A Graphical Exploration of the Deepwater Horizon Oil Spill

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Abstract

This paper investigates some of the immediate impact of the Deepwater Horizon Oil Spill of 2010 on the environment using graphics means. The exploration focuses on the effects of the oil spill on wildlife, the chemical pollution in the area following the spill, and salinity levels in the aftermath of the spill. Thousands of animals including birds, turtles, dolphins, and whales were found dead along the beaches and in the Gulf of Mexico in the months after the oil spill. Levels of Polycyclic Aromatic Hydrocarbons were found to be at dangerous levels along the coast line, making conditions for wildlife highly unfavorable. Salinity measurements, which can be used to determine currents and oil movement, are examined over time as well as geographically.

1. Introduction

April 20th, 2010 marked the beginning of the largest oil spill in the history of off-shore drilling. Following an explosion in the Deepwater Horizon drilling rig and failure of all emergency systems, crude oil began to gush into the ocean. After an estimated 4.1 million barrels of oil discharged with 0.8 million barrels being recovered before entering the ocean, the leak was finally stopped on July 15th of 2010 when the well head was capped. The completion of the relief well took until September 19, 2010. In the months following the explosion, vast amounts of data were collected in the area. This data represents an unprecedented body of information concerning the oil pollution. The immediate impact of the oil spill on people and wildlife alike was overwhelming and can still be felt today. The oil destroyed many habitats for birds, turtles, and other marine wildlife. Waters had to be closed for fishing, affecting the livelihood of the people that depend on the fishing industry. Longterm effects are certain.

It is of course impossible to do an analysis that adequately reflects the full extent and complexity of the effects of the BP oil spill. The focus of this paper is therefore on immediate environmental impacts of the oil spill on the Gulf of Mexico and present graphical analyses of data such as: temperature and salinity provided by the Environmental Protection Agency (EPA), chemical measurements obtained by the National Oceanic and Atmospheric Administration (NOAA) and data on wildlife from the US Fish and Wildlife Service (FSW). These measurements are of interest as they serve

Variable	Description
Class	type of animal found:
	Birds (5,552), Whales and Dolphins (98), Sea Turtles (546)
Species	species of animal
Latitude	latitude of sighting in degrees
Longitude	longitude of sighting in degrees
Alive	condition of animal:
	Alive (2,197), Dead (6,196)
Observation Date	date of observation 'mm-dd-yyyy'.

Table 1: Overview of variables used as well as brief results. Animal Sightings between April 26, 2010 and October 18, 2010, source: Avian Observations from US Fish and Wildlife (Southeast Region), Marine Mammal Observations reported by the National Marine Sanctuary, NOAA, and the Office of Protected Resources, NOAA.

as indicators for environmental stability and conditions; salinity, for example, has a major influence on determining oceanic flow; Polycyclic Aromatic Hydrocarbons (PAHs), a class of mostly carcinogenic chemicals present in oil, are a quantifiable measure of environmental pollution.

2. Graphical Exploration

2.1. Animal Sightings

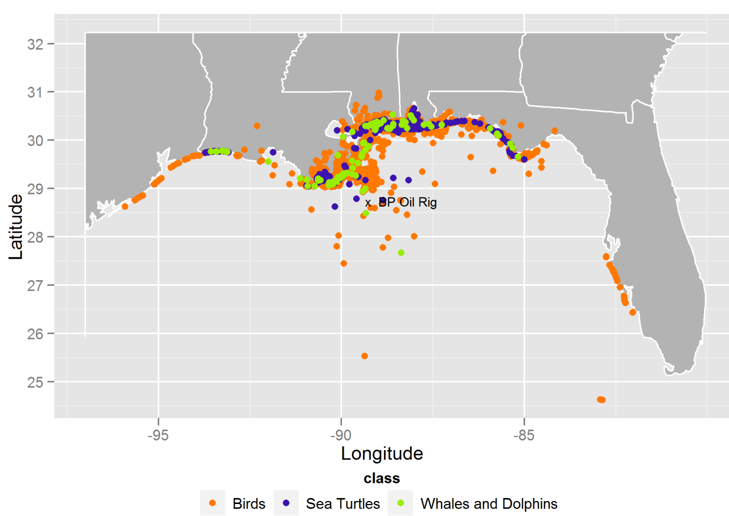

Figure 1: Map of a part of the Gulf of Mexico. The location of the water Horizon rig is marked by a black cross. Each dot on top of the map represents the sighting of one dead animal: 5,552 birds (orange), 546 sea turtles (blue), and 98 dolphins and whales (green).

