Texas City Y Oil Spill
Natural Resource Damage Assessment
Marine Mammal Injury Quantification

February 4, 2018

Natural Resource Trustees:
National Oceanic and Atmospheric Administration (NOAA)
U.S. Fish and Wildlife Service (USFWS)
U.S. National Park Service (NPS)
Texas Parks and Wildlife Department (TPWD)
Texas General Land Office (GLO)
Texas Commission on Environmental Quality (TCEQ)

Report Prepared By:

Liza Hernandez
NOAA NOS, Office of Response and Restoration, Assessment and Restoration Division

Lance Garrison
NOAA NMFS, Southeast Fisheries Science Center, Protected Resources and Biodiversity Division

Jenny Litz
NOAA NMFS, Southeast Fisheries Science Center, Protected Resources and Biodiversity Division

Erin Fougères
NOAA NMFS, Southeast Regional Office, Protected Resources Division

Table of Contents

1. Introduction

On March 22, 2014 the bulk carrier M/V *Summer Wind* and the oil tank-barge *Kirby 27706* collided in Galveston Bay near Texas City, Texas. As a result of the collision the #2 starboard tank of *Kirby 27706* was punctured, discharging approximately 168,000 gallons (4,000 barrels) of Intermediate Fuel Oil (IFO-380) into the Houston Ship Channel and state and federal waters of the Gulf of Mexico (GOM; Texas City Y Spill or the Spill). Within the first few days of the release, some of the oil came ashore impacting habitats and species along the Galveston Bay area. Much of the remaining surface oil traveled down the Texas coast and ultimately came ashore in areas as far south as Padre Island National Seashore in Corpus Christi, Texas. Overall, oil was observed on over 160 miles of shoreline, including salt marsh, sandy beaches, and mangroves.

The Department of Interior (DOI), as represented by the United States Fish and Wildlife Service (USFWS) and the National Park Service (NPS), the National Oceanic and Atmospheric Administration (NOAA) on behalf of the Department of Commerce (DOC), the Texas Commission on Environmental Quality (TCEQ), the Texas General Land Office (GLO) and the Texas Parks and Wildlife Department (TPWD) for the State of Texas are acting as the Natural Resource Trustees for the Spill (collectively, the Trustees). In coordination with the Responsible Party (RP), Kirby Inland Marine, LP (Kirby), the Trustees are conducting a Natural Resources Damage Assessment (NRDA) for the Spill.

The Trustees have identified numerous categories of impacted and potentially impacted natural resources, including marine mammals. This technical memorandum summarizes the Trustees' assessment of injury to marine mammals as a result of the Texas City Y Spill.

2. Known Impacts to Marine Mammals from Oil Exposure

The adverse impacts to marine mammals from exposure to oil are well-documented and well-known. They are documented in a variety of scientific studies, including studies following oil spill events, limited experimental exposure studies, and laboratory studies.

Historically, scientists have relied on studies conducted in the wake of the *Exxon Valdez* (EVOS) oil spill for information on the effects of oil spills on marine mammals. These studies have demonstrated that oil exposure can have profound impacts on the reproduction, health, and mortality of marine mammals (Lipscomb et al. 1993; Peterson et al. 2003; Matkin et al. 2008).

More recently, significant investigation has been conducted on the impacts to marine mammals from oil exposure in the wake of the *Deepwater Horizon* (DWH) oil spill. On April 10, 2010 the DWH oil spill occurred resulting in the largest marine oil spill in U.S. history. Estuarine, nearshore, and offshore waters of the northern GOM were contaminated with DWH oil, and marine mammals were observed swimming in oiled waters over several months. Significantly elevated polycyclic aromatic hydrocarbon (PAH) levels were detected in the coastal GOM waters, including in Louisiana, Mississippi, and Alabama. Following the spill, the effects of the DWH oil spill on marine mammals in the GOM were evaluated, with intensive DWH NRDA studies focused in Barataria Bay and Mississippi Sound. While the focus of the intensive efforts was on nearshore common bottlenose dolphin populations, the results served as case studies for extrapolating to coastal and oceanic populations that received similar or worse exposure to DWH oil.

The results of this evaluation provide strong evidence for adverse impacts of oil exposure on cetaceans, including increased mortality, increased reproductive failure, and a series of adverse health effects, including lung disease, adrenal disease, and poor body condition (Schwacke et al. 2014; DWH MMIQT 2015; Lane et al. 2015; Venn-Watson et al. 2015). Specifically, live common bottlenose dolphins in Barataria Bay demonstrated a high prevalence of abnormalities, including hypoadrenocorticism, a condition that, if left untreated in humans and companion animals, can be life-threatening, particularly when ill, stressed, or pregnant (Schwacke et al. 2014). When tissues of stranded carcasses were evaluated histologically, a high prevalence of adrenal cortical atrophy was noted, consistent with Schwacke et al.'s (2014) evidence of hypoadrenocorticism in live dolphins (Venn-Watson et al. 2015). Additionally, the live Barataria Bay dolphins also were more likely than dolphins from outside the spill area to have moderate to severe lung disease, consistent with studies and clinical reports of humans and animals exposed to oil via ingestion, inhalation, or aspiration. The Barataria Bay dolphins also experienced a higher prevalence of serum hepatobiliary abnormalities (i.e., liver malfunction), excessive tooth loss, and general poor body condition (Schwacke et al. 2014). The severe bacterial pneumonias found in the dead stranded dolphins are also consistent with the high prevalence of lung disease found in live dolphins (Schwacke et al. 2014), and while no significant difference was found in the prevalence of liver injury relative to the reference dolphins, liver lesions suggestive of oil exposure were observed in two of the dolphins stranded following the DWH oil spill (Venn-Watson et al. 2015). Lung disease may also be directly linked to reproductive failure and immunotoxicity can increase vulnerability to reproductive pathogens (Lane et al. 2015).

Additionally, because limited experimental exposure studies have been conducted on cetaceans, inferences about the impacts of oil exposure on cetaceans are commonly drawn from the results of laboratory studies on other marine mammals (e.g., pinnipeds) and surrogate mammalian species (i.e., mink) (reviewed in Englehardt 1983; Mazet et al. 2000; Schwartz et al. 2004; Mohr et al. 2008). The results of these experimental studies conducted on pinniped and mink suggest that, when exposed to oil, cetaceans will likely experience adverse health effects and possibly death.

For species that frequent or live in nearshore waters such as the common bottlenose dolphin, they may experience both acute and/or chronic exposure to oil mainly through inhalation of the volatile toxic compounds at the air-water interface, aspiration of oil at the water's surface, and through ingestion of contaminated prey, all of which pose a significant risk to the animal (Helm et al. 2015). These exposure pathways are discussed in detail in Sections 3.3.2 and 3.3.3., and as described above, acute exposure, particularly in the lungs, through inhalation or aspiration, could have both acute and chronic consequences.

3. Texas City Y Spill Marine Mammal Injury Assessment Background

The Trustees' assessment of the marine mammal injury resulting from the Texas City Y Spill focuses only on short-term or acute impacts to the common bottlenose dolphin (*Tursiops truncatus*; herein also referred to as bottlenose dolphin or dolphin). Specifically, the Texas City Y Trustees' marine mammal injury assessment examines increased mortality in common bottlenose dolphins in the oil impacted area during the 2 – 3 week period following the Spill (i.e., March 23 – April 12, 2014). To assess this increase in common bottlenose dolphin mortality resulting from the Spill, the Trustees evaluated the pathways and exposures of marine mammals to the Texas City Y oil, and conducted a statistical analysis of marine mammal stranding data for the common bottlenose dolphin over the approximate 160 miles over which oiling was observed along the Texas shoreline, for the 2 – 3 week period following the incident.

Because the Trustees' injury assessment only quantifies the acute adverse impacts suffered by the common bottlenose dolphin stocks in the oiled area, it is a conservative estimate of the injury to marine mammals resulting from the Texas City Y Spill, and does not include or otherwise account for a range of adverse long-term and/or chronic impacts likely caused by the Spill, including hypoadrenocorticism, reduced reproductive success, liver malfunction, and other well-known impacts caused by prolonged exposure. Further, because the Trustees have elected, at this point, to limit their marine mammal injury assessment to acute adverse impacts, questions raised regarding whether the duration of the injured dolphins exposure to the Texas City Y oil should affect the Trustees' injury determination are not relevant here.

3.1. Oil on Water Footprint for the Texas City Y Spill

The first step in the Trustees' marine mammal injury assessment was to determine the area off the Texas coast impacted by Texas City Y oil, in order to evaluate the geographic scope of the common bottlenose dolphin stocks impacted by the Spill. To determine the oil on water footprint of the Texas City Y Spill, the Trustees developed an estimated cumulative, area–swept footprint of surface oiling for the Texas City Y Spill using data collected during the response. The Trustees developed two footprints outlining the likely cumulative geographic extent of surface oiling. The "TCY Oil Exposure Observations Extent" footprint was based strictly on observational data and the "TCY Maximum Extent of Oil Exposure" footprint relied on observational as well as trajectory modeled data. The data sets used in the development of the oil on water footprint include the following and are depicted in Figure 1:

A. *Shoreline Cleanup and Assessment Technique (SCAT) Observations*

SCAT is a systematic method for surveying an affected shoreline following an oil spill. These data are collected during the spill response to provide information on shoreline oiling conditions in order to develop the objectives and strategies for cleanup operations. SCAT data provide a measure of the timing, spatial extent, and degree of oiling during a spill.

For this spill, coastal areas were oiled at various times, beginning on March 24, 2014. Final SCAT operations predominantly concluded at the end of April. Throughout this timeframe, SCAT teams surveyed shoreline from as far north as Goat Island, near Galveston Bay, to the southern end of Padre Island, Texas.

B. *Overflight Observations*

Between March 23 – April 4, 2014, overflights were conducted by NOAA, the U.S. Coast Guard (USCG), and Kirby/The Response Group (TRG) to assess the extent of the Texas City Y Spill. During overflights, specialists note the location of the oil, along with detailed observations about its appearance, areas of shoreline impact, oceanographic features that affect the movement of oil, as well as other information necessary for response efforts. They record this information in photographs and overflight maps of the area surveyed.

C. *NOAA Office of Response & Restoration's (OR&R) Oil Spill Trajectories*

GNOME (General NOAA Operational Modeling Environment) is OR&R's modeling tool used to predict a pollutant's trajectory, such as oil, in or on a body of water. Using wind, currents, and other relevant atmospheric and oceanographic information, combined with information on the oil's chemical and physical properties, this model is able to predict the oil's trajectory. It displays this forecast as an animation in which the oil is depicted as a swarm of dots, called "splots," each representing a portion of the volume of spilled oil. The splots are then used to map, in contours, four different forecasts: heavy, medium, light, and uncertainty. Each set of contours defines the density distribution of the model trajectory forecast:

1) Forecast areas of light oil concentrations at one percent of the maximum value for the distribution;
2) Forecast areas of medium oil concentrations at four percent of the maximum value for the distribution; and
3) Forecast areas of heavy oil concentrations at sixteen percent of the maximum value for the distribution.

During the Texas City Y Spill response, trajectory forecasts were developed from March 24 – 28, 2014 and reached as far south as Matagorda Island.

D. *National Environmental Satellite, Data and Information Services (NESDIS) Observations*

The NESDIS Operational Marine Pollution Surveillance Report (MPSR) and the Anomaly Analysis Composite are products of the NOAA Satellite Analysis Branch (SAB). SAB analysts manually integrate data from numerous imagery sources including Synthetic Aperture Radar (SAR) and high resolution visible imagery along with various ancillary data sources. The result is a quality-controlled display of the locations of possible detected oil on the surface of the ocean. These products are then used to provide surveillance support to oil spill responders working in the GOM.

During the course of the Texas City Y Spill response, only one NESDIS anomaly analysis was reported as satellites and specific sensors are not always available for specific geographic regions. The one NESDIS anomaly analysis during the response was analyzed on March 30, 2014 and depicted oil off East Matagorda Bay.

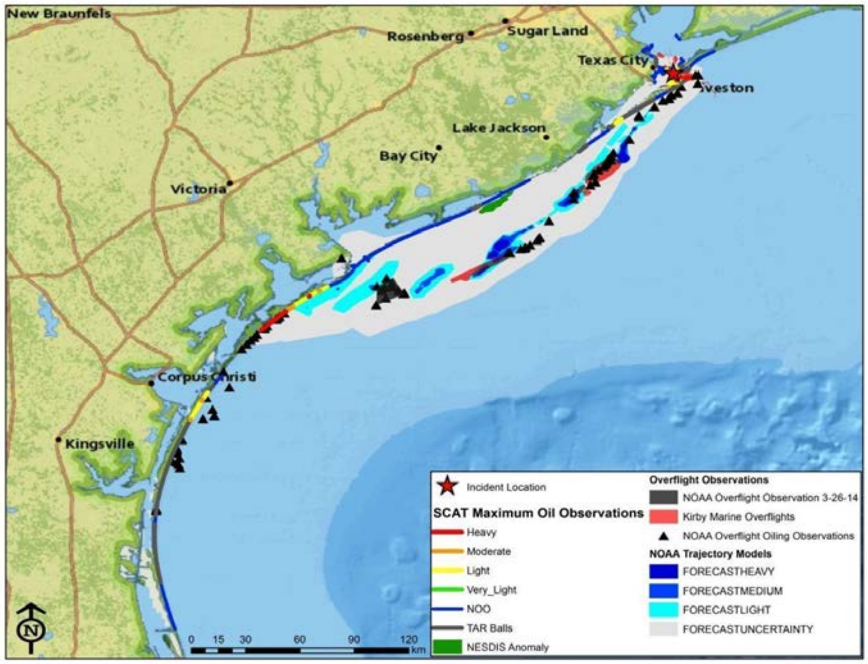


Figure 1. Data sources used to create the on-water, area-swept footprint of cumulative surface oiling.

3.1.1. Oil on Water Footprint Methodology

Next, to ascertain the area off the Texas coast impacted by Texas City Y oil, two estimated oiling footprints were developed from the data sources described above. Each footprint followed the same methodology but one footprint omitted the trajectories as an input. The data sources were first consolidated using the following steps in ArcGIS v10.4 (ESRI 2016):

1) All the trajectory forecast polygons were merged together, maintaining all four forecast categories (i.e., light, medium, heavy, and uncertainty).
2) All point-referenced and polygonal overflight observations were buffered by 1 kilometer (km) to account for the positional inaccuracy, transcription errors, and oil movement over fine spatial scales immediately before and after observation. The single observation inside Matagorda Bay was excluded from this analysis because the methods used here are not appropriate for reproducing on-water oiling footprints within complex tidal estuaries. Additionally, this single observation was determined to be an outlier as it appears over land and apart from all other oiling observations made on the overflight that was conducted along the coast.
3) Similarly, the single NESDIS anomaly polygon was also buffered by 1 km.
4) All oiled shoreline identified during SCAT surveys was buffered by 1 km offshore.
5) Finally, all polygons derived above were merged together.

The polygonal data sets were then used to generate two different (observation-only, and observation-and-trajectory data) on-water, area–swept footprints using alpha-shapes following these steps:

1) In ArcGIS, the merged buffered polygons were dissolved to a single data set, and were simplified to discard 99% of all vertices using the Visvalingam/Weighted Area method using Mapshaper (Harrower and Bloch 2006). The vertices of the simplified buffer polygons

were then converted to points.

