United States Environmental Protection Agency

# 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):

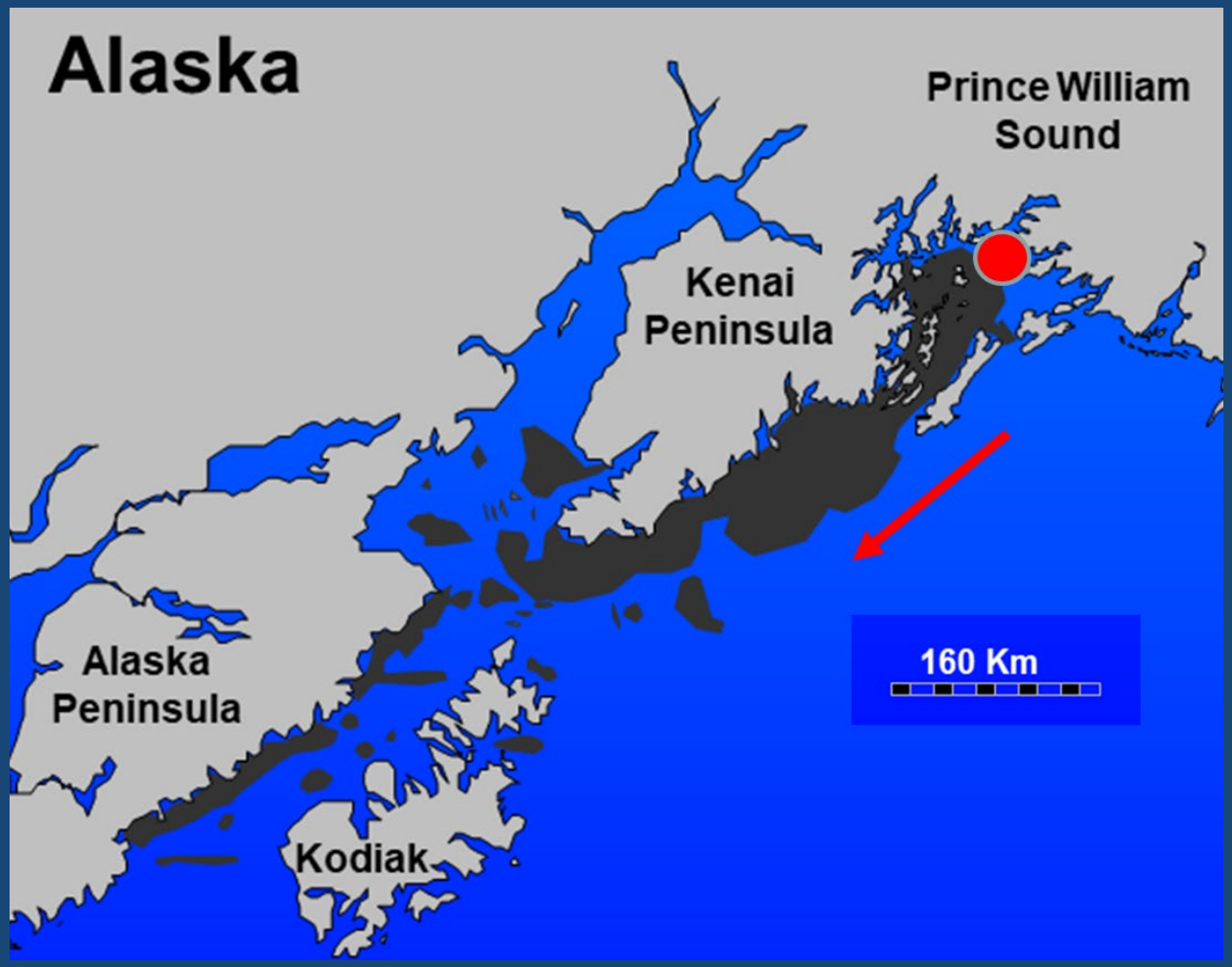
- How EVOS discoveries informed HSOS and DWH
- Learned: spill dynamics, environment, response actions interact to determine impacts and recovery