Pictures of oiled beaches littered with washed-up bodies of oil-blackened animals are often the most intense and affecting visuals the public gets to see in the immediate aftermath of any oil spill. The value of such pictures for the purpose of educating the public about the impacts of oil spills becomes clear when noting that a photo depicting oiled pelicans from the BP oil spill was voted this year's winning entry in the Veolia Environment Wildlife Photographer of the Year by Beltrá (2011) exhibited in the Natural Historic Museum (2011). Seeing such photographs in the media countless of times led us to investigate which animals were effected the most by the BP oil spill and how these effects extended geographically.

Counts for animal sightings, both alive and dead, were collected by the local Departments of Natural Resources and National Agencies. For the Data Expo 2011 Challenge we had access to data from the National Marine Sanctuary, the Office of Protected Resources as well as the US Bureau of Fish and Wildlife Service. Table 1 gives a more detailed overview of the variables that we used for our graphical exploration.

Figure 1 shows a map overlaid by a scatterplot indicating locations of animal sightings. Most of the sightings follow the coastline – this is not surprising since many animals were washed up onto beaches or found in shallow coastal waters which generally provide the easiest access to make these kind of observations. Note that there is some overprinting and that rarer animals are plotted on top.

From Figure 1 we can see that the shores of Louisiana and Mississippi, closest to the oil rig show the highest concentration of dead animals. Each dot corresponds to one dead animal, where the orange dots represent birds, blue dots represent sea turtles, and green dots indicate large mammals, such as whales and dolphins. Overall a total of 6,196 animals were reported dead during the six month period from April to October 2010. We plan to continue to look at collected data to see the effects over time.

Birds, sea turtles, and dolphins and whales each show a unique death pattern during the data collection period as Figure 2 illustrates. The top figure displays the cumulative death rate for each species over time; the birds' response to the disaster happens at a later time than that of sea turtles, whales and dolphins. Their death rate is relatively low from May to July, after which the rate begins to increase. Sea turtles, dolphins and whales, on the other hand, peak in their death rates from May through July and then begin to flatten out.

These patterns are shown in more detail in the bottom three charts of figure 2, which represent daily death counts between May and October for each class of animals. For sea turtles, dolphins, and whales, the highest daily death counts occur in the earlier weeks and then decrease over time. The majority of dead bird findings occurs later in time and their death counts per day begin to climb rapidly around July. After the leak in the oil rig was stopped on July 15th, the number of daily deaths begins to exhibit much more variability until the sightings begin to decrease by mid-September. However, it is important to keep in mind the effect reporting rates may have had on these patterns.

Four species of sea turtles were found and identified during the data collection period, all of which are considered to be either threatened or endangered. These species are: Kemp's Ridley (Endangered), Hawksbill Sea Turtle (Endangered), Green Sea