2) A random sample of point locations was generated within the interior of the simplified buffer polygons at a density of 1 point per 4 square kilometer (km^2), equivalent to the approximate point spacing for the NOAA overflight point observations.
3) Boundary vertices and interior random sample were then merged together to form the set of points that represent observed oil on water observations. These sets consisted of 898 and 2,733 points for the merged buffer polygons from the observation-only, and observation-and-trajectory data, respectively.
4) The convex hull polygon for the set of all points was also generated, and a random sample of point locations was generated within the interior of the minimum convex hull at a density of 1 point per 4 km^2 yielding 4,956 points.
5) Using the R v3.3.1 statistical computing language (R Core Team 2016), the points were divided randomly into an equal size training and test set, and alpha-hull and alpha shapes were generated using the sp and alphahull packages (Pebesma and Bivand 2005; Pateiro-López and Rodríguez-Casal 2010) for the training set using a series of 30 different alpha values ranging from 0.01 to 10.
6) For each alpha value, true positives were computed as the proportion of the test set that were included in the alpha-hull polygon, and false positives as the proportion of a random set of background points generated at the same density (1 point per 4 km^2) within the convex hull polygon.
7) These two values were plotted as a Receiver Operator Characteristic (ROC) plot (Swets 1988) that indicated an alpha value of 0.24 yielded polygons that best distinguished between areas that include the observation points, and areas "outside" of the observation points, in that this value maximized true positives and minimized false positives. This value was the same for both observation-only, and observation-and-trajectory data.
8) This value was used to generate alpha shapes from the full set of points from both observation-only, and observation-and-trajectory data. The resulting polygons were converted to shapefiles and land areas were clipped out.

The result of the Trustees' work, shown in Figure 2, depicts the observation-only "TCY Oil Exposure Observations Extent" footprint and the observation-and-trajectory data "TCY Maximum Extent of Oil Exposure" footprint. The "TCY Maximum Extent of Oil Exposure" footprint was then used to determine the maximum geographic area of exposure for bottlenose dolphins adversely impacted by spilled Texas City Y oil.

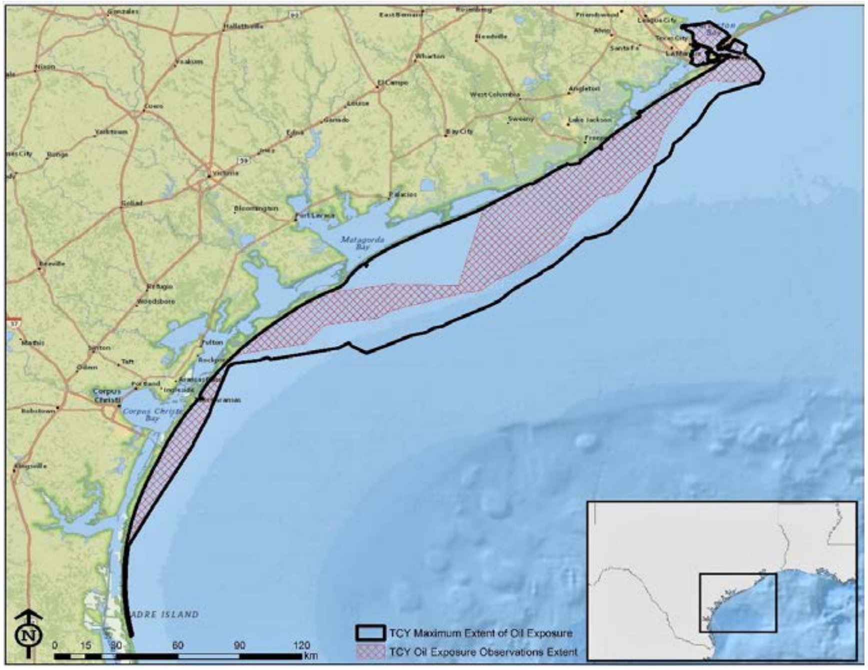


Figure 2. On-water, area-swept footprints of oiling. The "TCY Oil Exposure Observations Extent" footprint (i.e., the red hatched area) is 2,016 mi^2 (or 5,221 km^2) and was derived from observational data. The "TCY Maximum Extent of Oil Exposure" footprint (i.e., the black outlines area) is 3,406 mi^2 (or 8,821 km^2) and was derived from observation data and trajectory forecasts.

3.2. Common Bottlenose Dolphin Stocks in the Oil Spill Impacted Area

Once the extent of oiling had been evaluated, the Trustees next sought to determine the stocks of common bottlenose dolphins likely impacted by Texas City Y oil.

Common bottlenose dolphins can be found in aquatic habitats throughout the world. In addition to their broad geographic range, they can also be found in bays, sounds, estuaries (BSE), along nearshore coastal waters, over the continental shelf, and in deeper oceanic waters (Rosel and Mullin 2015). Two morphologically and genetically distinct forms of bottlenose dolphins—offshore and coastal—occur in the GOM and can be further separated into demographically independent populations, referred to as stocks (Rosel and Mullin 2015). In total, there are currently 36 stocks of bottlenose dolphins in the northern GOM. These include 31 BSE stocks in the inshore waters, 3 coastal stocks (inhabiting waters out to the 20 meter (m) depth), the northern GOM Continental Shelf Stock (inhabiting waters from 20-200 m depth), and the GOM Oceanic Stock (inhabiting waters >200 m depth) (Waring et al. 2013).

The delineation of distinct BSE stocks in the GOM was initiated by work in Sarasota Bay, Florida, and in bays in Texas that documented year-round residency of individual bottlenose dolphins in estuarine waters (Shane 1977; Gruber 1981; Irvine et al. 1981). Since these early studies, long-term (year-round, multi-year) residency has been reported for some individuals from nearly every site where photographic identification (photo-ID) or tagging studies have been conducted in the GOM, including Galveston Bay (Waring et al. 2013). Of the 31 BSE stocks present in the GOM, 7 are present in the oil spill impacted area off the Texas coast and were likely impacted by Texas City Y oil (see Figure 3).

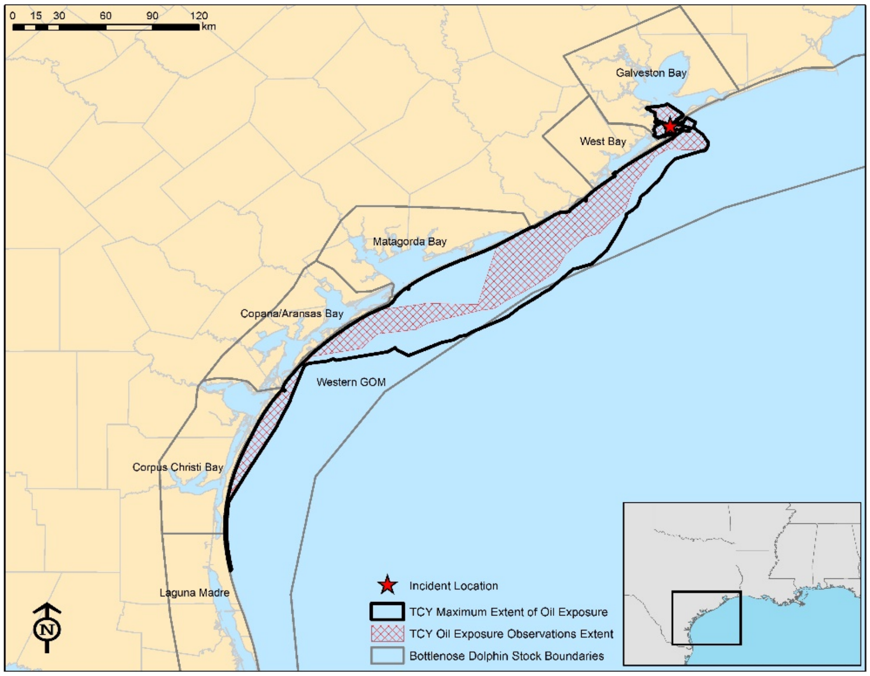


Figure 3. The range of the seven bottlenose dolphin stocks, as defined in annual stock assessments, that were likely impacted as a result of the Texas City Y Spill. The hatched red polygon represents the extent of oiling; the black outline represents the approximate maximum area of oil exposure.

3.3. Common Bottlenose Dolphin Exposure Pathways to Oil

As part of the Texas City Y Spill marine mammal injury assessment, the Trustees reviewed scientific literature and worked with experts from NOAA's National Marine Fisheries Service (NOAA Fisheries or NMFS) Office of Protected Resources (OPR; Silver Spring, MD), the Southeast Regional Office (SERO; St. Petersburg, FL), and the Southeast Fisheries Science Center (SEFSC; Miami, FL), as well as with Dr. Kathleen Colegrove[1] from the University of Illinois College of Veterinary Medicine, to determine the oil exposure pathways most likely to have resulted in common bottlenose dolphin exposure to Texas City Y oil.

Known direct pathways of oil exposure for marine mammals include ingestion, inhalation, aspiration, dermal contact, ocular, *in utero*, and lactation, each of which may result in a suite of adverse physiological responses (Colegrove 2013; Helm et al. 2015). The relevance of any given exposure pathway varies with the particular species at risk and types of oil compounds involved.

During the Texas City Y Spill, approximately 168,000 gallons (4,000 barrels) of IFO-380 was discharged into the Houston Ship Channel and state and federal waters of the GOM. This type of oil is dense and viscous, and spreads in thick slicks that are unlikely to disperse into the water column. It is persistent oil, meaning that only a very small fraction (i.e., 5-10%) is expected to evaporate within the first hours of a spill (NOAA Fact Sheet: No. 6 Fuel oil (Bunker C) Spills; available at http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/no-6-fuel-oil-

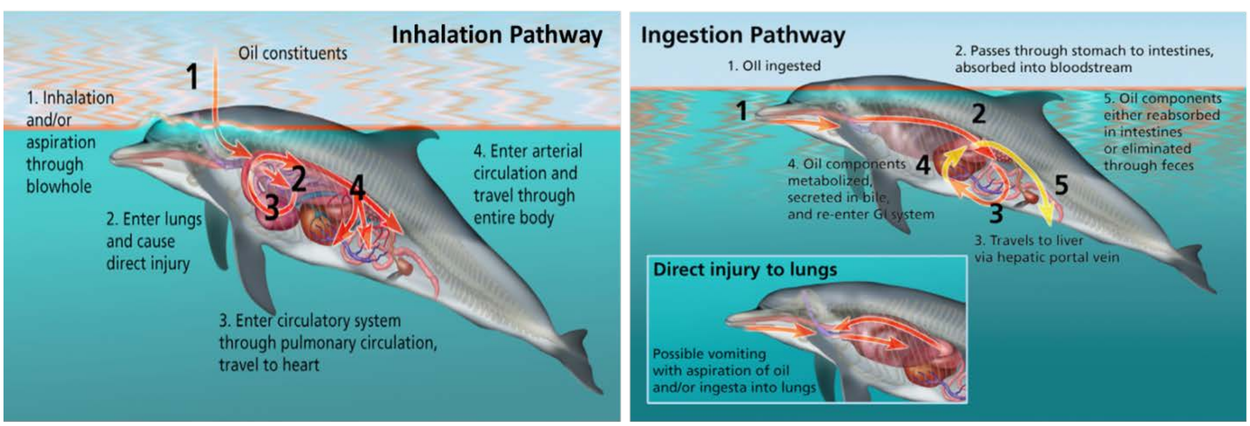
[1] Kathleen Colegrove, D.M.V., Ph.D., is a Clinical Associate Professor and head of the Veterinary Diagnostic Laboratory at the University of Illinois at Urbana-Champaign College of Veterinary Medicine in Urbana, Illinois. She performed the histopathology examination of the bottlenose dolphin tissue samples analyzed under the 2015 Sample Analysis Plan, which was submitted to Kirby on March 24, 2015.

spills.html). For these reasons, this type of oil is of particular concern to bottlenose dolphins, which spend time at the surface of the water, because these dolphins are likely to be directly exposed to the toxic volatile and aerosolized oil components, floating oil, tarballs, or tarmats via inhalation and aspiration. Bottlenose dolphins may also be exposed to oil via ingestion of contaminated water and prey as well as via direct contact with their skin and mucous membranes. Each of these exposure pathways could reasonably occur within a short timeframe and lead to acute impacts, which may ultimately result in animal illness and/or mortality (Venn-Watson et al. 2015; T. Rowles[2], personal communication, November 1, 2016).

3.3.1. Conceptual Model for Exposure Pathways

In coordination with NOAA's marine mammal experts and Dr. Kathleen Colegrove, the Trustees then worked to develop a conceptual model to evaluate (1) potential pathways and routes of exposure of bottlenose dolphins to Texas City Y oil, as well as (2) the likely adverse impacts to the dolphins as a result of this exposure (Figure 4). The model takes into account the fact that bottlenose dolphins in the nearshore waters of Texas experience a spring calving peak from February through April. Therefore, at the time of the Texas City Y Spill, which occurred in late March 2014, it is reasonable to expect that there would have been numerous later term pregnant females and/or newborn bottlenose dolphin calves in the nearshore and estuarine waters of Texas that were affected by the Spill. These dolphins are likely to be the most susceptible to oil exposure, since they spend increased time at the surface of the water, where they could be exposed through inhalation or aspiration of oil. Dolphins may also have been exposed by ingesting contaminated water, sediments, and/or prey, and as a result of contact between the spilled oil and the dolphins' skin and mucous membranes. Exposure, particularly in the lungs, through inhalation or aspiration, could have both acute and chronic consequences.

The primary exposure pathways likely to have affected bottlenose dolphins off the Texas coast after the Texas City Y Spill—exposure by inhalation, aspiration, and ingestion—are described in more detail below.



Images: K. Sweeney, DWH PDARP

[2] Teri Rowles, D.V.M, Ph.D., is the Marine Mammal Health and Stranding Response Program Coordinator with NOAA's Office of Protected Resources (OPR). OPR is a headquarters program office of NOAA's National Marine Fisheries Service based in Silver Spring, Maryland.

