generate this level of egg production. This number can be compared to estimates of the overall number of adult females in the population as a basis for evaluating the significance of the exposure.

The toxicity data for this study were provided by Gardiner et al. (2013) and the larval and early juvenile stage density data were obtained from Bongo-net surveys of the Alaska Beaufort Sea shelf conducted in August-September of 2011 (Norcross et al. 2017). Arctic cod collected in these surveys were measured and aged in days based on otolith microstructure. These data enabled estimates of hatch dates, growth, and mortality rates necessary for the assessment. The estimates were supplemented by information from the literature to conduct the assessment described below. We chose the maximum larval and early juvenile stage density data reported by Norcross et al. (2016) to provide additional conservatism for this evaluation.
METHODS

Oil Spill Scenarios

We assumed multiple scales of a spill event—1,000 tons, 10,000 tons, and 100,000 tons of Arctic North Slope crude oil (ANS). For perspective, 100,000 tons of ANS would equate to 600,000 barrels of oil (1 metric ton is about 6 barrels) which, considering there are 42 gallons of oil per barrel, equates to about 25 million gallons. A 10,000-ton spill would be on the order of 60,000 barrels (2.5 million gallons), and a 1,000-ton spill equates to 6,000 barrels or 250 thousand gallons. The location of the respective spills was defined as being the area having the highest density of Arctic cod as determined by the 2011 summer Bongo net surveys. We modeled two scenarios: physically dispersed oil and 100% chemically dispersed oil using COREXIT® 9500.

Gardiner et al. (2013) measured LC$_{50}$ values of 80 ppb PAH (polynuclear aromatic hydrocarbons) when Arctic cod juveniles were subjected to physically dispersed oil alone and 1,640 ppb PAH when subjected to oil plus dispersant (chemically dispersed oil). These were the LC$_{50}$ values for the breaking wave water accommodated fraction (BW-WAF) and the chemically enhanced water accommodated fraction (CE-WAF) described by Gardiner et al. (2013). However, much of the PAH in chemically dispersed oil is not dissolved but rather it resides within dispersed oil droplets, but acute toxicity is driven by the dissolved fraction. Thus, we estimated that the majority of the PAH in chemically dispersed oil resides in the dispersed oil droplets as opposed to being dissolved. The estimated fraction of PAH in dispersed oil was subtracted resulting in an LC$_{50}$ of 240 ppb dissolved PAH for the chemically dispersed scenario. PAH almost entirely resides in the dissolved form when dispersants are not used because very
few dispersed oil droplets are entrained in the water. So we used the 80 ppb PAH measured by Gardiner et al. (2013) for the physically dispersed scenario. The SIMAP™ Model (Applied Science Associates, Inc. 2011; French-McCay 2009) was used with these thresholds to determine the volume of water (m³) where Arctic cod larvae would be exposed. However, instead of assuming only half the larvae were removed from the water volume (consistent with the 96-h LC₅₀ measurements) we assumed 100% were removed, and we assumed that they were removed even if they were exposed for only one model time step (1 h) even though the thresholds were based on exposing Arctic cod larvae to PAH for 96 hours.

SIMAP™ considers the physical fate of spilled oil as influenced by processes such as evaporation, spreading, emulsification, entrainment, interaction with sediments, and dispersion. Ambient environmental conditions, including wind speed and direction, ocean current speed and direction, and temperature, were considered in predicting the volume of water containing PAH concentrations exceeding our chosen thresholds.

The model background conditions assumed a 15 kt constant wind from the NW for the entire period. Surface currents were wind driven and water temperature was assumed to be 5°C. The model provided maximum water concentrations of oil at any location by hour and was used to determine the water volume with a soluble PAH concentration that equaled or exceeded our chosen thresholds at any time.

COREXIT® 9500-Alone Scenarios

We also examined COREXIT® 9500-alone scenarios where, in one case, a C-130 aircraft accidentally and instantly dumps 5,000 gallons onto seawater at a point location where no oil is present. In the second scenario, a C-130 sprays 5,000 gallons of COREXIT® 9500 in 1 hour onto
a 10 km$^2$ area of seawater where no oil is present. In the third scenario, the C-130 sprays 5,000 gallons of COREXIT® 9500 in 1 hour onto a 4 km$^2$ area of seawater where no oil is present. The COREXIT® 9500 thresholds we used to estimate exposure volumes were based upon the Gardiner et al. (2013) studies. The envelope of 96-h LC$_{50}$ for COREXIT® 9500 spills ranged from about 25 to 35 ppb (Gardiner et al. 2013).