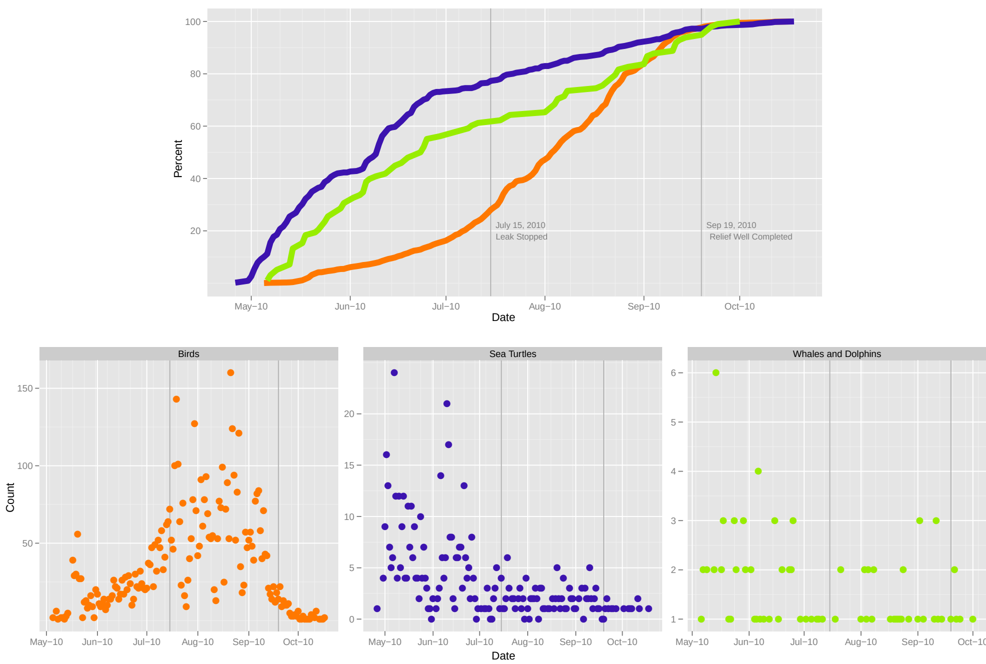

Figure 2: Cumulative animal deaths scaled relative to the total number of deaths in each group (top) and absolute number of dead animal sightings (bottom) between April and October 2010.

Turtle (Threatened or endangered, depending on the distinct population segment), and Loggerhead Sea Turtle (Threatened or endangered, depending on the distinct population segment). Figure 3 shows the time and location these turtles were found and whether they were alive or dead. Most dead turtles, across all species, were found along the shoreline. Alive sea turtles were mostly spotted off the coast. From the graphs we can identify two main areas along the coasts of Louisiana and Florida in which the majority of alive sea turtles were found. This is most evident among the Green Sea Turtle and Kemp's Ridley. The species with the greatest number of found casualties is Kemp's Ridley, an endangered species which lives primarily in the Gulf of Mexico. Due to migratory patterns, it is more common for Kemp's Ridley sea turtles to be present in the northern part of the Gulf of Mexico during June, July, and August. Female Kemp's Ridleys, like other sea turtles, nest between May and July and lay their eggs on various beaches of the Gulf of Mexico (Office of Protected Resources, NOAA Fisheries, 2011). This explains why there were more turtles in the area during the months after the oil spill occurred, and thus more sea turtles to be found. After August, however, it is natural for these turtles to begin to leave the area and to head south. Very few turtles were found after September, 2010.

2.2. Chemicals

Various chemicals were sampled in the Gulf of Mexico during the months following the oil spill. This analysis focuses on Polycyclic Aromatic Hydrocarbons firstly