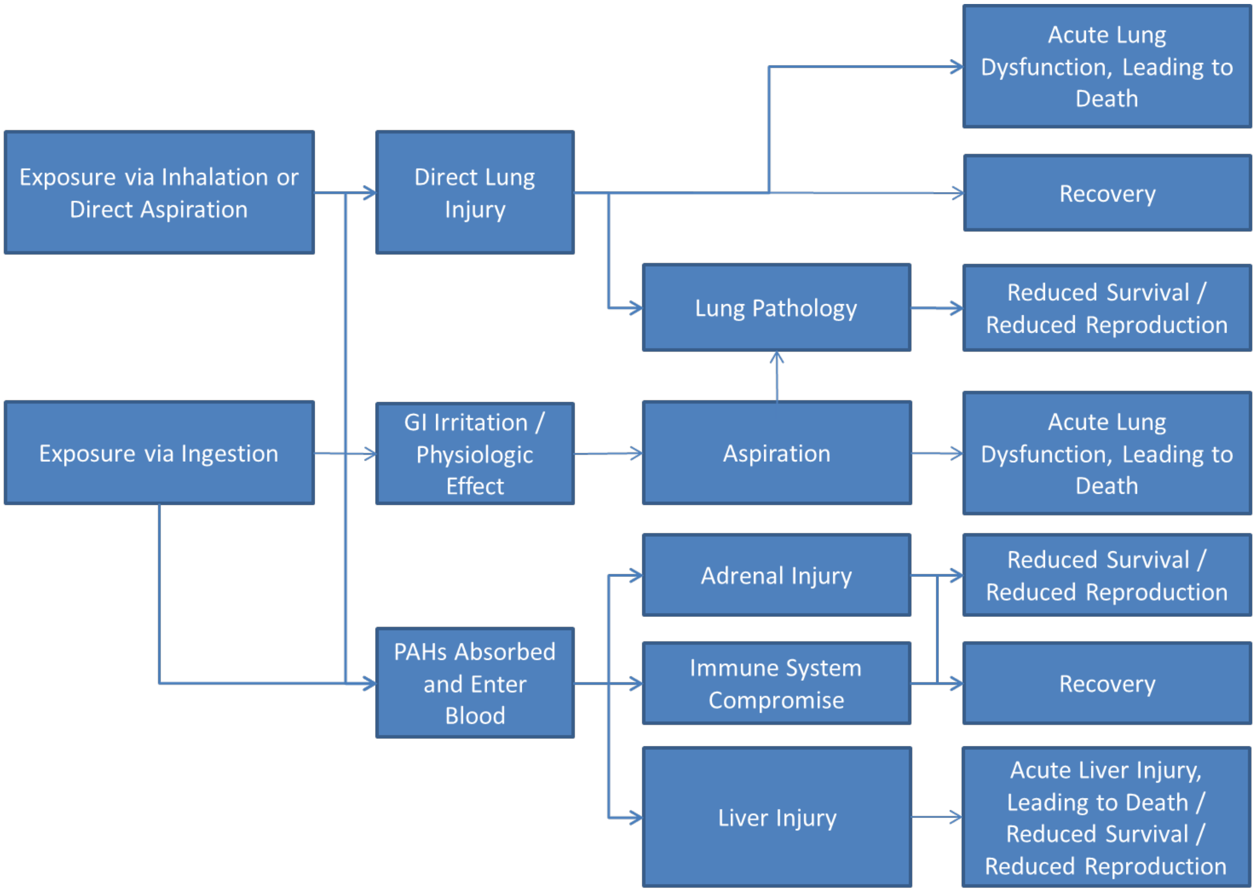


Figure 4. Conceptual model to support the Texas City Y marine mammal injury assessment.

3.3.2. Exposure via Inhalation or Direct Aspiration

When oil is released into the water and forms a surface slick, its chemical components escape and become available to marine mammals as volatile compounds (DWH NRDAT 2016). These same compounds may also become aerosolized via disruptions to the air-water interface, and through subsequent chemical transformations and coalescence (DWH NRDAT 2016). Since dolphins inhale and exhale through their blowhole at the air-water interface where volatile contaminants would be at their highest concentrations, the inhalation and direct aspiration exposure pathways are of particular concern.

When dolphins breathe at the surface of oil-contaminated waters, they risk aspirating volatile contaminants, oily water or droplets directly into their blowhole, through the larynx and trachea, and potentially into their lungs, resulting in physical and chemical injuries to the animal's exposed respiratory tissues (DWH NRDAT 2016). Severe inflammation and lung disease has been noted in cattle due to exposure of the respiratory tract to oil associated contaminants (Coppock et al. 1995; Coppock et al. 1996). Inhalation or direct aspiration may also create a pathway for the contaminant to enter into the animal's bloodstream and circulate throughout its entire body.

The severity of an injury from chemical inhalation is dependent on the breathing patterns of the animal. Thus, given the unique respiratory anatomy and physiology of dolphins and their requirement of inhalation at the air-water interface, oil exposure and lung injury to dolphins via inhalation may be greater than that of other mammals. Specifically, dolphins exchange 75-90% of deep lung air[3] and lack nasal turbinate structures designed to filter air prior to reaching the lungs. They also have deep inhalations followed by extended breath holds that provides potential for prolonged contact and exchange between air-borne particles and the blood (Venn-Watson et al. 2015). All of these factors result in a high likelihood of lung exposure and injury and facilitate the transport of inhaled contaminants into the blood, directly to the heart, and then throughout the body. Additionally, this exposure occurs without the blood first going through the liver, which is a major organ involved in metabolizing toxicants absorbed via ingestion.

3.3.3. Exposure via Ingestion

In the presence of oil, the likelihood of dolphins inadvertently ingesting oil from contaminated water, sediment, and/or prey can be very high. Once the oil enters the gastrointestinal tract, its components may be subsequently released into the bloodstream and taken up by the liver and metabolized (DWH NRDAT 2016). In addition, PAH exposure can lead to toxicity in the liver, which may cause significant liver injury (Lipscomb et al. 1993; Cullen 2007; Venn-Watson et al. 2015). The adrenal gland will also be exposed to oil components or metabolites from the bloodstream and may be a site for metabolism of circulating PAHs; thus, direct exposure to these contaminants and their metabolites can ultimately lead to impaired adrenal function (Venn-Watson et al. 2015). Adrenal injury was documented in both live and dead dolphins following the DWH oil spill (Venn-Watson et al. 2015). Exposure to oil via ingestion may also lead to reduced reproductive success as was observed in sea otters where population recovery has been notably slow post EVOS, as well as in bottlenose dolphin following the DWH oil spill (Bodkin et al. 2012; Lane et al. 2015).

While the detoxification pathway associated with ingestion has fewer potential lung impacts, serious lung impacts may occur if ingestion results in vomiting and subsequent aspiration. Specifically, ingestion of oil can cause gastrointestinal mucosal irritation, nausea, and vomiting or regurgitation. After vomiting, dolphins are at risk of aspirating the vomitus (a collection of food, oil, and stomach acids) into the lungs, which can lead to acute or chronic lung injury resulting in aspiration pneumonia (DWH NRDAT 2016). This is considered a rare condition in dolphins, but was documented in stranded animals in the northern GOM in the wake of the DWH oil spill (Venn-Watson et al. 2015).

4. Determining the Level of Acute Marine Mammal Injury Associated with the Spill

To assess the adverse impacts to marine mammals resulting from the Texas City Y Spill, the Trustees evaluated the pathways and exposures of marine mammals to the Texas City Y oil, reviewed the known adverse impacts to marine mammals from oil exposure (both with NOAA's marine mammal experts and based on published scientific literature), and analyzed bottlenose dolphin stranding data available from 2000-2015 for the Texas coastline impacted by Texas City Y oil, an area extending from the Galveston Bay area southward to the Padre Island area.

As noted in Section 3.0, although both NOAA's marine mammal experts and the scientific literature describe known adverse impacts to marine mammals from oil exposure, including adrenal effects, reduced reproductive success, liver malfunction, and lung disease, the Trustees have elected at this point to limit the scope of the marine mammal injury assessment to the acute consequences associated with exposure to Texas City Y oil (i.e., increased mortality suffered by bottlenose dolphins off the Texas coast during the 2 – 3 week period immediately following the Spill). The Trustees evaluated this acute injury using stranding data collected by the Texas Marine Mammal

[3] By comparison, humans exchange only 10-20% of their lung volume.

Stranding Network (TMMSN).

Stranding data were evaluated to assess increased bottlenose dolphin mortality resulting from the Texas City Y Spill using a county-based regional approach (described in detail in Section 4.3.1). After standardizing the data to remove stranded mummified/skeletal remains (i.e., Code 5 strandings) (for years 2000-2015) and accounting for increased search efficiency during the Texas City Y Spill response period (i.e., March 23 – April 5, 2014), the Trustees worked with experts from NOAA Fisheries SEFSC to compare the 2014 stranding data to the average weekly stranding baseline data (i.e., 2000-2013, 2015). Pursuant to this analysis, the Trustees determined that strandings were higher than expected for the two-week period immediately following the Spill (i.e., March 23 – April 5, 2014 or weeks 13 and 14) for the Galveston Bay Region (Region 1). The ability to evaluate the effects of the Spill on strandings in the Port O'Connor Region (Region 2) in the two-week period immediately following the Spill was limited by historical and existing data gaps in the stranding network coverage, however. Therefore, the Trustees were not able to clearly separate the effects of the Spill within Region 2 from the effects of increased search effort for the two-week period immediately following the Spill. Lastly, there was no conclusive evidence for elevated strandings in the Port Aransas (Region 3) and Corpus Christi (Region 4) Regions for the three-week period immediately following the Spill (i.e., March 23 – April 12, 2014 or weeks 13 – 15). As described in more detail below, the numbers of excess strandings for each region were quantified using parameters estimated in a log-linear Generalized Additive Model (GAM). Total mortality for the excess strandings in the Galveston Bay Region (Region 1) was calculated using Wells et al.'s (2015) 33% recovery rate.

4.1. NOAA's Marine Mammal Stranding Network

NOAA's Marine Mammal Stranding Network (MMSN) was formalized under the 1992 Amendments to the Marine Mammal Protection Act (MMPA), which designated NOAA NMFS as the lead agency for program establishment and coordination for cetaceans (whales, dolphins, and porpoises) and pinnipeds (seals and sea lions). Volunteer MMSNs exist throughout all coastal states to respond to marine mammal strandings. Volunteer MMSN organizations and participants must either be authorized under Section 112c (Stranding Agreements from the NMFS regional offices) or Section 109h (Federal, State or local government officials) of the MMPA to respond to and/or rehabilitate stranded marine mammals.

In Texas, the TMMSN is based in Galveston, Texas, near Texas City, Texas, where the collision resulting in the Texas City Y Spill occurred. The TMMSN is the one Stranding Agreement holder in Texas authorized to respond to and investigate all stranded marine mammals and rehabilitate live stranded marine mammals. TMMSN also has two Designee organizations to assist them with stranding response and rehabilitation: the Texas State Aquarium in Corpus Christi and SeaWorld San Antonio. The TMMSN response activities are organized into six geographically defined sub-regions. Marine mammal strandings are recorded under different codes for each of the different sub-regions. The six sub-regions include Sabine Pass (SP; Jefferson and Chambers Counties), Galveston (GA; Galveston, Harris, and Brazoria Counties), Port O'Connor (PO; Matagorda, Calhoun, and Jackson Counties), Port Aransas (PA; San Patricio, Refugio, Aransas, and Nueces Counties), Corpus Christi (CC; Kleberg and Kenedy Counties), and Padre Island (PI; Willacy and Cameron Counties). Each geographic sub-region has a designated TMMSN regional coordinator and a cache of equipment for response within the region. At a minimum, the majority territory within each region is consistently surveyed on a weekly basis, year round.

Of the six designated TMMSN response regions, nearly half of all strandings occur in the Galveston area, which generally has the most populated beaches and, thus, historically the highest level of reporting and investigation of marine mammal strandings. However, the Texas coastline extends roughly 367 miles[4] and some areas are remote and difficult to access. Most notably, the area extending from the mouth of Matagorda Bay (28.38729, -96.37807) to Mitchell's Cut at the northeastern tip of East Matagorda Bay (28.74921, -95.65921) historically and presently is not regularly surveyed, thus this area represents the greatest gap in stranding network coverage along the Texas coast.

For NOAA's Southeast Region, headquartered in St. Petersburg, Florida, oversight and administration of the MMSN is performed by the NMFS Marine Mammal Stranding Program Administrator[5] and the NMFS Marine Mammal Stranding Program Coordinator[6]. Together they are responsible for:

- Authorizing the MMSN;
- Coordinating responses to stranding events;
- Monitoring stranding rates;
- Monitoring human caused mortalities;
- Maintaining the southeast stranding data; and
- Conducting investigations to determine the cause of unusual stranding events including mass strandings and mass mortalities.

Basic information, referred to as Level-A data (e.g., species, date, stranding location, carcass condition, sex, length, and signs of human interaction), is collected by the MMSN for each marine mammal stranding in accordance with approved NOAA protocols and using nationally standardized forms (NOAA Form 89-864; OMB No. 0648-0178; form available at www.nmfs.noaa.gov/pr/pdfs/health/levela.pdf; the Level-A Examiner's Guide with the definitions of the terms used for Level-A data collection are available at www.nmfs.noaa.gov/pr/pdfs/health/levela_definitions.pdf). These data are entered into NOAA's Marine Mammal Health and Stranding Response Program National Database and are publicly available upon request. The data are used to establish baseline stranding rates and determine when unusual mortality events (UMEs; described in further detail in section 4.3.4) may be occurring. However, Level-A data does not generally include information that determines or shows cause of death.

Overall, NOAA has extensive expertise in the management of and research on marine mammals, which includes using data collected from marine mammal strandings to assess the health of populations and impacts on marine mammals from oil and non-oil related environmental perturbations. Analyses of historical marine mammal strandings data assist in the bottlenose dolphin injury assessment by providing evidence of both oil and non-oil stressors that are known to affect their populations. Non-oil factors may include disease, human and fisheries interactions, biotoxins, cold events and numerous other environmental factors (Litz et al. 2014). The Trustees drew upon NOAA's extensive experience with bottlenose dolphins, including, but not limited to,

[4] The Coastline of the United States. U.S. Dept. of Commerce, NOAA, NOAA/PA 71046 (Rev. 1975).
[5] Erin Fougères, Ph.D., with NOAA Fisheries, Protected Resources Division based at NOAA's Southeast Regional Office in St. Petersburg, Florida serves as the NFMS Marine Mammal Stranding Program Administrator.
[6] Blair Mase-Guthrie with NOAA Fisheries, Protected Resources and Biodiversity Division based at NOAA's Southeast Fisheries Science Center in Miami, Florida serves as the NMFS Marine Mammal Stranding Program Coordinator.

known oil exposure pathways, known adverse impacts from oil exposure, and evaluation of UMEs in the GOM to determine whether a measurable adverse impact to bottlenose dolphins, in terms of acute increased mortality, occurred as a result of the Texas City Y Spill.

All bottlenose dolphin strandings along the entire impacted Texas coastline for the 2 – 3 week period following the Texas City Y Spill are depicted below in Figure 5.

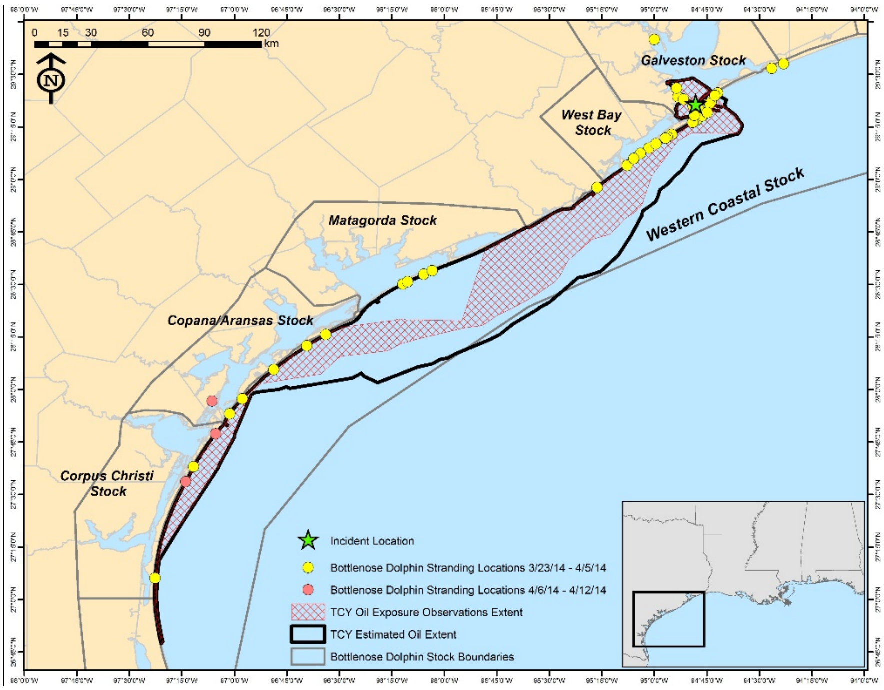


Figure 5. Bottlenose dolphin strandings for the entire Texas City Y Spill impacted coastal area during the 2 – 3 week period immediately following the Spill overlaid with the bottlenose dolphin estuarine stock boundaries as defined in annual stock assessments, and Texas county boundaries. The yellow dots indicate those bottlenose dolphin strandings that occurred the two weeks following the Texas City Y Spill (i.e., March 23 – April 5, 2014). The pink dots represent bottlenose dolphin strandings that occurred in the third week following the Texas City Y Spill (i.e., April 6 – April 12, 2014).

