The effects of MOSSFA on pelagic and benthic organisms
Contributors: Amy Baco-Taylor, Gregg Brooks, Jeff Chanton, David Hastings, David Hollander, Joel Kostka, Bekka Larson, Ian MacDonald, Will Overholt, Isabel Romero, Patrick Schwing

Outline
- Introduction
- Effects in the water column and in planktonic ecosystems
- Effects in benthic ecosystems
- Summary and conclusions

Published results largely skewed to offshore and to deep plumes
Mechanisms of transport and deposition

Gas and oil entrained water

Deep plumes

Cloud of Oil Droplets (10-60 μm)

Sources: biogenic, lithogenic, petrogenic, pyrogenic

Particle formation

Potential Scenarios for Oil in Sub-surface Areas

OSAT Report, December 2010
Primary Mechanisms of Sedimentary Oil Deposition Associated with a Deep-Water Oil-Well Blowout

- **Flocculent Blizzard:** Enhanced flocculation and sinking of particles containing petrogenic, pyrogenic lithogenic and biologic (organic and inorganic, marine and terrestrial) sources.

- **Toxic Bath-Tub Ring:** Direct intersection-contact of toxic subsurface plume containing dissolved (BTEX) and microdroplets (PAHs) with slope sediments.

---

**Water column effects**

- Barreleyes come from the sea through a filter feeder. A filter feeder is any filter-feeding organism that extracts nutrients from a water current. Some common filter feeders are sea sponges, sea urchins, and sea cucumbers.

- Some filter feeders can be quite large, and they play an important role in the marine ecosystem. For example, sea urchins are herbivorous grazers that help control the growth of seaweed and other vegetation at the bottom of the ocean.

- Other filter feeders are carnivores that feed on smaller organisms. For example, sea cucumbers are omnivorous filter feeders that eat a variety of organisms, including plankton and other small marine creatures.

- Filter feeders are important for the health of the marine ecosystem because they help maintain the balance of the food web and prevent the overgrowth of certain species.
Two endmember model for plankton studies

Chanton

- Mixing between modern surfaced-fixed carbon and fossil petro-carbon

\[ \delta^{13}C_{\%o} \]

-27\%o to -60\%o

\[ \Delta^{14}C_{\%o} \]

-100\%o

Modern surface

PETRO

Mixing Lines

-20\%o

Stable C isotope composition indicates that Macondo oil C entered the coastal planktonic food web

Graham et al., 2010

- C isotope depletion coincident with arrival of oil slicks in northern Gulf
- Both small suspended particles (1 um to 0.2 mm) and “mesozooplankton” (0.2 to 2 mm) showed evidence of oil-derived C
- Terrestrial C sources ruled out
Radiocarbon evidence that Macondo oil C entered the offshore planktonic food web

Chanton et al., 2012

- Radiocarbon provides a more sensitive tracer
- Radiocarbon from plankton samples much more depleted relative to DIC
- Linear correlation between $^{14}$C and $^{13}$C
- Isotope mass balance indicates more methane than petroleum was incorporated

Microbial ecology of hydrocarbon degradation

- Hydrocarbon metabolism involves the entire microbial food web, including microbes that do not degrade oil

Head et al., 2006
Effects on planktonic microbes - Deep

Dubinsky et al., 2013 – Deep Plumes

- Large shift in community structure and diversity correlated with presence of HCs
- Enriched taxa were exclusively Gammaproteobacteria
- Evidence for succession of populations related to HCs present

Oceanospirillaceae linked to degradation of alkanes and cycloalkanes
Other taxa linked, Colwellia and Alteromonads linked to aromatics
Large overlap with HC-degraders observed in surfaced oil (Gutierrez et al., 2013)
Effects on planktonic microbes - deep

Most reads in plume transcriptome matched to Oceanospirales, Methylococcaceae, Colwellia, Methylophaga  
Consistent with hypothesis that Methylococcaceae are primary methane consumers in system

Rivers et al., 2013 – Deep Plumes

Benthic effects

Photos by Ian MacDonald
Sediment Collection:
- 63 cores collected at 49 sites in DeSoto Canyon region
- Aug 2010 to Oct 2012
- Multicorer - 8 core/deployment
- Cores extruded @ high resolution
  2 mm to 20 cm, 5 mm to 60 cm