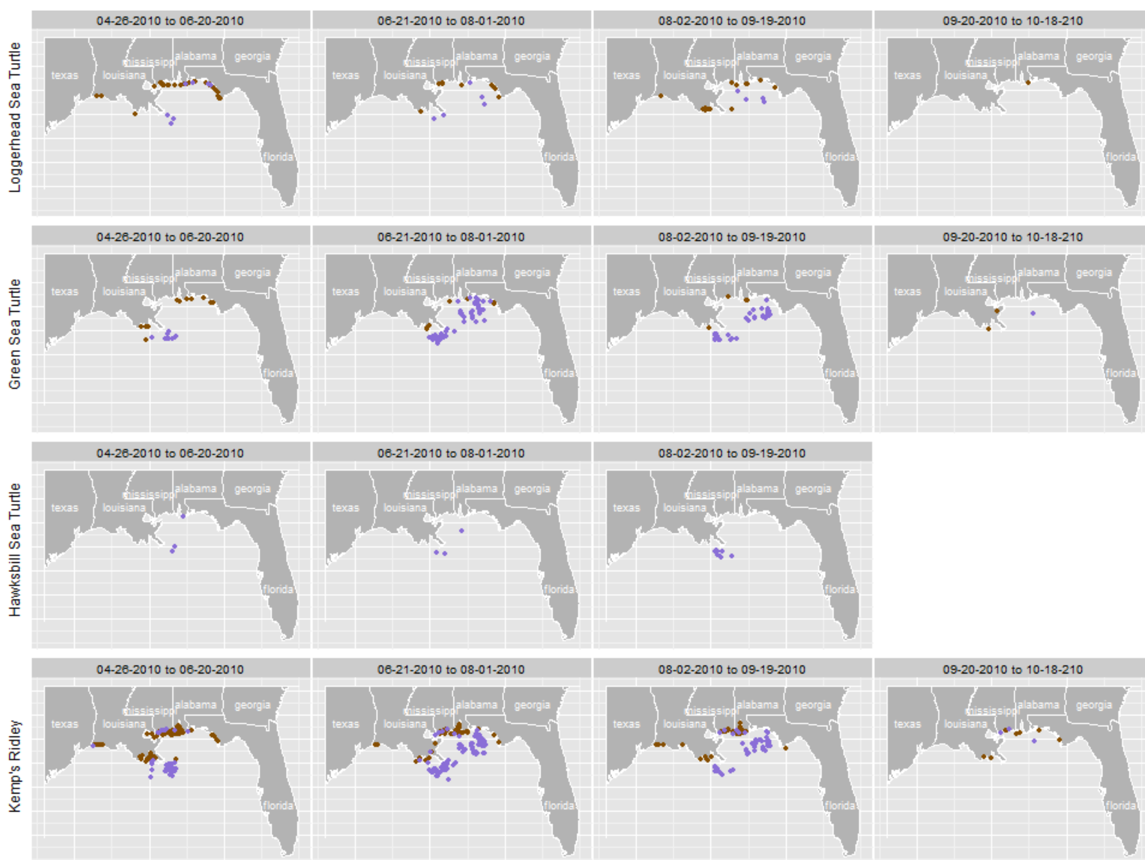

Figure 3: Sightings of four species of endangered or critically endangered sea turtles observed in the Gulf of Mexico from April 26th to October 18th 2010. Blue dots indicate turtles found alive; brown dots indicate those found dead.

Variable	Description
Substance	Polycyclic Aromatic Hydrocarbon (PAH) substance
Date	date of observation.
Latitude	latitude of sampling in degrees.
Longitude	longitude of sampling in degrees.
Result	measured amount
Unit	unit of measurement:
	μg/l for water, μg/kg for sediment
Danger Level*	health effects:
	carcinogenic (23,201), other health effects (3,640)
Alkylation Multiplier**	used for calculations, see Appendix A
Acute Potency Divisor**	used for calculations
Chronic Potency Divisor**	used for calculations

Table 2: Water and sediment chemistry data of petrochemical products, sampled near the coastline in the months after the oil spill, source: US Environmental Protection Agency.
*according to recommendations of US Environmental Protection Agency (2011)
**following Mount (2010)

because of their direct relationship with oil and secondly because of their toxicity to wildlife. Polycyclic Aromatic Hydrocarbons, or PAHs, are semi-volatile organic substances which come mainly from oil and the burning of oil. However, they can also come from exhaust and from the burning of gas, coal, garbage and other organic substances (US Environmental Protection Agency, 2010). Many of these substances are considered carcinogenic, mutagenic, and teratogenic and all are considered harmful to the health of living organisms. Based on EPA guidelines (US Environmental Protection Agency, 2010), we added this information to the existing data.
A hurdle to overcome for these data presented the units of measurements that were recorded in the original spreadsheets. Units of measurements varied depending on the nature of the chemical and were also not reported consistently. To judge the combined effect of the sum of these chemicals on life in the Gulf of Mexico we put all chemicals on a common scale. To do so, we followed the approach by Mount (2010): measurements of the PAHs are aggregated across substances for each location and considered in terms of their acute and chronic potency: a location is considered to be at a chronic level when the total amount of harmful substances is thought to bring harmful effects over a long period of time. For an acute level the overall amount of substances is at a level that rapidly induces a negative and possible irreversible effect on an organism.

Each PAH substance has a unique threshold at which it has an acute and chronic effect on humans. These thresholds are called potency divisors and can be used to find the corresponding potency ratios by dividing the observed amount of the chemical by its potency divisor. (For a more detailed discussion we refer the reader to Appendix A.) If the amount of substance measured at any location exceeds the level of the acute potency divisor, (i.e. resulting in an acute ratio of greater than one) this substance has an acute detrimental effect on a human being's health.

For surface water and sediment samples alike, these ratios are additive in effect. We can therefore sum ratios at each location to determine the overall effect of all chemicals on human beings. Again, a ratio of greater than one on the acute level is generally considered as causing immediate harmful effects on human beings.