Field Sampling

An 81-station Bongo-net survey was conducted at depths of 13 to 183 m in the Alaska Beaufort Sea onboard the R/V Norseman II from 16 August to 3 September 2011 (Figure 1). These surveys were conducted by a team of scientists from the University of Alaska Fairbanks, the U.S. Bureau of Ocean Energy Management (BOEM), and the Alaska Department of Environmental Conservation. Larval and juvenile fish were collected using paired, 0.5-m Bongo nets with 505-µm mesh in the cod ends. The nets were deployed from the stern at a speed of approximately 40-45 m/min. The net was towed in a single oblique haul at 2 kts and fished from the surface to a maximum depth of 5-10 m above the bottom. Larval and juvenile fish were retained from one side of the Bongo net and preserved in 95% ethanol.

Laboratory Analysis

In the laboratory, Bongo net samples were rough-sorted and shipped to Université Laval, Quebec City, Canada for identification and otolith analysis. Larval and juvenile fish were issued an identification number and individually transferred to a 20-ml scintillation vial. Each individual was measured for its standard length (SL) and body width, and identified to species or lowest taxonomic level possible.
Upon identification, otoliths of all Arctic cod individuals were taken for daily aging. Lapilli were extracted and mounted separately on a microscopic slide with Crystalbond® thermoplastic cement (Fortier et al. 2006). Each otolith was ground on its medial side on 3-μm aluminum grit paper. Daily increments of the left lapillus (Figure 2) were enumerated and measured under a light microscope coupled to a camera and image analyzer system (Image-Pro Plus®). In some individuals, the left lapillus was damaged so the right lapillus was analyzed instead. The hatch date of an individual fish was determined by subtracting its age (in days) from its date of capture. The hatch-date frequency distribution of the young fish captured was tabulated by summing the number of fish hatched in the same 7-d period.

Fecundity Hindcasting

Following Gallaway et al. (2007), estimated larval and early juvenile losses were translated to egg equivalents, which can be placed into context by the number of females required to produce this level of egg production.

The calculation of egg equivalents (EE) is:

\[
EE = \frac{E}{\sqrt{SE}} + \frac{L}{SE \sqrt{SL}}
\]  
(1)

Where E is the number of eggs killed by the oil spill, L is the number of larvae killed by the oil spill, and SE and SL are the stage survival of the egg and larval stages, respectively.

RESULTS AND DISCUSSION

In total, 545 larval and juvenile fish were identified to species or the lowest taxonomic level possible from the samples collected in the Beaufort Sea during the ice-free season of 2011. These specimens represented a total of 19 taxa (Table 1). *Liparis gibbus* (22.6%), *Leptoclinus*
maculates (20.7%), Boreogadus saida (18.2%), and Myxocephalus sp. (13.8%) represented 75% of the total catch. In total 99 Arctic cod (B. saida) individuals were identified in the collections.

Abundance

Small Arctic cod were patchily distributed across the study area with the highest concentrations occurring in the eastern portion (Figure 3). As sampling was not conducted in shallow (< 13 m) nearshore zones and abundances were similar across the depths sampled, we can only evaluate east-west differences. Maximum observed density was on the order of seven Arctic cod per 1,000 m³.

Size, Age, Growth, and Mortality

Most of the Arctic cod collected for this analysis were in the late larval to early juvenile stage, from about 15 to 55 mm SL (Figure 4). The hatch data of Arctic cod sampled during the 2011 survey ranged from early January to mid-June with a peak at the end of April (Figure 5). Spawning of Arctic cod in this region is thought to take place from October to March, usually in January and February (Morrow 1980). Age at maturity is typically 2–3 years (Kent et al. 2016). They average about 12,000 eggs per female with a range of 9,000 to 25,000 (Morrow 1980; Graham and Hop 1995). The eggs are the largest of any gadid, and, when combined with the small size of Arctic cod, show that the fecundity of this species is low. The observed age-length relationship (Figure 6) suggests a growth rate of about 2 mm/d.

We observed a distinct mortality/dispersion phase for fish older than 110 days (Figure 7). Arctic cod between 110 and 235 d in age were lost due to mortality or dispersion out of our sampling area at a rate of 2.2% per day. This is a particularly high rate of loss attrition (mortality + dispersion) for this age group.
Comparison to Previous Studies

Tarbox and Moulton (1979) sampled larval Arctic cod during the same season using paired 0.5-m Bongo nets with 505-µm mesh (similar to our gear) at six stations in a very nearshore area (< 10 m deep) off Prudhoe Bay, Alaska in the central Alaska Beaufort Sea. Our growth rates were about the same as they observed (1.9 mm/d vs. 2.0 mm/d) but our August/September abundance level (7 cod per 1,000 m$^3$) was considerably lower than the average density they observed in the nearshore area (58 cod per 1,000 m$^3$). The abundance level differences could be attributable to any of an array of factors, e.g. proximity to shore, year class strength, annual environmental differences, etc.

