Long term ecological impacts from oil spills:

Comparison of *Exxon Valdez*, *Hebei Spirit*, and Deepwater Horizon

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Prior to the EVOS, impacts considered to be:
• Short-term direct effects
• Controlled by mono-aromatic and less persistent components of oil
• Narcosis-driven acute toxicity to fish
• effect concentrations in parts per million

Long term impacts of Exxon Valdez (EVOS), Hebei Spirit (HSOS), Deepwater Horizon (DWH):
• How EVOS discoveries informed HSOS and DWH
• Learned: spill dynamics, environment, response actions interact to determine impacts and recovery

Images source: NOAA, KPNS, USCG
Exxon Valdez Oil Spill (EVOS)

Image source: NOAA
• March 24, 1989, tanker spill into Prince William Sound, Alaska
• 42 million liters of Alaska North Slope crude oil
• Oiled 2000 km shoreline in cold pristine subarctic environment
• Killed: 300,000 birds, 3000 sea otters

Images source: NOAA
Population level impacts of EVOS

- **Glaucous-winged Gull**: R
- **Bald Eagle**: R
- **River Otter**: R
- **Marbled Murrelet**: NR
- **Pigeon Guillemot**: NR
- **Sea Otter**: R
- **Harlequin Duck**: R
- **Killer Whale**: NR

*Adapted from: Esler et al. 2018. Deep-Sea Res 147:36-42*
Sea Otters

Harlequin Ducks

Killer Whales (Orca)

Salmon and Herring

Pink salmon:
- part per billion PAHs delayed growth and reduced marine survival (Heintz et al. 2000. MEPS 208:205-216)

Pacific herring:
- developmental effects at <10 ppb
- syndrome of edema, malformations

Images source: NOAA
Herring population crash after EVOS

Adapted from: Esler et al. 2018
Deep-Sea Res 147:36-42
What we learned from EVOS

Oil persisted in rocky intertidal shorelines for decades
  • small pockets of residual oil continue to be observed
  • continued exposure to wildlife
  • ppb levels of PAHs cause a syndrome of embryo toxicity
    • salmon affected for two generations
    • unclear role in catastrophic reductions in herring populations
  • weathered crude oil can be more toxic than fresh
  • Long term population level impacts on seabirds, sea otters, orcas, subtidal communities (10+ years)
    • some orca pods going extinct

Images source: NOAA
Hebei Spirit Oil Spill (HSOS)

Image source: Korea National Park Service
• December 7, 2007, tanker spill in coastal western Korea
• 12 million liters of Middle Eastern crude oils
• Oiled >200 km shoreline of ecologically important environments
• Immediate impacts to fisheries, mariculture, beaches
• Extensive removal of stranded oil by 1 million volunteers

Images source: KNPS
Oil exposures declined within two years

Adapted from: Yim et al. 2017. AECT 73:47-54
Recovery of subtidal within 5 years

Adapted from: Yim et al. 2017. AECT 73:47-54
Recovery of intertidal within 10 years

Adapted from: Yim et al. 2017. AECT 73:47-54
What we learned from HSOS

Rapid removal of stranded oil limited exposure:
• hydrocarbons declined in most areas within first year
• some lingering oil in some areas

And limits long term ecological impacts:
• plankton: ≤ 1 year
• Fish: ≤ 2 years
• subtidal communities: ≤ 5 years
• intertidal benthos: lingering impacts on abundance and composition

Lab embryo toxicity similar to EVOS also observed for HSOS oil
sea bass, olive flounder (Yung et al. 2015. ES&T 49:13639)

Images source: KNPS
Deepwater Horizon (DWH)
• April 20, 2010: largest accidental spill in human history
• Deep ocean release into the Gulf of Mexico following rig collapse
• 507 million liters of light Louisiana crude oil over 4 months
• 7 million liters of chemical dispersants: surface, subsea injection
• Impacts to deep ocean, pelagic, and coastal ecosystems
• Oiled 2000 km shoreline of beaches and coastal wetlands
Maximum shoreline oiling

http://gomex.erca.noaa.gov/ermi.html
Shoreline oiling conditions: 3.5 years later
(Aug-Nov 2013 SCAT surveys)

http://gomex.erca.noaa.gov/erma.html; Nov 14, 2013 download
Reported Wildlife Oiling

Numbers Reported to UAC

- **Birds**:
  - Oiled Dead: 10
  - Oiled Live: 1
  - No oil Dead: 1

- **Turtles**:
  - Oiled Dead: 1
  - Oiled Live: 10
  - No oil Dead: 100

- **Mammals**:
  - Oiled Dead: 1
  - Oiled Live: 100
  - No oil Dead: 1000

Source: USDOJ  www.fws.gov/home/dhoilspill/pdfs/ConsolidatedWildlifeTable042011.pdf; April 20, 2011 cumulative
Federal fishery closures (May 2-Oct 22, 2010)
20 million hectares; 37% of Gulf
EVOS embryotoxicity: demonstrated in 7 Gulf fish species

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>oil-exposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Bluefin tuna</td>
<td><img src="image1" alt="Image" /></td>
</tr>
<tr>
<td>B</td>
<td>Yellowfin</td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>C</td>
<td>Amberjack</td>
<td><img src="image3" alt="Image" /></td>
</tr>
</tbody>
</table>