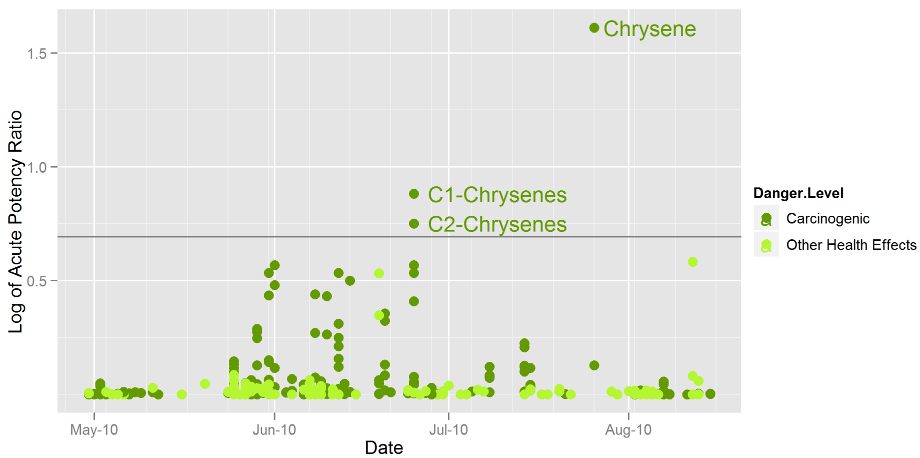

Figure 4: Timeline of logarithm of acute potency ratios. Each dot is a single measurement taken of a substance. Points are colored according to a substance's effect on health. There is a period of time between June and July in which the acute value is heightened. Points which exceed the acute benchmark are labeled.

Figure 4 shows the (log) acute potency ratios for measurements recorded between May and August of 2010. Three measurements of PAH substances exceed the acute potency ratio, indicating that these substances by themselves were high enough to be acutely dangerous. All of them belong to the Chrysene family, which is considered to be carcinogenic. During the period between June and July measurements of these PAH substance showed elevated values.

Figure 5 shows a map of the gulf coast overlaid by yellow points at locations where PAH measurements were taken. All values are aggregated which minimizes the impact of individual extreme values. Locations with elevated PAH values are emphasized by colored dots: orange (at or above chronic) and red (at or above acute thresholds). Particularly along the outer coast of Louisiana, many of the observed PAH values exceeded the benchmarks. This might be an indication that this area had the most direct contact with the oil.

2.3. "Where does the oil go?" – Salinity Analysis

In the days after the explosion the question "Where does the oil go?" was the second most interesting question after "How big is the spill?." The oil flow is mostly driven by the current which can be determined based on measurements of salinity, depth and temperature. In order to keep track of the oil movement, NOAA pulled most of its resources into the Gulf area to measure these characteristics: two boats, 11

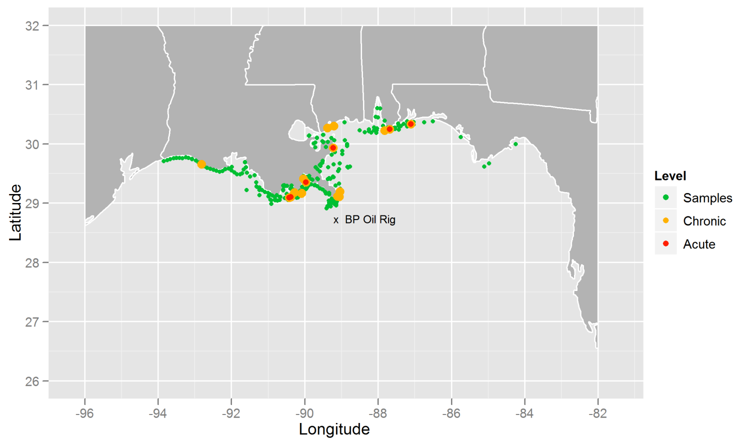

Figure 5: Map of the Gulf Coast area overlaid by locations at which PAH measurements were taken (green). Orange dots represent locations that are at a chronic level, red dots mark locations with an acute level. This figure represents data pooled over both time and position. More dangerous points are plotted on top of less dangerous points. The most dangerous area is along the outermost shore of Louisiana: many locations here have PAH levels at or above chronic or acute benchmarks.

Variable	**Description**
Date	date of observation.
Latitude	latitude of sampling in degrees
Longitude	longitude of sampling in degrees.
Depth	depth of measurement in feet
Salinity	amount of salinity in mg/l
Type	type of measuring device:
	Boat (24,381), Float (10,332), Glider (368,563)

Table 3: Recordings of Salinity, Depth and Temperature at various locations throughout the Gulf, source: National Geographic Data Center (NODC)

floats, and 10 gliders, which recorded salinity, temperature, and depth measurements at various locations in the Gulf of Mexico. The floats tended to stay in the deeper water while the boats and the gliders recorded measurements in locations further away from the oil rig. Figure 6 shows the patterns of these three measuring methods.