Our peak hatch date (end of April) was earlier than the mid-July peak hatch date estimated by Tarbox and Moulton (1979) for fish present in the nearshore zone in August 1979. The mean length of Arctic cod we captured in offshore areas during August–September was 28.7 mm SL, as compared to Arctic cod mean lengths of 9.8 mm total length (TL) in mid-August and 11.7 mm TL in late August in the nearshore zone (Tarbox and Moulton 1979). Lastly, our estimated mortality/dispersion rate (2.2% per day) was much higher than a mortality rate of 0.9% per day estimated from Tarbox and Moulton’s (1979) length frequency and abundance data. The observed differences could result from many factors (i.e., annual differences, differences in sampling protocol, etc.) or they may reflect habitat use or habitat quality differences.

Our data suggest, based on peak hatching date, that most of the Arctic cod were representatives of a spring cohort (April) which appeared to be characterized by low abundance and high mortality (or dispersion into other habitats). Our estimated mortality rate for individuals >100 d old (2.2%/d) was higher than the values reported by Lafrance (2009) in the southeastern
Beaufort Sea in 2004. In that study, the mortality rate for individuals age >120 d was so low it could not be quantified. The Tarbox and Moulton (1979) data suggest that most of their fish were representatives of a summer cohort (July) and even though the fish were smaller and younger than the cod we collected, their apparent attrition rate appeared much lower than we observed.

Fortier et al. (2006) observed the presence of both spring (May-June) and summer (June-July) cohorts of Arctic cod in the Northeast Water Polynya (Greenland Sea). The spring cohort almost completely vanished by age 10 d, while the summer cohort survived well and dominated the August collections. Similar cohort production is suggested as a possible explanation for the differences between our study and that of Tarbox and Moulton (1979).

Life History Schedule

The first step in the assessment was to develop a schedule depicting life history stages, stage duration in days, daily mortality rate, and total mortality by stage. The first stage is defined as eggs. Arctic cod spawn under the ice in winter and the eggs rise to the ice-water interface (Graham and Hop 1995). Incubation time is temperature dependent and is presumed to range from 29 to 90 d (Rass 1968; Sakurai et al. 1998; Graham and Hop 1995; Kent et al. 2016). In our study, peak hatch occurred at the end of April. According to Morrow (1980) and Craig et al. (1982), spawning in northern Alaska usually occurs in January and February. This suggests a 90-d incubation period. At a water temperature of -1.5°C, total mortality for Arctic cod eggs was estimated from laboratory studies to be about 60% over a 90-d incubation period (Sakurai et al. 1998).

Based on the information presented above we conclude that two larval stages were needed. For early larvae (1 to 30 days in age), we use a mortality/dispersion rate of 13.9% per day
(Fortier et al. 2006) as the best estimate. A daily mortality rate of 0.139 over 30 days yields a total instantaneous “mortality” of 4.17. For the balance of the first year (245 d) we first used the mortality/dispersion rate from this study (0.022) to obtain a total mortality for late stage larvae/juveniles of 5.39. Collectively, then, the total mortality of Arctic cod for the first year was 10.16 (0.6 for eggs plus 4.17 for early-stage larvae plus 5.39 for late-stage larvae).

A total mortality rate of 10.16/yr would equate to a survival rate of 0.00004. If this were true, it would take about 25,846 eggs to yield a single 1-yr old Arctic cod. Given an average fecundity of 12,000 eggs/female, two females would be required to produce a single 1-yr old fish. Even if average fecundity was 25,000 eggs, the estimated mortality rate would, in our opinion, remain suspect. Thus, a mortality rate of 10.16/yr is not a credible value. The mortality/dispersion rate we observed for Arctic cod in offshore waters is likely due more to dispersion into nearshore areas used as nursery areas rather than mortality.