*D南方蓝鳍金枪鱼, 黄鳍金枪鱼, 黄尾 amberjack*

- Edema
- Deformities
- Heart rate effects
- Threshold effects at 0.3 – 6 ppb

*Mahi Mahi*

- Reduced swim performance
- Effects at 1.2 ppb for 48 hours

Source: USDOJ

TREX-013333; TREX-013338

D-32618A
Offshore Impacts

• deep ocean coral
• deep sea bed organisms
• oceanic fishes with embryo-larvae at surface (bluefin, mahi)
• floating sea weed communities
• marine mammals, sea turtles
• sea birds

Phototoxicity validated in blue water of Gulf

Source: USCG USDOJ NOAA LDWF
Impacts to Coastal Systems

• **Oiled shoreline** (2113 km; 1300 miles): over the 87 day release
• **Oiled wetlands** (175 km; 108 miles): degraded health of coastal marsh vegetation/fauna; loss of nearshore oyster cover; increased marsh erosion
• **Oiling & response actions**: lost sand beach habitat; submerged vegetation
• **Loss of billions of oysters**: failed recruitment over several years
• **Affected ecosystem services**: primary production; resource abundance; storm/flood protection; nutrient cycling; water filtration
• **Continuing dolphin impacts**: poor health, stranding, mortality, reproduction

Source: USCG USDOJ NOAA LDWF
Near shore recovery times:
2 - > 10 years

<table>
<thead>
<tr>
<th>Model species/injury metric</th>
<th>Maximum % change relative to reference</th>
<th>Km (miles) of shoreline affected</th>
<th>Observed time period of injury</th>
<th>Expected recovery time (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainland herbaceous live above-ground biomass(^a)</td>
<td>45</td>
<td>&gt;563 (&gt;350)(^b)</td>
<td>2010–2013</td>
<td>2–8(^c)</td>
</tr>
<tr>
<td>Mainland herbaceous total live cover(^a)</td>
<td>44</td>
<td>&gt;563 (&gt;350)(^b)</td>
<td>2010–2013</td>
<td>2–8(^c)</td>
</tr>
<tr>
<td>Amphipod survival(^d)</td>
<td>95</td>
<td>249 (155)</td>
<td>2010–2013</td>
<td>&gt;4</td>
</tr>
<tr>
<td>Periwinkle abundance(^e)</td>
<td>90</td>
<td>62 (39)(^d)</td>
<td>2011</td>
<td>&gt;10</td>
</tr>
<tr>
<td>White shrimp growth (oil)(^d)</td>
<td>46</td>
<td>288 (179)</td>
<td>2011</td>
<td>&gt;2</td>
</tr>
<tr>
<td>Brown shrimp growth (oil)(^d)</td>
<td>56</td>
<td>288 (179)</td>
<td>2011</td>
<td>&gt;2</td>
</tr>
<tr>
<td>Fundulus hatch success(^d)</td>
<td>99</td>
<td>62 (39)</td>
<td>2010–2013</td>
<td>&gt;4</td>
</tr>
<tr>
<td>Flounder growth(^d)</td>
<td>90</td>
<td>62 (39)</td>
<td>2011–2013</td>
<td>&gt;3</td>
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<tr>
<td>Red drum growth(^d)</td>
<td>47</td>
<td>62 (39)</td>
<td>2010–2012</td>
<td>3</td>
</tr>
<tr>
<td>Fiddler crab burrow density(^f)</td>
<td>39</td>
<td>NC</td>
<td>2010–2014</td>
<td>&gt;4</td>
</tr>
<tr>
<td>Nearshore oyster cover(^g)</td>
<td>99.5</td>
<td>250 (155)</td>
<td>2012–2013</td>
<td>No recovery</td>
</tr>
</tbody>
</table>

Adapted from: Baker et al. 2017. MEPS 576:219-234

Recovery: up to 20 years in highest impact near shore areas
Large scale persistent ecological impacts from DWH

- Deep ocean corals and vent communities
- Failed recruitment of oysters over multiple years
- Damage to coastal wetlands
- Reduced dolphin, sea turtle and sea bird populations

- Possible massive sea bird mortalities
- Cascading impacts on menhaden and other coastal species from disruption of predator-prey relationships

(Short et al. 2017. AECT 73:76-92)
Complex Ecological Interactions

What have we learned?

Oil spills will continue to happen:
• likely in new and complex environments such as the Arctic

New paradigms established in EVOS were validated in HSOS in DWH:
• new mechanisms of oil toxicity at ppb PAHs (embryo cardiotoxicity; phototoxicity)
• oil persistence and continuing exposure
• ecological cascades and long term consequences

Images source: NOAA, KPNS, USCG
Long term socio-cultural Impacts

- Disrupted livelihoods and patterns of daily living
- Exacerbated social and economic inequality
- Challenged individual and collective identity
- Fostered conflict and divisiveness
- Disempowered local governments and NGOs

Source: USDOJ
• Value of rapid, extensive clean up
• Power of the human spirit to overcome ecological catastrophe

Images source: KPNS
Questions?