4.2. Methodology for Analyzing Tissue Samples from Stranded Bottlenose Dolphin

This section describes the dolphin tissue sample collection efforts and analyses undertaken by the Trustees to support the marine mammal injury assessment.

4.2.1. Stranded Common Bottlenose Dolphin Tissue Collection and Analysis

To obtain high quality tissues samples (i.e., samples from animals as fresh dead as possible) from stranded animals requires the ability to respond quickly and ensure proper handling and storage of the samples obtained. It also depends on the condition of the animal at the time of stranding (i.e., in many cases animals sink upon death and refloat during decomposition at which time they wash ashore and strand). Obtaining high quality tissues samples can be challenging for the TMMSN given the remoteness of the beaches, typical condition of carcasses upon stranding, and limited resources available to collect samples.

Following the Texas City Y Spill, the Trustees presented a plan (the 2014 Plan) to Kirby for collection and analysis of bottlenose dolphin samples to support the Texas City Y NRDA. Kirby and the Trustees were unable to reach a consensus on the 2014 Plan as proposed, and Kirby ultimately agreed to fund only a limited sample collection and preservation, and not sample analysis. As agreed to by the Trustees and Kirby in the 2014 Plan, the TMMSN was directed by NOAA to conduct a limited, targeted sampling effort, focused on the following types of stranded bottlenose dolphins:

- Fresh and moderately decomposed dolphins that may have been visibly oiled;
- Pregnant females; and
- Perinatal or young of the year.

All of the sampling followed NOAA's strict NRDA sampling, necropsy, handling and retention, and documentation protocols. The targeted sampling of stranded bottlenose dolphins was conducted from the onset of the Spill (March 22, 2014) through six months following the Spill (September 22, 2014), because the Trustees and Kirby agreed that a six-month sampling period was a reasonable and sufficient time frame for assessing whether acute impacts from the Texas City Y Spill occurred. Furthermore, in discussions with Kirby, the Trustees agreed to the limited, targeted sampling of the types of stranded bottlenose dolphins identified above in an effort to generate only reasonable damage assessment costs when responding to the Texas City Y Spill. NOAA's marine mammal experts have since concluded that they would not recommend such a limited or targeted sampling effort in the future since the types of bottlenose dolphins suffering (or showing) acute or chronic impacts from oil exposure are not limited to the types identified above.

Along the impacted coastline of Texas, TMMSN responded to 58 stranded bottlenose dolphins during the March 22 – September 22, 2014 period. These included zero pregnant females, 26 perinates (1 of which was visibly oiled), and 2 visibly oiled adults. Thus, of the 58 stranded dolphins responded to by the TMMSN, 28 fell into the targeted categories. However, only 4 carcasses were in a sufficient state to be sampled (e.g., not too decomposed, organs were not missing due to scavengers, etc.) including the visibly oiled perinate. The sampled animals are listed in Table 1.

Table 1. Stranded dolphins that fit the targeted Texas City Y Spill NRDA sampling criteria.

Field Number	**Strand Date**	**Sex**	**Total Length (cm)**	**Age Class**
GA1894 *	March 27, 2014	Female	183	Yearling
GA1905	March 30, 2014	Female	101	Perinate
GA1915	April 2, 2014	Female	187	Yearling
PA1049	June 6, 2014	Male	99 **	Calf/Perinate

* Externally visibility oiled

** Caudal peduncle and tail flukes cut off due to shark bite.

Samples were obtained from the four animals identified in Table 1 to assess contributing factors and causes of death following the Texas City Y Spill. Chemical analysis, histopathological evaluations and diagnostic tests of dolphin tissue and/or swab samples were conducted to assess bottlenose dolphin exposure to PAHs and/or the effects of exposures to PAHs resulting from the Texas City Y Spill. Specifically, the Trustees analyzed collected samples to meet the following objectives:

- Determine if the samples contained oil consistent with the Texas City Y source oil and to quantify the PAH concentrations for each of the samples;
- Identify lesions and diseases that may be consistent with oil exposure, and, as possible, cause of death; and
- As possible, rule in or out common causes of mortality events for bottlenose dolphins in the GOM (e.g., biotoxins and brucellosis).

In addition, because NOAA's marine mammal experts concluded that the types of bottlenose dolphins that may suffer (or show) acute or chronic impacts from oil exposure are not only those types sampled as part of the Texas City Y NRDA (i.e., fresh and moderately decomposed dolphins that may have been visibly oiled, pregnant females, or perinatal or young of the year), the Trustees chose to send additional bottlenose dolphin samples from 3 other fresh dead dolphins that stranded after the Spill (i.e., GA1887, GA1927, and GA1921) for histopathological analysis.

The chemical analysis, diagnostic tests, and histopathological analysis conducted on the collected samples is described below. The results of these tests and analyses are explained in Section 5.6.

4.2.1.1. Chemical Analysis

Five internal tissue (stomach contents and/or lung) and seven external swab samples collected from 3 stranded bottlenose dolphins (i.e., GA1894, GA1905, and GA1915) were analyzed through chemical fingerprinting and compared to the chemical compositions of the fresh and weathered Texas City Y source oils (Stout 2014). Samples from PA1049 were not analyzed since the dolphin stranded 2.5 months (i.e., June 2, 2014) after the spill and no oil was present in the sediments or coastal waters at that time.

4.2.1.2. Diagnostic Tests and Histopathology

Whenever possible, gross necropsies are performed at the time of stranding for all stranded bottlenose dolphins. However, in most cases the cause of a particular dolphin's death can neither be determined nor ruled out based on these necropsies or the Level-A data (e.g., species, date, stranding location, carcass condition, sex, length, and signs of human interaction) collected by a MMSN. Often, cause of death may only be determined via tissue histopathological analysis. Though, in some cases, even with histopathological analysis cause of death cannot be determined. Regardless, to assess potential contributing factors and causes of death, tissue samples from major organs for each of the four dolphins sampled as part of the Texas City Y Spill NRDA were evaluated. In addition, tissues samples from major organs of three dolphins sampled outside of 2014 Plan (i.e., GA1887, GA1927, and GA1921) were also evaluated. Biotoxin tests were conducted to determine if the dolphin may have been exposed to a toxic algal bloom that was occurring in Texas concurrent with the Spill. Furthermore, *Brucella* sp. tests were conducted to determine if the dolphin may have been infected by the bacterium, which is a known threat to marine mammals and can result in perinate die-offs (Colegrove et al. 2016).

4.3. Methodology for Analyzing Stranding Data

This section describes the stepwise process the Trustees took to analyze the TMMSN data to quantify the bottlenose dolphin injury.

4.3.1. Determining Regional Boundaries

The first step in the Trustees stranding data assessment was to determine the appropriate geographic resolution at which to evaluate the bottlenose dolphin stranding data. To do so, the Trustees worked with experts from NOAA Fisheries SEFSC and Ms. Heidi Whitehead[7], the TMMSN

[7] Ms. Heidi Whitehead is Texas Marine Mammal Stranding Network State Operations Coordinator. She is based in Galveston, Texas.

State Operations Coordinator, and decided on a county-based regional approach that is largely consistent with the regional breakdown of the standard TMMSN response activities and operations described in Section 4.1. The differences lie in the inclusion of Jefferson County as part of Region 1, the inclusion of Willacy County as part of Region 4, and the exclusion of Jackson County from Region 2; these differences are based on the defined incident Response Area, which extends from Galveston to North Padre Island[8]. Accordingly, for the purposes of this assessment, the Trustees defined four distinct geographic areas for evaluation: Galveston, Port O'Connor, Port Aransas, and Corpus Christi (Figure 6).

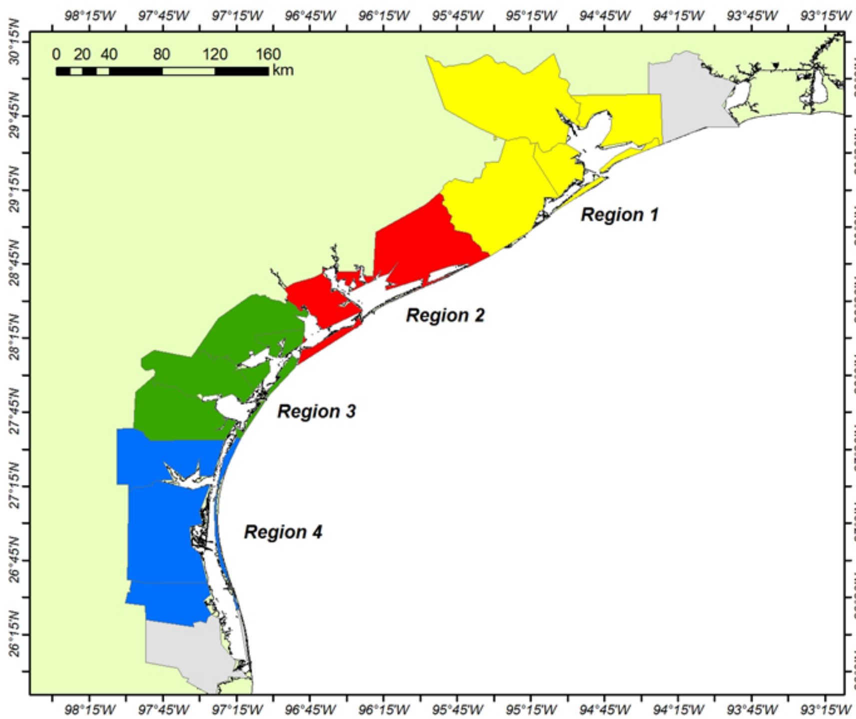


Figure 6. Regional boundaries for stranding analysis. Region 1 in yellow (i.e., Galveston) includes Chambers, Harris, Galveston, and Brazoria Counties. Region 2 in red (i.e., Port O'Connor) includes Matagorda and Calhoun Counties. Region 3 in green (i.e., Port Aransas) includes Aransas, Refugio, San Patricio, and Nueces Counties. Region 4 in blue (i.e., Corpus Christi) includes Kleberg, Kenedy, and Willacy Counties.

4.3.2. Developing a Weekly Historical Baseline

The second step to the Trustees stranding data assessment was to determine the historical baseline strandings. The Trustees worked with experts from NOAA Fisheries SEFSC to extract, review, and analyze Level-A data for years 2000-2015 from the National Marine Mammal Health and Stranding Database for Galveston, Harris, Chambers, Brazoria, Matagorda, Calhoun, Aransas, Refugio, San Patricio, Nueces, Kleberg, Kenedy, and Willacy counties. These Level-A data were extracted on January 12, 2017. As part of the Level-A data, strandings are categorized based on the condition of the stranded carcass (condition code) with Code 1 being alive, Code 2 fresh dead, Code 3 moderately decomposed, Code 4 severely decomposed, and Code 5 mummified/skeletal body. Since the Texas City Y marine mammal assessment is focused on acute mortality, and thus the time period immediately following the Spill, the Trustees removed all Code 5 strandings from the Level-A strandings dataset (i.e., 2000-2015) used to develop the historical baseline and to assess injury.

[8] Stepdown of Marine Mammal Stranding Response, Carcass Collection and Sampling, dated April 11, 2014.

Code 5, or mummified/skeletal, carcasses could persist in a location for weeks or more before being collected. Thus, it would be difficult to know whether the Code 5 carcasses found in the weeks immediately following the Texas City Y Spill had stranded before or after the Spill. For that reason, the Trustees removed all Code 5 strandings from the complete Level-A strandings dataset.

Over the 2000-2013, 2015 period (i.e., the period which represents historical baseline strandings), the mean number of strandings per year for all counties within the oil impacted area combined was 97.2 strandings, ranging from 67.0 to 137.0 dolphins. By region, the total number of strandings, excluding Code 5 strandings, varies greatly with an annual average of 4.2 strandings in Region 2 to 55.7 strandings in Region 1 (Table 2).

Table 2. Summary statistics of the 2000-2013, 2015 Level-A Stranding Data by Region, by Year, excluding Code 5 strandings.

Year	**Number of Strandings**				
	Region 1	Region 2	Region 3	Region 4	Total
2000	61.0	1.0	24.0	1.0	87.0
2001	46.0	8.0	25.0	7.0	86.0
2002	74.0	5.0	33.0	11.0	123.0
2003	57.0	3.0	36.0	17.0	113.0
2004	46.0	5.0	28.0	10.0	89.0
2005	50.0	0.0	25.0	6.0	81.0
2006	40.0	1.0	24.0	2.0	67.0
2007	72.0	5.0	14.0	7.0	98.0
2008	78.0	7.0	20.0	11.0	116.0
2009	47.0	1.0	36.0	4.0	88.0
2010	40.0	6.0	31.0	10.0	87.0
2011	49.0	6.0	25.0	7.0	87.0
2012	69.0	8.0	48.0	12.0	137.0
2013	66.0	6.0	42.0	8.0	122.0
2015	41.0	1.0	33.0	2.0	77.0
Average	55.7	4.2	29.6	7.7	97.2
Standard Deviation	12.8	2.7	8.4	4.2	19.4

As noted in Section 4.1, the Galveston area (Region 1) historically and presently experiences the highest number of strandings, and has the highest level of reporting and investigation of marine mammal strandings. Not surprisingly, the baseline yearly average number of strandings (i.e., 55.7 dolphins) for this region exceeds that of all the other regions evaluated for the strandings analysis.

Stranding data were consolidated into weekly counts, which is useful in demonstrating seasonal differences in strandings. Typically, bottlenose dolphin strandings in Texas follow a seasonal pattern, with most strandings occurring from February to April, after which the number of strandings declines during the summer months. Strandings then begin to increase again in December and January (Worthy 1998). This pattern is consistent with the Trustees' analysis of the historical baseline strandings for each region, where a seasonal peak number of strandings culminates between weeks 7 and 11, depending on the region (Figure 7-10).