Examination of abundance declines for the dominant larval cohort in the nearshore region of Prudhoe Bay in August 1979, as reported by Tarbox and Moulton (1979), suggests a 91.3% survival rate over a 10-d period. This equates to a daily mortality rate of 0.0091 which, over a 245-d period, yields a total mortality estimate of 2.2288. A low mortality rate is consistent with the observations of Lafrance (2009). Using this value suggests a total mortality of 6.9988 (0.60 for eggs plus 4.17 for early stage larvae plus 2.2288 for late stage larvae). This yields a survival rate of 0.000913; 1,095 eggs would be required to produce a single one-year-old fish. Using the average fecundity value, a single female would produce about 11 one-year-old fish. We adopted this life history schedule as being the most reasonable of our alternatives.
Estimated Oil Spill Impacts

The oceanographic modeling for the physically dispersed scenario predicted that a 100,000-ton spill of ANS crude oil would result in a water volume of 71.1 million m$^3$ with concentrations equal to or higher than our exposure thresholds (Table 2). In contrast, the same spill treated with dispersant would result in a water volume of 266.1 million m$^3$ exceeding our exposure threshold.

Combining these volumes with our density data we estimate that a 100,000-ton spill treated with dispersants resulted in removal of 1.9 million larval/early juvenile Arctic cod. This equates to 87.2 million EEs, or the reproductive output of about 7,265 adult females, assuming an average fecundity of about 12,000 eggs per female. The same size spill but without dispersants would remove an estimated 517,608 larvae representing the reproductive output of 1,941 females (Table 2).

Untreated oil forms slicks that largely remain in the near-surface layer and are transported laterally by winds and currents. Wind and waves break up and drive some of the oil into the water column in relatively large globules. In contrast, the application of dispersants to oil rapidly transports large quantities of the petroleum into the water column, which reduces exposure of marine birds, marine mammals, and other animals living at or near the air-water interface. However, animals living in the water column (especially those with limited mobility like ichthyoplankton) are subjected to higher exposure concentrations than would occur if dispersants were not used.

The potential that the reproductive outputs of up to 7,000 adult female Arctic cod would be required to replace the estimated losses of eggs and larvae associated with a large oil spill raises the issue of how many adult Arctic cod live in the region. Parker-Stetter et al. (2011) estimated
an average of 3.3 billion age 1+ Arctic cod were present in the U.S. Beaufort Sea in 2008. Based on the mean ±1 SD, the range was from 2.3 to 4.3 billion fish. Age-1+ Arctic cod were more abundant in the 100- to 500-m depth range than in the 40- to 100-m depth range. Age-0 fish dominate in shallow, nearshore waters, from the shore to 40 m. The age-0 population estimate for the 20–40 m depth was 1.967 billion cod and the estimate for the 40–100 m depth was 1.608 billion cod. In the 100–500 m depth zone, the population estimate for age-0 cod was 1.212 billion. Parker-Stetter et al. (2011) estimated a total of 4.8 billion age-0 fish were present in the Alaska Beaufort Sea in 2008. Overall, Parker-Stetter et al. (2011) estimated the total Arctic cod population in the western half of the U.S. Beaufort Sea to be about 8 billion fish.

Crawford and Jorgenson (1996) documented two aggregations of adult Arctic cod in Lancaster Sound, Canada each totaling over 900 million individuals. Welch et al. (1993) reported schools of adult Arctic cod in the Barrow Strait region in the eastern Canadian Arctic consisting of some 400 million individuals. Based on the estimates for age-1+ Arctic cod (2 to 4 billion) and observations elsewhere describing the numbers of adult Arctic cod in spawning aggregations, it seems reasonable to assume that adult Arctic cod in the Alaskan Beaufort Sea number in the 10s if not 100s of millions.

Estimated Dispersant Spill Impacts

Gardiner et al. (2013) provide information showing the 96-h LC50 envelope for COREXIT® 9500 spills ranged from about 25 to 35 ppb. That concentration level was reached in only one of our scenarios—an instantaneous point release of 5,000 gallons. Even in that instance the 96-h LC50 level was exceeded at the point of release for only 1 to possibly 2 hours (Figure 8).
CONCLUDING REMARKS

In this paper we describe an approach showing how toxicity data, oceanographic modeling, and even very limited biological data (relative abundance and distribution, vital rates) can be integrated to provide an assessment of hypothetical oil spill effects in Arctic habitats. Our predictions have significant uncertainty because relative abundance and density approximation of Arctic cod larvae were based on a single year’s observations, as were the vital rate estimates. Multiple years of observations are needed to evaluate the veracity of our results. Such data were not available at the time of our studies, nor are they available now. Considering that we used the very conservative assumptions that Arctic cod larvae/eggs only required 1 hr of exposure to be removed and that spills happened in the most densely populated regions measured by Norcross et al. (2016), our estimate of only 7,300 adult female Arctic lost to the population for our largest spill scenario might be on the high end of the uncertainty range. However, if we assume that actual losses were ten times higher (73,000 adult females), this is still a small fraction of a population that could be in the 10s to 100s of millions.