Sample Locations and Methods

Methods:
1. Geochronology
   \(^{234}\text{Th},^{210}\text{Pb}, \text{MAR-gm/cm}^2/\text{yr}\)
2. Sedimentology
   (Grain size, clays)
3. Redox metal chemistry
   (MnO\textsubscript{2} oxid, Re-anoxia)
4. Organic Geochemistry
   (Org-C, Aliphatics, PAHs)
5. Benthic Foraminifera
   (mortality, recovery)
6. Microbial Ecology
   (community structure)
7. Bulk \(^{14}\text{C}\)
   (Org-C source indicator)
Evidence for rapid sedimentation

- $^{234}\text{Th}$ profiles reflect deposition and not bioturbation
- Deposition of a 0.4 to 1.2 cm thick layer in 4-5 months
- MAR much higher than average rates for previous 100 yrs based on $^{210}\text{Pb}$

Brooks et al., 2013

---

Evidence for rapid sedimentation

- Time series from sites reoccupied over multiple cruises over a 2 yr period indicates that $^{234}\text{Th}$-derived MAR declined from 2010 to 2012

Brooks et al., 2013
Evidence for rapid sedimentation

Multiple lines of evidence indicate that the surface 1-2 cm depth is distinct from underlying sediments

Brooks et al., 2013
See Gregg’s poster

Hydrocarbon deposition and pathways

Fluxes of TOC, aliphatics, and PAHs increased up to 46, 100, and 50 X, respectively

Evidence indicates 3 transport pathways: marine snow, sinking of burned oil particles, and advective transport of dissolved oil from deep intrusion (deep plumes)

Romero et al., 2013
See Isabel’s poster
Primary Findings:
1. Decline in total abundance in late 2010, early 2011
2. Recovery is site specific: one site has not recovered as of Sept. 2011, abundance has recovered at another site with different community structure
3. Mechanisms for decline: increased anoxia and PAH concentrations
4. Depletion in δ¹³C (oil is δ¹³C depleted) synchronous with decline
5. δ¹³C mass balance: foram calcite composed of 0.1-7% petroleum carbon (at surface)

- Please see Schwing et al. poster for more detail

Schwing et al., 2013
Hastings et al., 2013

A substantial enrichment in gene sequences derived from phytoplankton chloroplasts in the top 2 cm of deepsea sediment cores is consistent with the hypothesis of a large, particle-rich blizzard-like depositional event directly after the Deepwater Horizon discharge.

<table>
<thead>
<tr>
<th>OTU_Name</th>
<th>Avg Percent Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacillariophyta_Phaeodactylum</td>
<td>2.30%</td>
</tr>
<tr>
<td>Bacillariophyta_unclass</td>
<td>0.89%</td>
</tr>
<tr>
<td>Bacillariophyta_unclass</td>
<td>0.69%</td>
</tr>
<tr>
<td>Bacillariophyta_Navicula</td>
<td>0.64%</td>
</tr>
<tr>
<td>Bacillariophyta_Synedra</td>
<td>0.56%</td>
</tr>
</tbody>
</table>
Effects on benthic microbes

Kimes et al., 2013

- Evidence for shift in community structure
- Metagenomes sampled in fall 2010 within a few km of wellhead showed enrichment of Deltaproteobacteria
- Genes associated with anaerobic HC degradation increased in abundance
- However, study based on single metagenomes and no geochemical data provided

Enrichment of aerobic HC-degraders from the deepsea

- Isolation and characterization of HC-degraders from PCB-06
- Rhodococcus and Halomonas isolated at 4 C from PCB 06
- Rhodococcus
  - Member of Actinobacteria
  - Produces EPS and shown to enhance growth of other strains
  - Degrades alkanes, aromatics
  - Psychrotolerant, genes for HC degradation detected in Antarctic soils
Detected Sequences in iTag Libraries