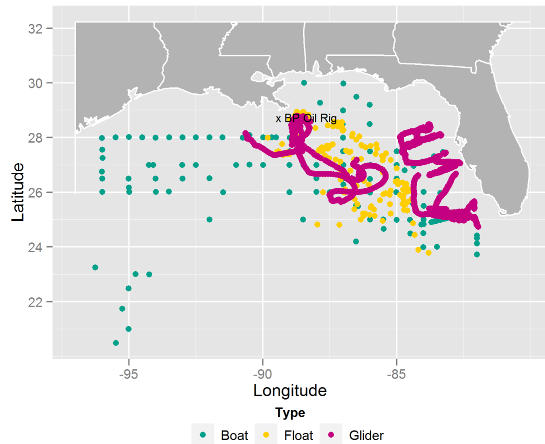

Figure 6: All observation points of boats (blue), floats (yellow), and gliders (purple). The paths the devices followed to take measurements in the months of data collection are visible. We can see that the boats follow a grid pattern, particularly in the Western region of the gulf. Floats and gliders seem to either be more affected by currents or are more easily maneuvered as they show a 'criss-cross' pattern across the area where the bulk of the oil went after the spill.

Figure 7 pictures salinity measurements over the whole data collection period. Points are color coordinated by time to link the left and right display. Approximately 99% of the salinity measurements stayed within a range of values close to 34 and 38 mg/l. We highlighted the locations with salinity values below 34 mg/l in the right side of figure 7. The highest concentration of these points is found near the rig during June and July.

Depth and salinity form a close relationship as can be seen in Figure 8. For depths below 100 feet salinity levels are nearly constant. This is not the case for many measurements taken near the surface. Figure 8 also shows two lines of measurements taken by a boat which do not follow the typical relationship. The surface water measurements for these cases were far below normal values and then rapidly dropped with depth. This, however, was observed in locations far from the rig and could be an unrelated incident.

2.4. Tools used

The tools that we used for formatting the data and making the charts are: `R` (R Development Core Team, 2011), `ggplot2` (Wickham, 2009), `RgoogleMaps` (Loecher, 2011), link between `ggplot2` and `RgoogleMaps` provided by Kahle (2010) as part of his entry in the ggplot2 competition.

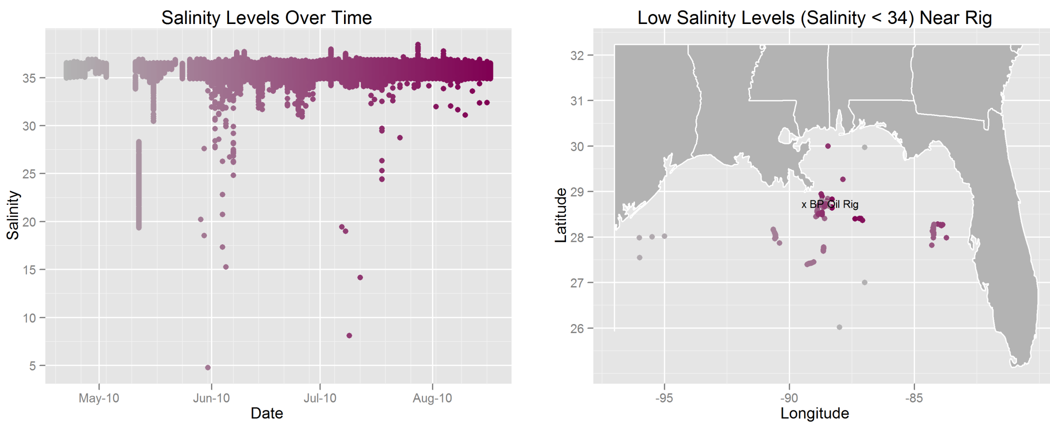

Figure 7: Salinity measurements: over time (left) and by location (right). Salinity measurements only rarely fall below 34 mg/l. In the months after the start of the oil spill salinity frequently drops below 34 mg/l. For later weeks this happens in particular in locations close to the oil rig.