Lower prices for crude oil and the disappointing findings from recent exploratory drilling in the Chukchi Sea provide an opportunity for additional data collection that could reduce uncertainty in the modeling we used. Scientific efforts could capitalize on the hiatus by gathering sufficient integrative baseline information to better evaluate the potential impacts of future development.

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The slope of the regression fitted to the 110–235 d age interval (\(\ln\) catch = -0.022*age + 5.293, \(R^2 = 0.825\), \(p < 0.0001\)) was used to estimate the rate of loss of juveniles due to mortality and dispersion out of the sampling area.

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\[
y = 0.1916x + 2.1182 \\
n = 90 \text{ (2 outliers removed)} \\
R^2 = 0.744
\]
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<table>
<thead>
<tr>
<th>Family</th>
<th>Taxa</th>
<th>Number</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
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<td>Leptoclinus maculatus</td>
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<td>Cottidae</td>
<td>Gymnocaanthus tricuspis</td>
<td>13</td>
<td>2.40%</td>
</tr>
<tr>
<td>Agonidae</td>
<td>Aspidophoroides olrikii</td>
<td>11</td>
<td>2.00%</td>
</tr>
<tr>
<td>Gadidae</td>
<td>Gadidae (Unidentified)</td>
<td>10</td>
<td>1.80%</td>
</tr>
<tr>
<td>Pleuronectida</td>
<td>Pleuronectida (Unidentified)</td>
<td>6</td>
<td>1.10%</td>
</tr>
<tr>
<td>Gadidae</td>
<td>Eleginus gracilis</td>
<td>4</td>
<td>0.70%</td>
</tr>
<tr>
<td>Cottidae</td>
<td>Icelus sp.</td>
<td>3</td>
<td>0.60%</td>
</tr>
<tr>
<td>Liparidae</td>
<td>Liparis fabricii</td>
<td>3</td>
<td>0.60%</td>
</tr>
<tr>
<td>Cottidae</td>
<td>Cottidae (Unidentified)</td>
<td>2</td>
<td>0.40%</td>
</tr>
<tr>
<td>Liparidae</td>
<td>Liparidae (Unidentified)</td>
<td>2</td>
<td>0.40%</td>
</tr>
<tr>
<td>Stichaeidae</td>
<td>Lumpenus sp.</td>
<td>2</td>
<td>0.40%</td>
</tr>
<tr>
<td>Ammodytidae</td>
<td>Ammodytidae (Unidentified)</td>
<td>1</td>
<td>0.20%</td>
</tr>
<tr>
<td>Stichaeidae</td>
<td>Stichaeidae (Unidentified)</td>
<td>1</td>
<td>0.20%</td>
</tr>
<tr>
<td>Cottidae</td>
<td>Triglopsis quadricornis</td>
<td>1</td>
<td>0.20%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>545</strong></td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Summary of estimated impacts of non-dispersed oil and oil spill dispersed with COREXIT® 9500.

<table>
<thead>
<tr>
<th>Spill Size (t)</th>
<th>Toxic volume (m³)</th>
<th>Number Larvae Killed</th>
<th>Egg Equivalents</th>
<th>Number Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>1K</td>
<td>300,000</td>
<td>2,184</td>
<td>98,289</td>
<td>8</td>
</tr>
<tr>
<td>10K</td>
<td>3,600,000</td>
<td>26,208</td>
<td>1,179,398</td>
<td>98</td>
</tr>
<tr>
<td>100K</td>
<td>71,100,000</td>
<td>517,608</td>
<td>23,294,398</td>
<td>1,941</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spill Size (t)</th>
<th>Toxic volume (m³)</th>
<th>Number Larvae Killed</th>
<th>Egg Equivalents</th>
<th>Number Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>1K</td>
<td>300,000</td>
<td>2,184</td>
<td>98,289</td>
<td>8</td>
</tr>
<tr>
<td>10K</td>
<td>65,700,000</td>
<td>478,296</td>
<td>21,524,204</td>
<td>1,794</td>
</tr>
<tr>
<td>100K</td>
<td>266,100,000</td>
<td>1,937,208</td>
<td>87,181,989</td>
<td>7,265</td>
</tr>
</tbody>
</table>