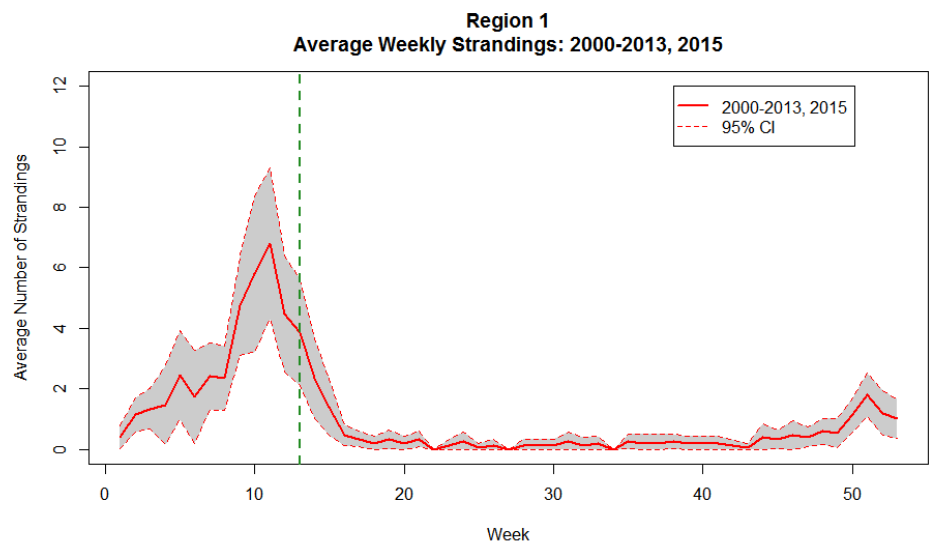


Figure 7. Average weekly number of strandings from 2000-2013, 2015 ± 95% Confidence Interval (CI) for Region 1. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

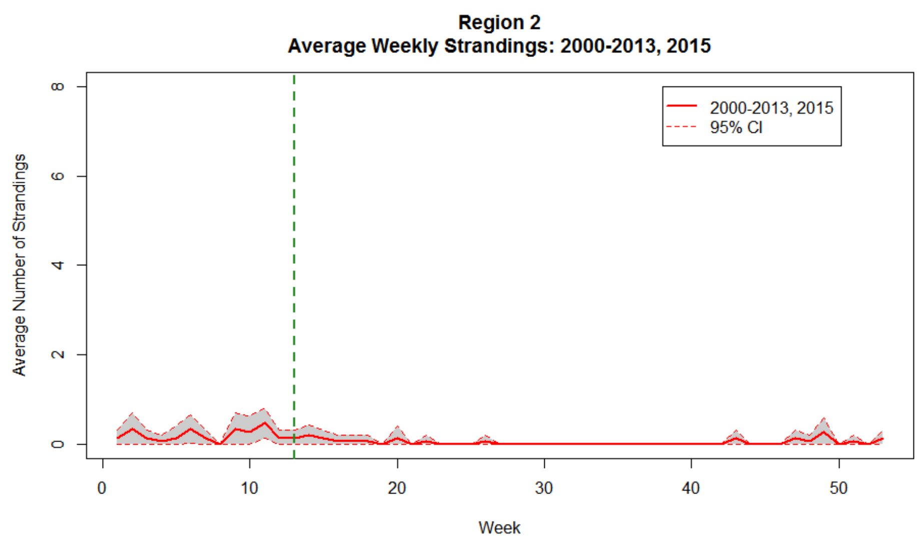


Figure 8. Average weekly number of strandings from 2000-2013, 2015 ± 95% Confidence Interval (CI) for Region 2. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

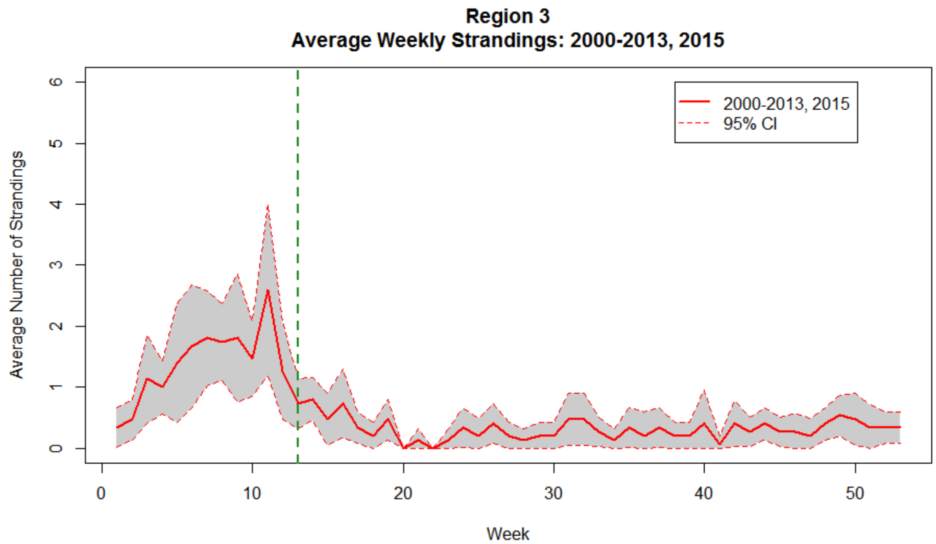


Figure 9. Average weekly number of strandings from 2000-2013, 2015 ± 95% Confidence Interval (CI) for Region 3. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

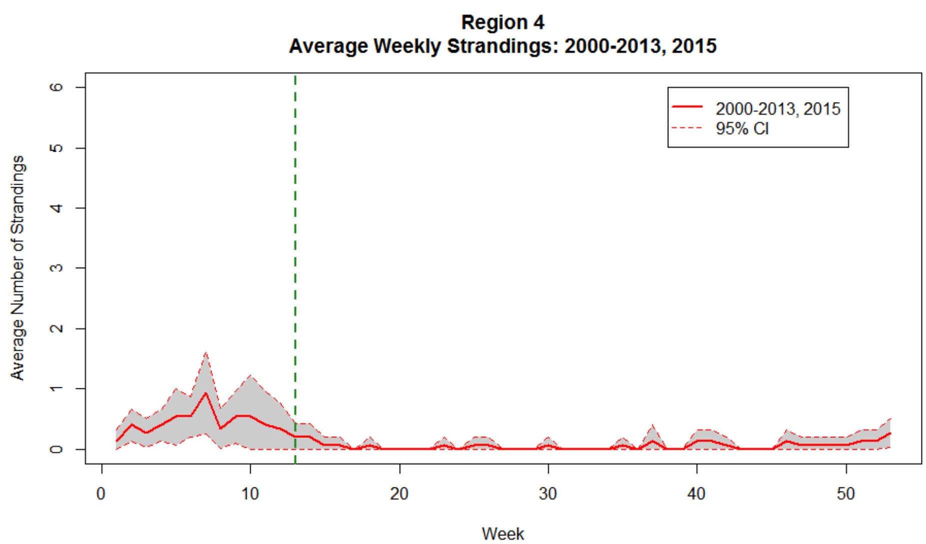


Figure 10. Average weekly number of strandings from 2000-2013, 2015 ± 95% Confidence Interval (CI) for Region 4. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

4.3.3. Correcting and Accounting for Increased Search Effort during the Texas City Y Spill Response Period

The next step was to adjust the stranding data to account for the increased search effort as a result of the response to the Texas City Y Spill. Increased search effort may be a confounding variable for identifying event-related increases in stranding rates. To address this, the Trustees collaborated with Ms. Whitehead to separate the strandings having occurred during the spill period into two categories: those that likely would have been found but for the increased search, and those that would not have likely been found. The approach the Trustees have elected to utilize to address increased search effort for the Texas City Y Spill is notably conservative in that stranding data is being eliminated even though those strandings may still be related to the Spill.

Ms. Whitehead reviewed the 2014 stranding data collected in the two-week period immediately following the Texas City Y Spill (i.e., weeks 13 and 14 or March 23 – April 5, 2014) to help identify dolphin carcasses that may not have otherwise been recovered but for the Spill and its associated search, sampling, and cleanup efforts. She identified those dolphin carcasses that were found in remote and personnel access limited areas, as well as those that were reported as having been found by NOAA surveyors within the Matagorda Bay/East Matagorda Bay area known to have a historical and existing coverage gap in standard TMMSN response operations. In quantifying the bottlenose dolphin injury, the Trustees used this information to correct and account for increased search efforts that may have resulted in increased stranding rates. In total, Ms. Whitehead identified 13 carcasses found based on increased search effort (listed below in Table 3). Those carcasses found in Brazoria and Galveston counties (in Region 1) were dropped from the 2014 dataset altogether. Those carcasses found in Calhoun and Matagorda counties (in Region 2) were retained in the 2014 dataset. However, as further described in section 5.2, the Trustees did not make an inference as to whether there were Spill related excess mortalities in Region 2 because the Trustees were unable to separate the effects of the Texas City Y Spill from the effects of increased search effort.

Table 3. Carcasses identified by Ms. Heidi Whitehead, the TMMSN State Operations Coordinator, as recovered likely due to increased search and sampling effort associated with the Texas City Y Spill response activities. Those flagged with a "1" were found in remote areas with access limitations. Those flagged with a "2" were recovered within the Matagorda area with an existing network coverage gap.

Field Number	Strand Date	County	Animal Condition	Sex	Age Class	Flag
GA1895	27-March-2014	Brazoria	Code 4	Unknown	Unknown	1
GA1899	28-March-2014	Galveston	Code 5	Male	Adult	1
GA1904	30-March-2014	Galveston	Code 5	Unknown	Adult	1
GA1910	1-April-2014	Galveston	Code 4	Female	Pup/Calf	1
GA1911	1-April-2014	Galveston	Code 5	Unknown	Unknown	1
GA1912	1-April-2014	Galveston	Code 5	Unknown	Adult	1
PO502	1-April-2014	Calhoun	Code 5	Unknown	Adult	2
PO503	1-April-2014	Calhoun	Code 4	Unknown	Adult	2
PO505	1-April-2014	Calhoun	Code 4	Male	Adult	2
PO506	2-April-2014	Matagorda	Code 4	Male	Adult	2
PO507	2-April-2014	Matagorda	Code 4	Unknown	Adult	2
PO508	3-April-2014	Matagorda	Code 4	Unknown	Adult	2
PO509	3-April-2014	Matagorda	Code 4	Male	Adult	2

4.3.4. Statistical Model to Determine Excess Mortality due to the Texas City Y Spill

To quantify the number of excess strandings associated with Texas City Y Spill, a log-linear Generalized Additive Model (GAM) was used to model the weekly number of strandings using the historical baseline stranding data for each of the four regions. The model controls for time and historical Unusual Mortality Events (UMEs) and evaluates the effects of Texas City Y (TCY) through comparison to the baseline (Equation 1).

Equation 1. The log-linear Generalized Additive Model (GAM) used for the Texas City Y marine mammal injury quantification.

$$log(n) = intercept + s(week) + TCY + UME$$

The Trustees define baseline to indicate stranding rates observed absent an identified external cause. The UME term in the model indicates periods when a discrete period of increased stranding rate has been identified and defined as a UME. Elevated levels of marine mammal stranding rates may occur for a variety of reasons, including but not limited to, disease, human interaction, biotoxins, malnutrition, and environmental perturbations, and in some cases may be deemed a UME under the MMPA. The MMPA defines a UME as a stranding that is unexpected, involves a significant die-off of any marine mammal population, and demands immediate response (16 U.S.C. 1421h). A formal process directed by the MMPA for declaration of a UME requires consultation with a federally appointed Working Group for Marine Mammal Unusual Mortality Events (WGMMUME or Working Group), which is a congressionally mandated panel of marine mammal health experts with expertise in biology, toxicology, pathology, ecology, and epidemiology. The WGMMUME uses seven criteria to determine whether a mortality event is unusual, including higher than expected numbers of stranded marine mammals; a temporal, spatial or demographic shift in strandings; similar or unusual clinical or pathologic findings; and mortality in a vulnerable or declining population. For strandings in the GOM, the higher than expected standard used to initiate a consultation with the Working Group regarding a potential UME is typically defined as 2 standard deviations above the mean stranding rate for the time period and location of interest (Litz et al. 2014). Short-term, transient increases in stranding rates above baseline do occur and are not typically identified as UMEs. Therefore, these increases in strandings are part of the background variability accounted for in the historical baseline used for the Texas City Y assessment.

Since the establishment of the UME program in 1991, there have been 64 formally recognized UMEs throughout the United States. These UMEs have involved a variety of species and numerous individual marine mammals per event. A review of UMEs in the GOM between 1990-2009, demonstrates that causes of UMEs may not always be determined. Once a UME is declared, each UME is thoroughly investigated (Litz et al. 2014). This is especially true in areas with systematic, long-term MMSN coverage. Regardless, at times, the cause of a particular UME may remain undetermined. Three UMEs for bottlenose dolphins have been declared in Texas over the last 10 years: an event in the spring of 2007 (February 27 – March 31) affecting only those counties in Region 1, another in the spring of 2008 (February 1 – March 31) affecting all of the coastal counties, and a third event beginning November 1, 2011 and lasting through March 31, 2012 also affecting all the coastal counties (Litz et al. 2014).

Explanatory variables incorporated into the model included a smooth term for week, a binary term for UME (carcasses associated with UMEs stranded during the following date ranges: February 27 – March 31, 2007; February 1 – March 31, 2008; and November 1, 2011 – March 31, 2012), and a binary term for the Texas City Y Spill. The Texas City Y spill period was evaluated as weeks 13 – 14 for Regions 1 and 2, and weeks 13 – 15 for Regions 3 and 4.

4.3.5. Scaling Excess Strandings to Estimate Total Mortality of Excess Mortalities due to the Texas City Y Spill

The number of stranded dolphins observed on the shoreline is a function of multiple processes that vary both temporally and spatially. While some dolphins beach themselves before they die or float upon death and eventually drift ashore, most dolphins die at sea and sink to the bottom where they decompose and may later float and/or are subject to scavenging (DWH MMIQT 2015). Additionally, once a dolphin carcass is onshore, the probability of detection is dependent on the human use of the shore as well as the activity level and the public's understanding of how and where to report the stranding to the local stranding response network. Estimates of the number of dead animals not reported vary greatly across marine mammal species. For example, Williams et al. (2011) estimated historical carcass-detection rates ranging from 0% to 6.2% for 14 cetacean species in the northern GOM. Given no additional information, these estimates indicate that the true death toll of a cetacean species in the northern GOM could be 50 times the number of carcasses recovered. However, for the purposes of this analysis related to the Texas City Y Spill, and consistent with Wells et al. (2015), the Trustees assumed a 33% recovery rate for bottlenose dolphin carcasses stranded in Region 1.

5. Results of the Texas City Y Marine Mammal Injury Assessment

This section describes the results of the Trustees bottlenose dolphin injury assessment.

5.1. Region 1: Excess Mortality due to the Texas City Y Spill

Even after accounting for the increased search efforts associated with the search, sampling, and response activity following the Spill, the initial evaluation of the 2014 data relative to the historical baseline average weekly strandings was indicative of higher than expected strandings during the two-week period immediately following the Texas City Y Spill in Region 1 (Figure 11). However, post week 14, there is no indication of increased stranding rates. For the increase in strandings immediately after the Texas City Y Spill, a consultation with the WGMMUME was not initiated because (1) up until that point stranding rates within the oil impacted area had been normal for 2014 (i.e., there was no unusual mortality), and (2) high stranding rates did not persist beyond a few weeks following the Spill or beyond the oil spill response period. Thus, the increase in strandings associated with the Texas City Y Spill was not considered a potential UME under the MMPA. Instead, NOAA's marine mammal experts have concluded that the increased strandings are likely associated with acute injury to bottlenose dolphins resulting from the Texas City Y Spill, and as modeled below.