- Rhodococcus erythropolis str. HS18
- Rhodococcus sp. UF3.6528
- Rhodococcus erythropolis str. DSM43188
- Rhodococcus species
- Rhodococcus sp. 4
- Rhodococcus sp. AM6
- Rhodococcus fascians str. JPLto2-4
- Rhodococcus sp. str. 5-11
- Rhodococcus phenolicus str. G2P
- Rhodococcus gordoniae AK38
- Rhodococcus sp. str. 085-07
- Millsia brevis str. J82
- Tomitella bifomata str. AHU 1920
- Halomonas sp. str. ARD M14
- Deep Sea Aerobic Sediment clone
- Halomonas sp. str. YD06-R
- Halomonas sp. str. 2006
- Halomonas sp. str. W1025
- Halomonas sp. str. 7018
- Halomonas variabilis str. SW04
- Chromohalobacter salexigens str. TPSV 101
- Marinobacter sp. str. EM463
- Thialakalapia microaerophila str. ALEN 1

**Rhodococcus erythropolis** has previously been characterized as an oil degrader. Isolated on hexadecane, produces 2 types of biosurfactants.

**Actinobacteria, Nocardiaceae**

**Gammaproteobacteria, Halomonadaceae**

---

**Effects on benthic invertebrates: macrofauna and meiofauna**

- 68 stations sampled to 125 km from wellhead
- Bullseye design close to wellhead
- Severe reduction in faunal abundance and diversity extended to 3 km
- Moderate impacts to 17 km to SW and 8.5 km to NE

Montagna et al., 2013
Effects on benthic invertebrates: macrofauna and meiofauna

Montagna et al., 2013

Benthic effects correlated with TPH, PAH, Ba, and distance to wellhead
Not distance to HC seeps
Nematode to copepod ratio indicates HC impacts

Table 2. Percent change relative to overall mean for benthic community response in zones identified in Figs. 2–3.

<table>
<thead>
<tr>
<th>Color</th>
<th>Zone</th>
<th>Macrofauna Abundance</th>
<th>Meiofauna Abundance</th>
<th>Macrofauna Diversity</th>
<th>Meiofauna Diversity</th>
<th>Nematode: Copepod Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>1</td>
<td>−30.2%</td>
<td>43.2%</td>
<td>−53.7%</td>
<td>−38.3%</td>
<td>240.1%</td>
</tr>
<tr>
<td>Orange</td>
<td>2</td>
<td>17.6%</td>
<td>50.9%</td>
<td>−4.5%</td>
<td>−19.0%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Yellow</td>
<td>3</td>
<td>25.4%</td>
<td>14.3%</td>
<td>2.4%</td>
<td>−13.3%</td>
<td>16.4%</td>
</tr>
<tr>
<td>Lt. Green</td>
<td>4</td>
<td>−13.3%</td>
<td>−61.7%</td>
<td>6.3%</td>
<td>16.4%</td>
<td>−57.5%</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td>−7.1%</td>
<td>−27.3%</td>
<td>11.9%</td>
<td>22.8%</td>
<td>−58.4%</td>
</tr>
</tbody>
</table>

Effects on benthic invertebrates: macrofauna and meiofauna

Montagna et al., 2013

Impacts consistent with plumes observed to SW (Camilli et al., 2010) and to NE (Hollander et al., 2012; Passow et al., 2012) of wellhead
Some outliers may indicate effects from oil that surfaced
Brighter colors depict more 14C depleted petro-residues

Macrofauna and meiofauna in sediments of DeSoto Canyon

- Sites from 2000-02
- See Amy’s poster

- Increase in Density
- No Change in Diversity, BOPA
- Change in Community Structure
- Change in Trophic Structure
- Some Organic Enrichment Respondents
Effects on octocorals and sea fans

- Pinnacle Reefs- important for commercial and recreational fishing
- Surveyed 400 colonies at 65 to 75 m water depth
- Ocean surface in area covered by oil as shown by satellite observations
- Injuries documented at 3 sites

Silva et al., 2013

Effects on octocorals and sea fans

- Injuries include: retracted polyps, mucus secretion, flocculent material covering branches, and overgrowth by hydroids
- Effects consistent with those observed at 1370 m water depth by White et al. (2012) and linked to deep plumes
**Effects on octocorals and sea fans**

Silva et al., 2013

- Impacted sites in area of dispersant application, burning
- Floating oil may have been mixed down by tropical storm Bonnie, July 22-26, 2010