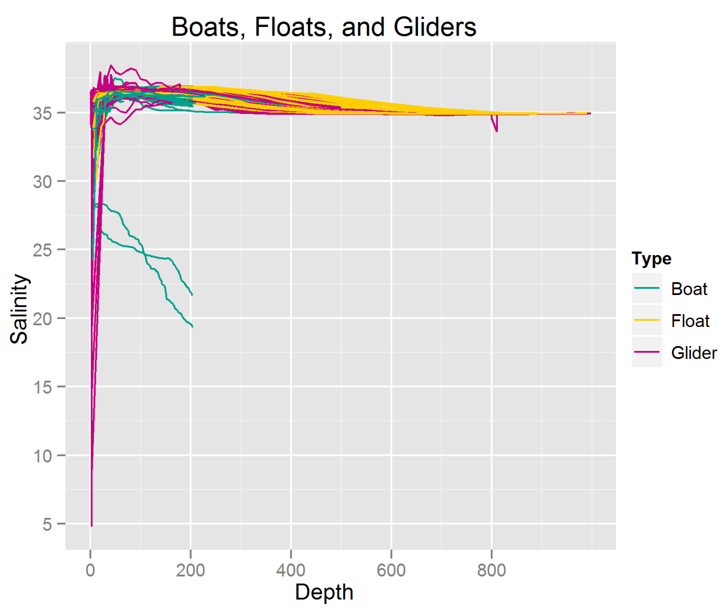

Figure 8: Relationship between depth and salinity grouped by each unique latitude and longitude combination. Depth and salinity almost always maintain a fixed relationship, as seen in most of the observations. However, some areas, mainly those at the surface of the water, experienced unusually low values of salinity. Two areas, which were measured by a boat, had a depth-salinity relationship very unlike the rest.

3. Conclusions

Although there is no doubt that the oil spill caused a tremendous amount of damage, the lack of data and necessary substance knowledge make it difficult to draw reliable conclusions. We have no information on the actual cause of death of the birds, sea turtles, dolphins, or whales. We also do not have past data to compare these findings with and so can only reasonably assume that the observed number of dead animals is higher than unusual, for example the data on birds indicated whether the found bird was oiled or not.

It is also hard to draw definite inferences based on the PAH measurements. While we know PAH substances were found at harmful levels along the coast, we, again, do not have baseline data to compare post-spill levels to. As with the animal deaths, we can only reasonably assume that the high levels of PAHs are unusual for the area.

Past data was available for salinity. However, the area in which these pre-spill salinity values were measured is quite different from the area in which the post-spill salinity values were measured. Salinity measurements taken along the coastline are quite different and therefore not directly comparable to those taken in the middle of the Gulf of Mexico. Better baseline data would have facilitated making conclusions about the effects of the Deepwater Horizon oil spill on chemicals in the gulf, these chemicals' effects on wildlife, and salinity levels.

What we do know is that the environmental conditions were highly unfavorable during the months after the oil spill. Polycyclic Aromatic Hydrocarbons were found at chronic and acute levels along the shoreline of the Gulf of Mexico. These levels are high enough to cause cancer and disrupt reproduction, development, and the immune system of many organisms. Effects of these PAHs are likely to be felt long after the spill. Animals which did survive the initial spill and its aftermath such as birds, sea turtles, dolphins, and whales are all at risk for developing health problems in the future related to this event. For this reason, the numbers in Figure 1, which only cover a five month period after the spill, do not entirely represent the number of animals that will have ultimately died as a result of the oil spill. The Deepwater Horizon oil spill was a disaster which affected the environment, wildlife, and society upon impact, and will continue to do so for an indefinite number of years.

Appendix A. Benchmark Calculations

Appendix A.1. Water Measurements

Chronic and acute benchmark vales are computed based on the observed amount of PAH substance as follows:

$$\text{Acute/Chronic Benchmark Value} = \sum \frac{\text{Alkylation Multiplier} \times \text{Measured Amount of Substance}(\mu g/L)}{\text{Acute/Chronic Potency Divisor}}$$

Appendix A.2. Sediment Measurements

For substances measured in sediment, the amount of organic carbon for that area must additionally be used to find the acute and chronic potency ratios. Taking the organic carbon into consideration is important for sediment samples because, when it is present in the sediment, the PAHs bind to it, thus making the PAHs less toxic. Organic carbon, like any other substance, was measured at each location.

The following formulas show how we attained the chronic and acute benchmark values for sediment:

Sediment

$$\text{Acute/Chronic Benchmark Value} = \sum \frac{\text{Alkylation Multiplier} \times \frac{\text{Measured Amount of Substance}(\mu g/kg)}{\text{Organic Carbon}}}{\text{Acute/Chronic Potency Divisor}}$$

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