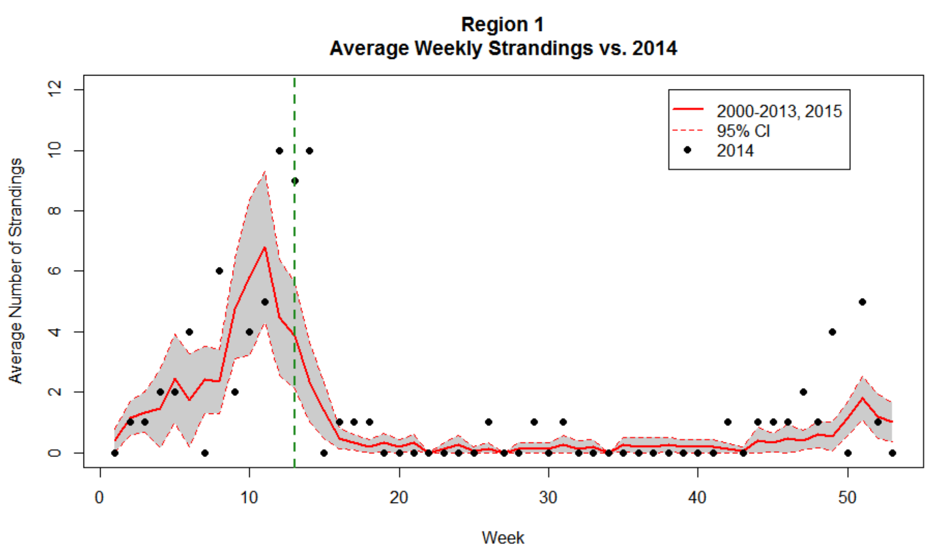


Figure 11. Average weekly number of strandings for Region 1 from 2000-2013, 2015 ± 95% Confidence Interval (CI) relative to the 2014 observed average weekly strandings. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

Consistent with the Trustees' initial evaluation of the long-term strandings data, the baseline model for Region 1 predicts a seasonal peak number of strandings culminating in weeks 10 and 11, followed by a steep decline in strandings over the next several weeks (Figure 12).

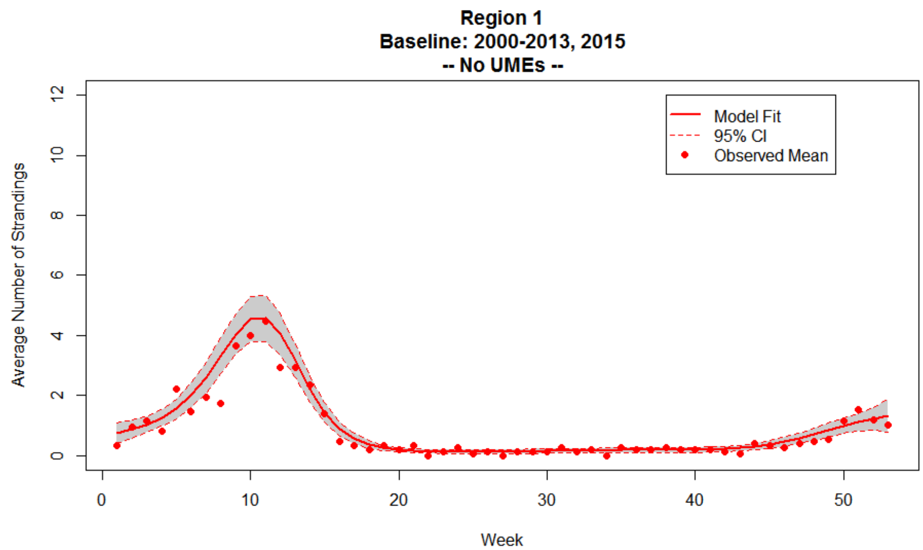


Figure 12. The baseline predicted (i.e., red line) and observed mean (i.e., red dots) number of strandings by week in the absence of UME and TCY effects from the GAM model for Region 1.

The GAM model including week, UME, and TCY variables was highly significant and explained 52.3% of the deviance in the data. There were significant, positive effects for both the UME and TCY factors (Table 4; see Appendix 1, table 1 for complete model output).

Table 4. Summarized results of the GAM (with Tweedie distribution) for Region 1.

Number of Observations (n) = 848			
Parametric Coefficients:			
	Estimate	Standard Error	*p*-value
Intercept	-0.74	0.07	< 2e-16
UME	0.65	0.13	1.2e-06
TCY	1.27	0.38	7.88e-04
Approximate Significance of smooth terms:			
	edf	Ref.df	*p*-value
s(week)	7.78	9	< 2e-16
Adjusted R-squared:	0.50		
Deviance Explained (%):	52.3		

By using the TCY variable, the model predicts a significant spill effect that corresponds with the high strandings in weeks 13 and 14. The estimated increase in the number of strandings following TCY was 3 times the baseline number (Figure 13).

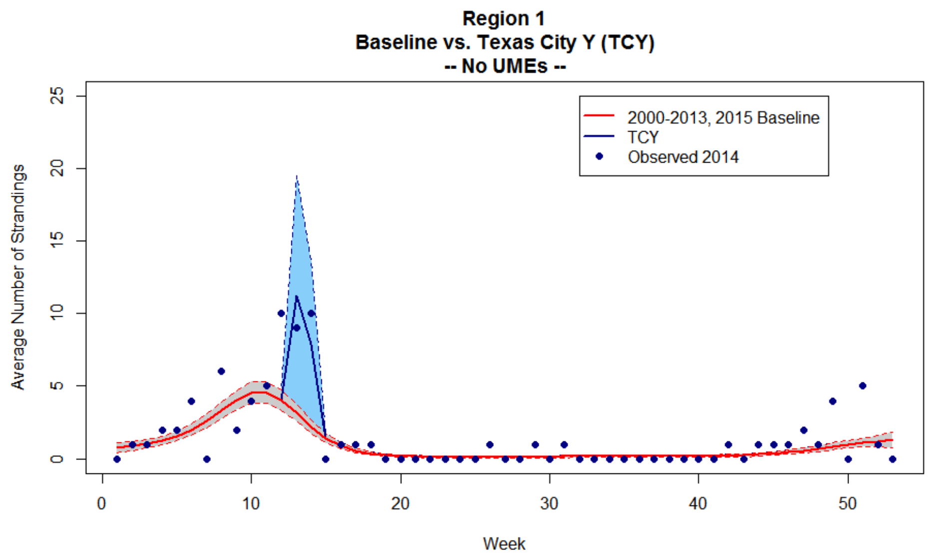


Figure 13. Region 1 baseline predicted weekly strandings (in red) and modeled value accounting for the effects of TCY (in blue). Observed values (i.e., blue dots) are weekly counts from 2014.

The difference in predictions from the baseline model versus the model including the effect of TCY provides an estimate of the number of excess strandings occurring during weeks 13 and 14 of 2014. To reflect the statistical uncertainty in the estimate (due to uncertainty in the estimation of GAM parameters), a parametric bootstrap was used to derive 5,000 predictions of excess strandings from the model parameters. The resulting distribution is shown in Figure 14. The median number of excess strandings from the bootstrap distribution was 13.85, with a 95% confidence interval (CI) of 3.92-34.49.

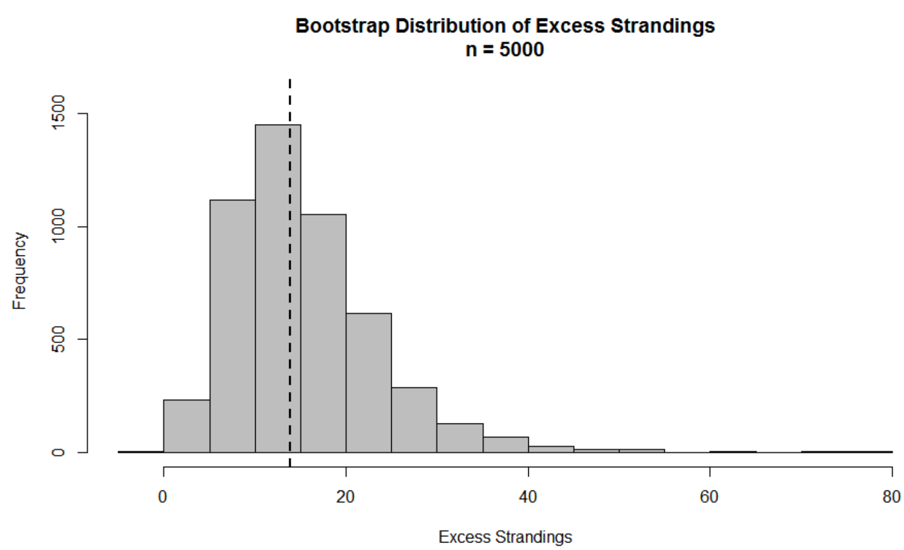


Figure 14. Bootstrap distribution of estimated excess strandings based on a parametric bootstrap with 5,000 iterations. The dotted line indicates the median of the distribution (13.85).

5.2. Region 2: Excess Mortality due to the Texas City Y Spill

The initial evaluation of the 2014 data relative to the historical baseline average weekly strandings for Region 2 demonstrated a peak in strandings during week 14 (Figure 15). However, all 6 of those strandings were reported by NOAA surveyors as part of the Texas City Y response efforts and were recovered within the Matagorda Bay/East Matagorda Bay area, which has no standard TMMSN network coverage. The baseline average weekly number of strandings (i.e., 0.08) and the yearly average of strandings (i.e., 4.2) for this region is very low. Additionally, no other strandings were reported for this area during 2014 and only a single stranding was reported for all of 2015.

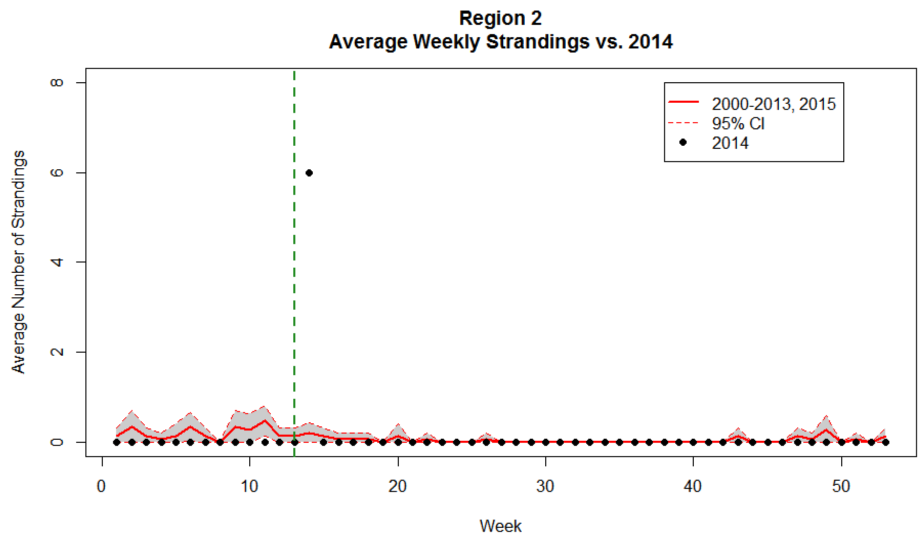


Figure 15. Average weekly number of strandings for Region 2 from 2000-2013, 2015 ± 95% Confidence Interval (CI) relative to the 2014 observed average weekly strandings. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

Although the results of the GAM model for Region 2 (Figure 16; Table 5; see Appendix 1, table 2 for complete model output) suggest significant, positive effects for both the UME and TCY factors, the ability to separate the effects of the Texas City Y Spill from the effects of increased search effort is limited by existing data gaps in historical coverage for this Region. Therefore, the Trustees did not make an inference as to whether there were spill related excess mortalities in this Region. In other words, these findings were not applied to the Trustees bottlenose dolphin injury quantification.

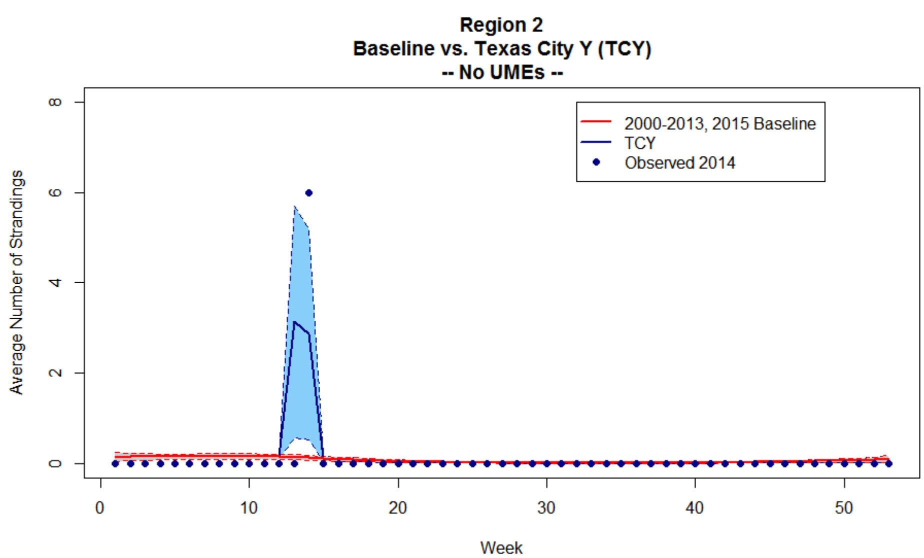


Figure 16. Region 2 baseline weekly strandings (in red) and modeled value accounting for the effects of TCY (in blue). Observed values (i.e., blue dots) are weekly counts from 2014.

Table 5. Summarized results of the GAM (with Poisson distribution) for Region 2.

Number of Observations (n) = 848			
Parametric Coefficients:			
	Estimate	Standard Error	*p*-value
Intercept	-3.24	0.20	< 2e-16
UME	1.44	0.31	5.03e-06
TCY	3.19	0.47	8.03e-12
Approximate Significance of smooth terms:			
	edf	Ref.df	*p*-value
s(week)	3.97	9	4.45e-07
Adjusted R-squared:	0.21		
Deviance Explained (%):	27.6		

5.3. Region 3: Excess Mortality due to the Texas City Y Spill

The initial evaluation of the 2014 data relative to the historical baseline average weekly strandings for Region 3 demonstrated a possible peak in strandings during the three weeks after the Spill (i.e., March 23 – April 12, 2014) (Figure 17).

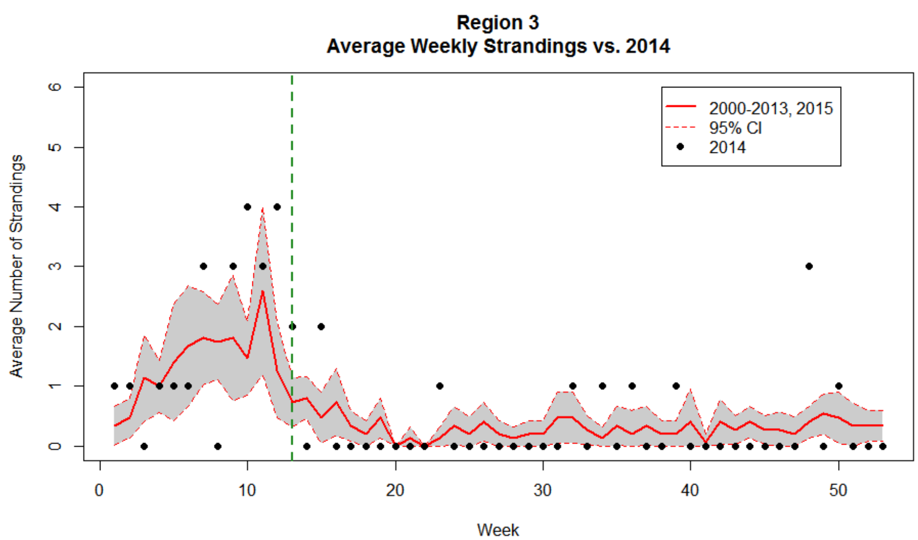


Figure 17. Average weekly number of strandings for Region 3 from 2000-2013, 2015 ± 95% Confidence Interval (CI) relative to the 2014 observed average weekly strandings. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

The baseline model shows a seasonal peak number of strandings culminating between weeks 7 and 9 followed by a steep decline in strandings over the next several weeks (Figures 18). The GAM model did not demonstrate a significant effect for either the UME and TCY factors (Table 6; see Appendix 1, table 3 for complete model output). The Trustees' conclusion regarding Region 3 is that there is no evidence of elevated strandings following the Texas City Y Spill.