**Summary**

- **Water column effects**
  - Most data collected offshore and in deep plumes
  - Pronounced impact on the abundance, distribution, diversity, and activity of microbial communities was observed
  - A succession of microbial populations was observed that correlated with the chemical evolution of oil hydrocarbons
  - Some HC-degrading taxa were detected that are capable of producing large amounts of surfactant/emulsifying compounds
  - Effects were linked to liquid and gaseous hydrocarbons
  - Isotope evidence indicates methane entered the food web and was passed on to higher trophic levels
  - Results often rely on qualitative sequencing approaches and are lacking in replication
  - Quantitative and functional data lacking
  - Communities associated with particles not studied specifically
Summary

Benthic effects

- Multiple independent lines of evidence indicate the rapid flocculation/sedimentation of oiled particles occurred in the DeSoto Canyon region during late summer/fall of 2010
- High resolution analysis of sedimented HCs implicated 3 transport pathways: marine snow, sinking of burned oil particles, and deep plumes
- A community-wide mortality event was observed for benthic foraminifera associated with sedimentation
- Evidence for shifts in benthic microbial communities near wellhead
- Sedimentary microbial communities recorded a surface or planktonic origin of sedimented particles
- HC degradation linked to marine snow formation in bacteria from deepsea sediments of DeSoto Canyon

Summary

Benthic effects

- A reduction in diversity and abundance as well as a shift in community composition of deepsea benthic invertebrates was correlated with TPH, PAH, and Ba
- Effects on benthic invertebrates were linked to deep plumes, and possibly surface oil
- Injuries to corals were documented and linked to surface oil and flocculation
Concluding remarks

- The Deepwater Horizon discharge resulted in profound effects on the abundance, distribution, diversity, composition, and activity of biological communities in the water column and sediments.
- Majority of data on population dynamics.
- Little information on physiological and behavioral response.
- Effects were linked to deep plumes, flocculation/sedimentation of surfaced oil, and sinking of burned oil.
- Few studies have addressed impacts to ecosystem function, especially to specific trophic levels.
- Paucity of knowledge on toxicity to specific taxa in situ.

Gulf of Mexico Mud & Blood Cruise, August, 2013
Gulf of Mexico Mud & Cigars Cruise
September, 2013
How did petro-metho-carbon enter the food web?

- 1. $\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
- or
- 2. $\text{CH}_4 + \text{O}_2 \rightarrow \text{CH}_2\text{O} + \text{H}_2\text{O}$

Methanotrophy is a very efficient process
- 50% to 75% to biomass, reaction 2.

That’s why methanotrophs are so good for mussels!
Hydrocarbon deposition and pathways

- Large PAH fluxes may indicate an ecological risk to benthic organisms
- Evidence indicates 3 transport pathways: marine snow, sinking of burned oil particles, and advective transport of dissolved oil from deep intrusion (deep plumes)

Romero et al., 2013
See Isabel’s poster

Figure 2. Photographs of selected cores showing a dark, <1-10 cm thick, surface layer, overlying light-colored homogeneous sediments to core base. Note presence of double, Mn-rich, dark band interpreted to represent an upward shift in an Mn oxide zone in response to the rapid sediment pulse (see Fig. 1 for core site locations).
# Constructed from biom file

- Transform: Square root
- Resemblance: S17 Bray Curtis similarity

<table>
<thead>
<tr>
<th>Core Date</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSH10_Aug_2010</td>
<td>▼</td>
</tr>
<tr>
<td>DSH10_Aug_2012</td>
<td>▼</td>
</tr>
<tr>
<td>DMH01_Aug_2012</td>
<td>▼</td>
</tr>
<tr>
<td>SL1040_Aug_2012</td>
<td>▼</td>
</tr>
<tr>
<td>SW01_Aug_2012</td>
<td>▼</td>
</tr>
</tbody>
</table>

- 2D Stress: 0.05

- Increase in Density
- No Change in Diversity, BOPA
- Change in Community Structure
- Change in Trophic Structure
- Some Organic Enrichment Respondents

See Baco Taylor poster
Evidence for change in redox

Hastings et al., 2013
DSH 10; August 2010; 1520

- MnO$_2$ reduced > 20 mm
- Re enriched to 2.1 ppb at 30 mm

Enrichment of aerobic HC-degraders from the deepsea

- Rates of degradation of Macondo oil in deepsea sediments from DeSoto Canyon
- Rates at 4 C close to that at 22 C

PCB06 22 C

~1000 m water depth
O$_2$ penetrates to 4-5 cm in core

Xiaoxu Sun