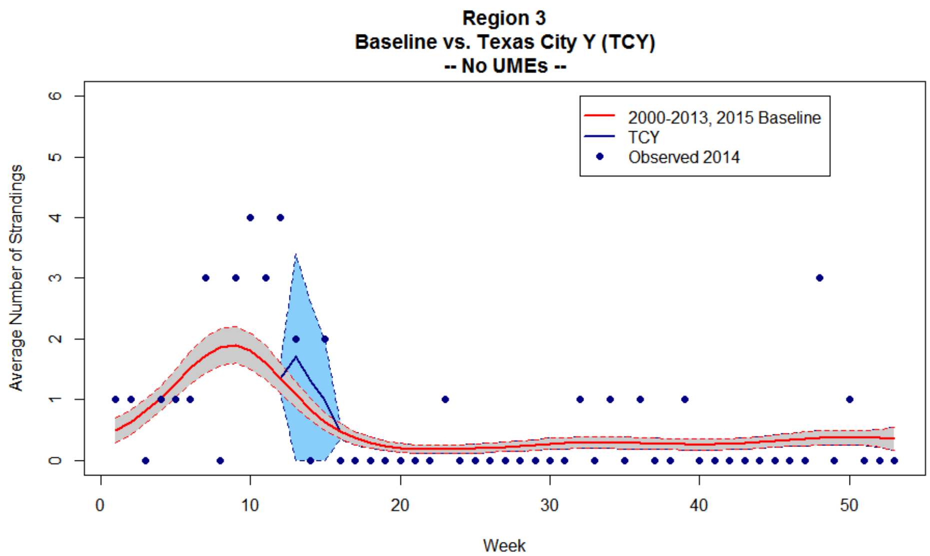


Figure 18. Region 3 baseline weekly strandings (in red) and modeled value accounting for the effects of TCY (in blue). Observed values (i.e., blue dots) are weekly counts from 2014.

Table 6. Summarized results of the GAM (with Poisson distribution) for Region 3.

Number of Observations (n) = 848			
Parametric Coefficients:			
	Estimate	Standard Error	*p*-value
Intercept	-0.89	0.06	< 2e-16
UME	0.26	0.17	0.125
TCY	0.45	0.51	0.377
Approximate Significance of smooth terms:			
	edf	Ref.df	*p*-value
s(week)	7.14	9	< 2e-16
Adjusted R-squared:	0.25		
Deviance Explained (%):	28.0		

5.4. Region 4: Excess Mortality due to the Texas City Y Spill

The initial evaluation of the 2014 data relative to the historical baseline average weekly strandings for Region 4 demonstrated a possible peak in strandings during the three weeks after the Spill (i.e., March 23 – April 12, 2014) (Figure 19).

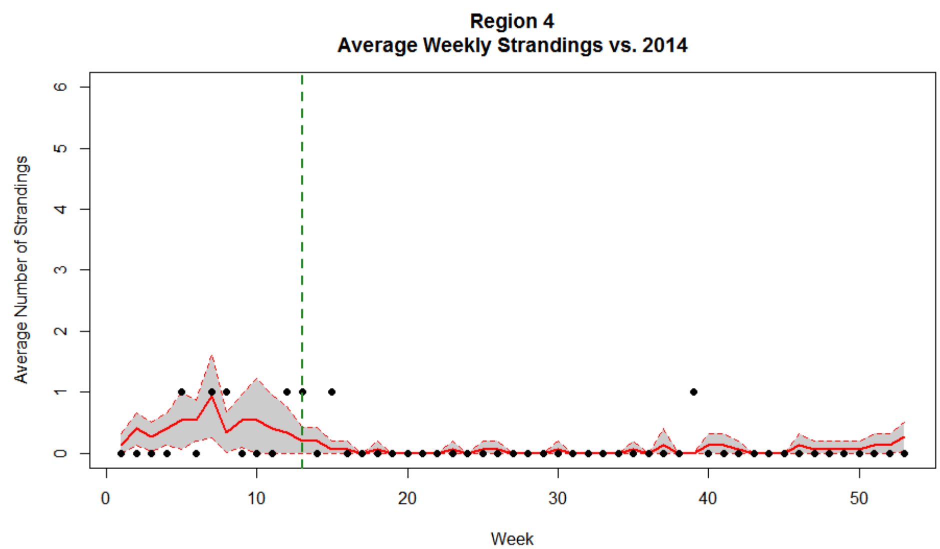


Figure 19. Average weekly number of strandings for Region 4 from 2000-2013, 2015 ± 95% Confidence Interval (CI) relative to the 2014 observed average weekly strandings. The vertical dashed line marks week 13 (i.e., the first week after the Spill).

Much like in Region 3, the baseline model for Region 4 shows a seasonal peak number of strandings culminating between weeks 7 and 9 followed by a steep decline in strandings over the next several weeks (Figures 20). The GAM model did not demonstrate a significant effect for the TCY factor, but did for the UME factor (Table 7; see Appendix 1, table 4 for complete model output). The Trustees' conclusion regarding Region 4 is that there is no evidence of elevated strandings following the Texas City Y Spill.

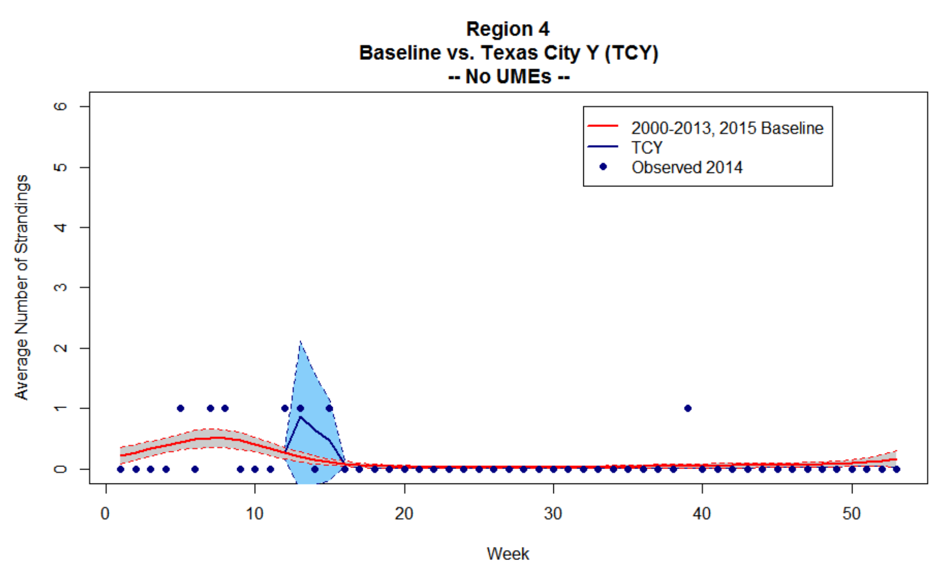


Figure 20. Region 4 baseline weekly strandings (in red) and modeled value accounting for the effects of TCY (in blue). Observed values (i.e., blue dots) are weekly counts from 2014.

Table 7. Summarized results of the GAM (with Poisson distribution) for Region 4.

Number of Observations (n) = 848			
Parametric Coefficients:			
	Estimate	Standard Error	*p*-value
Intercept	-2.62	0.16	< 2e-16
UME	0.74	0.26	0.004
TCY	1.49	0.74	0.044
Approximate Significance of smooth terms:			
	edf	Ref.df	*p*-value
s(week)	5.47	9	< 2e-16
Adjusted R-squared:	0.15		
Deviance Explained (%):	28.5		

5.5. Total Acute Mortality due to the Texas City Y Spill

Based on the GAM analysis of the TMMSN stranding data, the Trustees observed evidence of excess bottlenose dolphin mortality as a result of the Texas City Y Spill in Region 1. The median number of excess strandings was 13.85 dolphins, with a 95% confidence interval (CI) of 3.92-34.49. Assuming a 33% recovery rate, the level of total acute mortality corresponds to 41.6 dolphins (95% CI: 11.76-103.47).

5.6. Tissue Sample Analyses

Tissues from four bottlenose dolphins were analyzed under the 2014 Plan (i.e., GA1894, GA1905, GA1915 and PA1049). Although the histopathology showed the Spill may have led to chronic effects for one of the animals, the results do not provide a conclusive cause of the increased acute mortality in bottlenose dolphins observed in the oil impacted area following the Texas City Y Spill. This is not unexpected given the small number of animals available to evaluate due to the decomposed state of the majority of the carcasses recovered.

5.6.1. Chemical Analysis Results

The toxicology results for dolphin GA1905, GA1915, and GA1894 show the following: (1) the internal tissues from the three dolphins did not contain measureable oil or oil-derived hydrocarbons of any kind, (2) external swabs from GA1905 and GA1915 did not contain measurable oil or oil-derived hydrocarbons of any kind, and (3) external swabs from GA1894 contained weathered Texas City Y oil, confirming external exposure. The absence of any oil-derived PAHs or petroleum biomarkers in the lung and stomach samples of the animals is not unexpected (see Stout 2017) and does not indicate that these bottlenose dolphins did not ingest, inhale, or aspirate the Texas City Y oil. Rather, findings from harbor seals exposed to oil during the EVOS demonstrate that harbor seals and other marine mammals metabolize petroleum hydrocarbons rapidly and efficiently, mediated through the induction of mixed-function oxidases (O'Hara and O'Shea 2001; Helm et al. 2015). Thus, evidence of petroleum hydrocarbon exposure often does not persist in marine mammal tissue samples. Accordingly, although the presence of elevated concentrations of PAHs in the bottlenose dolphin samples would have confirmed internal exposure immediately prior to death, the absence of elevated PAH concentrations in the tissue samples is not evidence of a lack of exposure to oil from the Texas City Y Spill or in general.

5.6.2. Diagnostic Test Results

Biotoxins and *Brucella* sp. infection have been linked to previous mortality events in the Gulf (Litz et al. 2014). As a result, tissues from 3 cases and 2 cases were submitted for biotoxin and *Brucella* sp. testing, respectively, to rule out common causes of UMEs.

The biotoxin analysis on GA1905 and GA1915 performed using the enzyme-linked immunosorbent assay (ELISA) technique confirmed low levels of brevetoxin-like activity (7 ng/g and 4 ng/g, respectively). However, brevetoxin was not confirmed present in these samples using liquid-chromatography/mass spectrometry (LC-MS). Brevetoxin was not detected in samples for GA1894. Domoic acid was also detected in the feces of GA1915 at low levels (5 ng/g) and was not detected in the other two tissue samples. Saxitoxin-like activity was not detected in any of the samples. The low level of brevetoxin activity (unconfirmed by LC-MS) and the level of domoic acid found in GA1905 and GA1915 are much lower than those levels found in bottlenose dolphin samples associated with previous biotoxin events and likely represent standard background levels (Litz et al. 2014, Fire et al. 2011).

The *Brucella* sp. results for GA1905 were positive for *Brucella* sp. infection, which is consistent with the lung lesions found in the histopathology as described below. The negative *Brucella* sp. results for animal PA1049 indicate that this animal was not infected with the bacterium and, therefore, *Brucella* sp. did not contribute to the animal's mortality.

5.6.3. Histopathology Results

Despite the tissue sample results confirming external exposure of GA1894 to weathered Texas City Y oil, the cause of stranding and death of this dolphin was not apparent in the histopathologically examined tissues. Lesions were observed in GA1894. However, those lesions were relatively mild and consistent with parasitic infection.

Lesions were observed in the lung of dolphin GA1905 that were consistent with *Brucella* sp. *in utero* infection, which was confirmed by the positive results of the *Brucella* sp. analysis. The histopathological evaluation, therefore, concluded that this animal likely died *in utero* or immediately after birth without taking a breath.

The cause of death for dolphin GA1915 was determined to be likely secondary to chronic bacterial infection, possible peracute sepsis, and emaciation. This animal had a large abscess in its abdominal cavity and the bacteria observed in its heart was indicative of a bacterial infection. Based on the emaciated state of the animal and the lesions present on its tissues, it appears that this animal was suffering from a chronic bacterial infection and was not eating well, which ultimately led to its death.

The results of the tissue analysis of dolphin PA1049 demonstrated that oil exposure may have contributed to its death. Dolphin PA1049 stranded three months after the Spill in Aransas County at Goose Island State Park. Histopathology showed severe lung and liver lesions that ultimately led to the animal's death. In particular, the liver lesions were similar to those noted in several dolphins examined following the DWH oil spill (Venn-Watson et al. 2015) as well as those described in oiled sea otters following the EVOS (O'Hara and O'Shea 2001), and concluded to be consistent with oil exposure. The histopathology results for PA1049 indicate a potential for chronic effects of the Texas City Y Spill.

Three additional fresh dead animals that did not meet the 2014 Plan criteria were also examined histopathologically. Death for dolphin GA1887, which stranded three days following the spill, was due to chronic bacterial pneumonia. Dolphin GA1927 died as a result of chronic and likely age-related kidney disease and emaciation. For dolphin GA1921, death was secondary to a fisheries interaction (chronic entanglement).

5.6.4. Summary of Tissue Sample Findings

While there are no direct findings that the Texas City Y Spill was the cause of the increased acute mortality for the sampled dolphins, there is some evidence the Spill may have led to some chronic adverse health effects. Moreover, the results do not suggest any other cause for the increased acute mortality in bottlenose dolphins in the oil impacted area following the Spill (e.g., there was no common pathologic findings that would indicate the dolphins died as a result of any of the common causes of previous mortality events in the region such as morbillivirus or biotoxins). Therefore, while increased acute mortality was observed following the Texas City Y Spill, the limited cases available for tissue evaluations were ultimately not determinative of the cause for that increase.

6. Summary of the Texas City Y Marine Mammal Injury Assessment

On March 22, 2014 the bulk carrier M/V *Summer Wind* and the oil tank-barge *Kirby 27706* collided in Galveston Bay near Texas City, Texas, discharging approximately 168,000 gallons (4,000 barrels) of IFO-380 into the Houston Ship Channel and state and federal waters of the GOM. Some of the oil came ashore impacting habitats and species along the Galveston Bay area within the first few days of the Spill. Much of the remaining surface oil traveled down the Texas coast and ultimately came ashore in areas as far south as Padre Island National Seashore in Corpus Christi, Texas. Overall, oil was observed on over 160 miles of shoreline and impacted multiple natural resources.

A statistical model using 2000-2015 data of weekly marine mammal strandings, controlling for time of year and historical UMEs, showed a significant increase in bottlenose dolphin mortality in the two weeks following the Spill for Region 1. A significant increase in the two weeks following the Spill was also observed in Region 2; however, the ability to determine whether these were related to increased stranding rates or increased search effort was limited by baseline conditions. Therefore, the Trustees chose a conservative approach and did not make an inference as to whether they were any Texas City Y Spill related excess mortalities in Region 2. Finally, the models provided no statistical evidence for elevated strandings in Regions 3 and 4 during the three-week period following the Spill.

The median number of excess strandings in Region 1 (Galveston Bay area, closest to where the Spill incident occurred) was 13.85 dolphins, with a 95% CI of 3.92-34.49. Assuming a 33% recovery rate (Well et al. 2015) for bottlenose dolphin carcasses, the observed number of strandings in the two weeks following the Texas City Y Spill corresponds to a median estimated number of excess dolphin mortalities of 41.6 (95% CI: 11.76-103.47).

As described in Sections 4.3.3 and 4.3.4, the Trustees' calculation of the injury to bottlenose dolphins resulting from the Texas City Y Spill accounts for (i.e., omits) marine mammal strandings reported due to the increased search efforts associated with the Spill response. Additionally, NOAA's marine mammal experts have concluded that the increased dolphin mortality immediately following the Spill was more likely than not caused by the Spill, rather than a UME, and a consultation with the WGMMUME was not initiated as a result of the localized, short-term spike in dolphin mortality, because (1) up until that point stranding rates within the oil impacted area had been normal for 2014, and (2) high stranding rates did not persist beyond a few weeks following the Spill or beyond the oil spill response period.

Diagnostic tests performed on a limited number of fresh dead dolphins that stranded in the 6 month period following the Spill were not conclusive as to cause of death (i.e., while the results did not confirm that exposure to Texas City Y was the cause of increased mortality, the results neither demonstrated any other typical cause of increases in mortality such as morbillivirus, *Brucella* sp., or biotoxin events).

The injury quantification used in this assessment does not attempt to account for long-term chronic effects from oil exposure and/or mortalities resulting from the Spill that likely occurred in the months following the Spill. Furthermore, the Trustees elected to omit stranding data to account for increased search effort in Region 1, and exercised caution in drawing inferences on spill related mortalities in Region 2. Therefore, this assessment should be considered a conservatively low estimate of marine mammal impacts due to the Texas City Y Spill.

7. References

Bodkin, J.L., B.E. Ballachey, H.A. Coletti, G.G. Esslinger, K.A. Kloecker, S.D. Rice, J.A. Reed, and D.H. Monson. 2012. Long-term effects of the 'Exxon Valdez' oil spill: sea otter foraging in the intertidal as a pathway of exposure to lingering oil. *Marine Ecology Progress Series*, 447: 273-287. doi:10.3354/meps09523

Colegrove, K.M. 2013. Marine Mammals, Oil, and the Gulf of Mexico: Perspectives on the 2010-2013 Northern Gulf of Mexico Cetacean Unusual Mortality Event. 2013 ACVP Annual Meeting Proceedings Contributions. Mini-Symposia: Gulf of Mexico Deepwater Horizon Oil Spill: Response, Research and Perspectives. Retrieved from http://www.acvp.org/~acvp0906/index.php/en/23-public-pages/meetings/331-2013-acvp-annual-meeting-proceedings-contributions

Colegrove, K.M., S. Venn-Watson, J. Litz, M.J. Kinsel, K.A. Terio, E. Fougeres, R. Ewing, D.A. Pabst, W.A. McLellan, S. Raverty, J. Saliki, S. Fire, G. Rappucci, S. Bowen-Stevens, L. Noble, A. Costidis, M. Barbieri, C. Field, S. Smith, R.H. Carmichael, C. Chevis, W. Hatchett, D. Shannon, M. Tumlin, G. Lovewell, W. McFee, and T.K. Rowles. 2016. Fetal distress and *in utero* pneumonia in perinatal dolphins during the Northern Gulf of Mexico unusual mortality event. *Diseases of Aquatic Organisms*, 119: 1-16. doi:10.33554/dao02969

Coppock, R.W., M.S. Mostrom, A.A. Khan, and S.S. Semalulu. 1995. Toxicology of oil field pollutant in cattle: a review. *Veterinary and Human Toxicology*, 37(6): 569-576.

Coppock, R.W., M.S. Mostrom, E.L. Stair, S.S. Semalulu. 1996. Toxicopathology of oilfield poisoning in cattle: a review. *Veterinary and Human Toxicology*, 38(1): 36-42.

Cullen, J.M. 2007. Liver. Biliary system, and exocrine pancreas. In: M.D. McGavin and J.F. Zachary (Eds.), Pathologic Basis of Veterinary Diseases (Fourth Edition). St. Louis, MI: Mosby Elsevier. 1488 pp.

DWH NRDAT (Deepwater Horizon Natural Resource Damage Assessment Trustees). 2016. Deepwater Horizon oil spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Retrieved from http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan

DWH MMIQT (Deepwater Horizon Marine Mammal Injury Quantification Team). 2015. Models and Analyses for the Quantification of Injury to Gulf of Mexico Cetaceans from the Deepwater Horizon Oil Spill. *DWH NRDA Marine Mammal Technical Working Group Report*. DWH-AR0105866.

Englehardt, F.R. 1983. Petroleum effects on marine mammals. *Aquatic Toxicology*, 4(3): 199-217. doi:10.1016/0166-445X(83)90018-8

ESRI. 2016. ArcGIS Desktop: Release 10.4. Redlands, CA: Environmental Systems Research Institute.

Fire, S.E., Z. Wang, M. Byrd, H.R. Whitehead, J. Paternoster, and S.L. Morton. 2011. Co-occurrence of multiple classes of harmful algal toxins in bottlenose dolphins (*Tursiops truncatus*) stranding during an unusual mortality event in Texas, USA. *Harmful Algae*, 10, 330-336. doi:10.1016/j.hal.2010.12.001

Gruber, J.A. 1981. Ecology of the Atlantic bottlenose dolphin (*Tursiops truncatus*) in the Pass Cavallo area of Matagorda Bay, Texas. M.S. Thesis. Texas A&M University, College Station. 182 pp.

Harrower, M. and M. Bloch. 2006. MapShaper.org: a map generalization web service. *IEEE Computer Graphics and Applications*, 26(4), 22-27. doi:10.1109/MCG.2006.85

Helm, R.C., D.P. Costa, T.D. DeBruyn, T.J. O'Shea, R.S. Wells, and T.M. Williams. 2015. Overview of Effects of Oil Spills on Marine Mammals. In: M. Fingas (Ed.), Handbook of Oil Spill Science and Technology (First Edition). Hoboken, NJ: John Wiley & Sons, Inc. 728 pp. doi:10.1002/9781118989982.ch18

Irvine, A.B., M.D. Scott, R.S. Wells, and J.H. Kaufmann. 1981. Movements and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, near Sarasota, Florida. *Fisheries Bulletin*, 79(4): 671-688.

Lane, S.M., C.R. Smith, J. Mitchell, B.C. Balmer, K.P. Barry, T. McDonald, C.S. Mori, P.E. Rosel, T. K. Rowles, T.R. Speakman, F.R. Townsend, M.C. Tumlin, R.S. Wells, E.S. Zolman, and L.H. Schwacke. 2015. Reproductive outcome and survival of common bottlenose dolphins sampled in Barataria Bay, Louisiana, USA, following the Deepwater Horizon oil spill. *Proceeding of the Royal Society B: Biological Sciences*, 282(1818): 20151944. doi:10.1098/rspb.2015.1944

Lipscomb, T.P., R.K. Harris, R.B. Moeller, J.M. Pletcher, R.J. Haebler, and B.E. Ballachey. 1993. Histopathologic lesions in sea otters exposed to crude oil. *Veterinary Pathology*, 30: 1-11.

Litz, J.A., M.A. Baran, S.R. Bowen-Stevens, R.H. Carmichael, K.M. Colegrove, L.P. Garrison, S.E. Fire, E.M. Fougeres, R. Hardy, S. Holmes, W. Jones, B.E. Mase-Guthrie, D.K. Odell, P.E. Rosel, J.T. Saliki, D.K. Shannon, S.F. Shippee, S.M. Smith, E.M. Stratton, M.C. Tumlin, H. R. Whitehead, G.A.J. Worthy, and T.K. Rowles. 2014. Review of historical unusual mortality events (UMEs) in the Gulf of Mexico (1990-2009): providing context for the multi-year northern Gulf of Mexico cetacean UME declared in 2010. *Diseases of Aquatic Organisms*, 112: 161-175.

Matkin, C.O., E.L. Saulitus, G.M. Ellis, P. Olesiuk, and S.D. Rice. 2008. Ongoing population-level impacts on killer whales *Orcinus orca* following the 'Exxon Valdez' oil spill in Prince William Sound, Alaska. *Marine Ecology Progress Series*, 356: 268-281.

Mazet, J.A., I.A. Gardner, D.A. Jessup, L.J. Lowenstine, and W.M. Boyce. 2000. Evaluation of changes in hematologic and clinical biochemical values after exposure to petroleum products in mink (*Mustela vison*) as a model for assessment of sea otters (*Enhydra lutris*). *American Journal of Veterinary Research*, 61(10): 1197-1203.

Mohr, F.C., B. Lasley, and S. Bursian. 2008. Chronic oral exposure to bunker C fuel oil causes adrenal insufficiency in ranch mink (*Mustela vison*). *Archives of Environmental Contamination and Toxicology*, 54(2): 337-347. doi:10.1007/s00244-007-9021-5

O'Hara, T.M. and T.J. O'Shea. 2001. Toxicology. In: L.A. Dierauf and M.D. Gulland (Eds.), CRC Handbook of Marine Mammal Medicine (Second Edition). Boca Raton, FL: CRC Press. 471 pp.

Pateiro-López, B. and A. Rodríguez-Casal. 2010. Generalizing the convex hull of a sample: the R package alphahull. *Journal of Statistical Software*, 34(5): 1-28.

Pebesma, E.J. and R.S. Bivand. 2005. Classes and methods for spatial data in R. R News 5(2), http://cran.r-project.org/doc/Rnews/

Peterson, C.H., S.D. Rice, J.W. Short, D. Esler, J.L. Bodkin, B.E. Ballachey, and D.B. Irons. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. *Science*, 302(5653): 2082-2086.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rosel, P. and K. Mullin. 2015. Cetacean species in the Gulf of Mexico. *DWH NRDA Marine Mammal Technical Working Group Report*. DWH- AR0106040.

Schwacke, L.H., C.R. Smith, F.I. Townsend, R.S. Wells, L.B. Hart, B.C. Balmer, T.K. Collier, S. De Guise, M.M Fry, L.J. Guillette Jr., S.V. Lamb, S.M. Lane, W.E. McFee, N.J. Place, M.C. Tumlin, G.M. Ylitalo, E.S. Zolman, and T.K. Rowles. 2014. Health of common bottlenose dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, following the Deepwater Horizon oil spill. *Environmental Science and Technology*, 48(1): 93-103.

Schwartz, J.A., B.M. Aldridge, B.L. Lasley, P.W. Snyder, J.L. Stott, and F.C. Mohr. 2004. Chronic fuel oil toxicity in American mink (*Mustela vison*): systemic and hematological effects of ingestion of a low-concentration of bunker C fuel oil. *Toxicology and Applied Pharmacology*, 200(2): 146-158. doi:10.1016/j.taap.2004.04.004

Shane, S.H. 1977. The population biology of the Atlantic bottlenose dolphin, *Tursiops truncatus*, in the Aransas Pass area of Texas. M.S. Thesis. Texas A&M University, College Station. 238 pp.

Stout, S.A. 2014. Chemical analysis of Texas City Y source oil and floating oil samples. NewFields letter report to Dr. R. Haddad, NOAA, dated April 16, 2014.

Swets, J. 1988. Measuring the accuracy of diagnostic systems. *Science*, 240(4857): 1285-93.

Venn-Watson, S., K.M. Colegrove, J. Litz, M. Kinsel, K. Terio, J. Saliki, S. Fire, R. Carmichael, C. Chevis, W. Hatchett, J. Pitchford, M. Tumlin, C. Field, S. Smith, R. Ewing, D. Fauquier, G. Lovewell, H. Whitehead, D. Rotstein, W. McFee, E. Fougeres, and T. Rowles. 2015. Adrenal gland and lung lesions in Gulf of Mexico common bottlenose dolphins (*Tursiops truncatus*) found dead following the Deepwater Horizon oil spill. *PLoS ONE*, 10(5): e0126538. doi:10.1371/journal.pone.0126538

Waring, G.T., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2013. US Atlantic and Gulf of Mexico marine mammal stock assessments – 2012. *NOAA Technical Memorandum NMFS-NE-223*, 419 pp.

Wells, R.S., J.B. Allen, G. Lovewell, J. Gorzelany, R.E Delynn, D.A. Fauquier, and N.B. Barros. 2015. Carcass-recovery rates for resident bottlenose dolphins in Sarasota Bay, Florida. *Marine Mammal Science*, 31(1): 355-368.

Williams, R., S. Gero, L. Bejder, J. Calambokidis, S.D. Kraus, D. Lusseau, A.J. Read, and J. Robbins. 2011. Underestimating the damage: interpreting cetacean carcass recoveries in the context of the Deepwater Horizon/BP incident. *Conservation Letters*, 0: 1-6. doi:10.1111/j.1755-263X.2011.00168.x

Worthy, G.A.J. 1998. Patterns of bottlenose dolphin, *Tursiops truncatus*, strandings in Texas. In: R. Zimmerman (Ed.), Characteristics and causes of Texas marine strandings. *U.S. Department of Commerce, NOAA Technical Report NMFS 143*, 85 pp.

8. Appendix 1—GAM Model Outputs

Table 1: GAM Model Output for Region 1

```
Family: Tweedie(1.2)
Link function: log

Formula:
strand ~ s(week, bs = "ts", k = 10) + ume + tcy

Parametric coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -0.73883    0.07001 -10.554  < 2e-16 ***
ume          0.65214    0.13330   4.892  1.2e-06 ***
tcy          1.27236    0.37762   3.369 0.000788 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
          edf Ref.df    F p-value
s(week) 7.775      9 58.1  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.502   Deviance explained = 52.3%
-REML = 948.86  Scale est. = 1.6292    n = 848
```

Table 2: GAM Model Output for Region 2

```
Family: poisson
Link function: log

Formula:
strand ~ s(week, bs = "ts", k = 10) + ume + tcy

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -3.2386     0.2049 -15.803  < 2e-16 ***
ume           1.4366     0.3148   4.563 5.03e-06 ***
tcy           3.1872     0.4661   6.838 8.03e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
          edf Ref.df Chi.sq  p-value
s(week) 3.973      9  31.18 4.45e-07 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.205   Deviance explained = 27.6%
-REML = 213.04  Scale est. = 1         n = 848
```

Table 3: GAM Model Output for Region 3

```
Family: poisson
Link function: log
```

```
Formula:
strand ~ s(week, bs = "ts", k = 10) + ume + tcy

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) -0.89066    0.05903 -15.088   <2e-16 ***
ume          0.25687    0.16736   1.535    0.125
tcy          0.45078    0.51058   0.883    0.377
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
          edf Ref.df Chi.sq p-value
s(week) 7.144      9  301.1  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.252   Deviance explained =   28%
-REML = 791.94  Scale est. = 1         n = 848
```

Table 4: GAM Model Output for Region 4

```
Family: poisson
Link function: log

Formula:
strand ~ s(week, bs = "ts", k = 10) + ume + tcy

Parametric coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept)  -2.6227     0.1556 -16.855  < 2e-16 ***
ume           0.7437     0.2613   2.846  0.00442 **
tcy           1.4864     0.7394   2.010  0.04441 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
          edf Ref.df Chi.sq p-value
s(week) 5.467      9  99.57  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.154   Deviance explained = 28.5%
-REML = 318.52  Scale est. = 1         n = 848
```