Images source: NOAA, KPNS, USCG

# *Exxon Valdez* Oil Spill (EVOS)

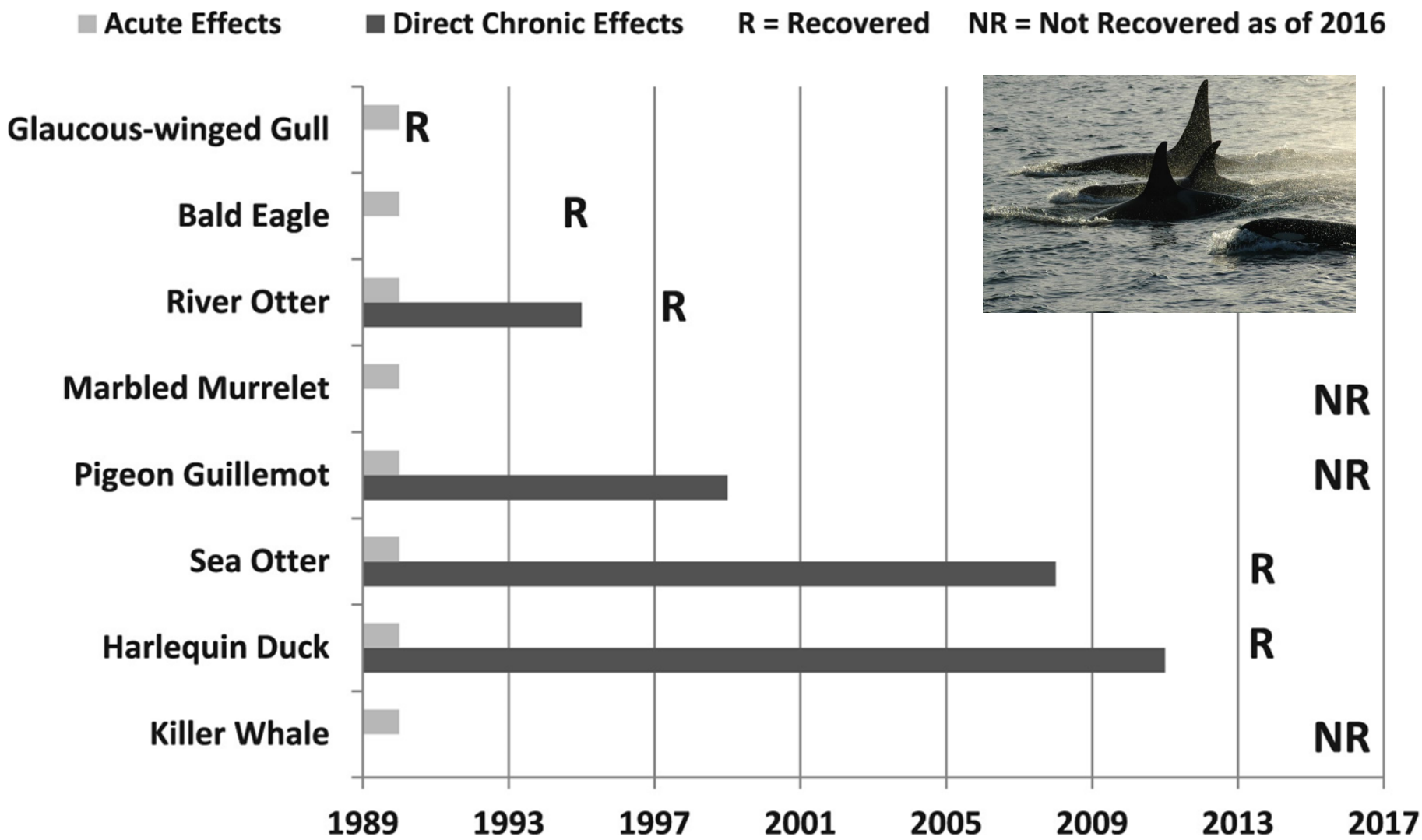

Image source: NOAA

- 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



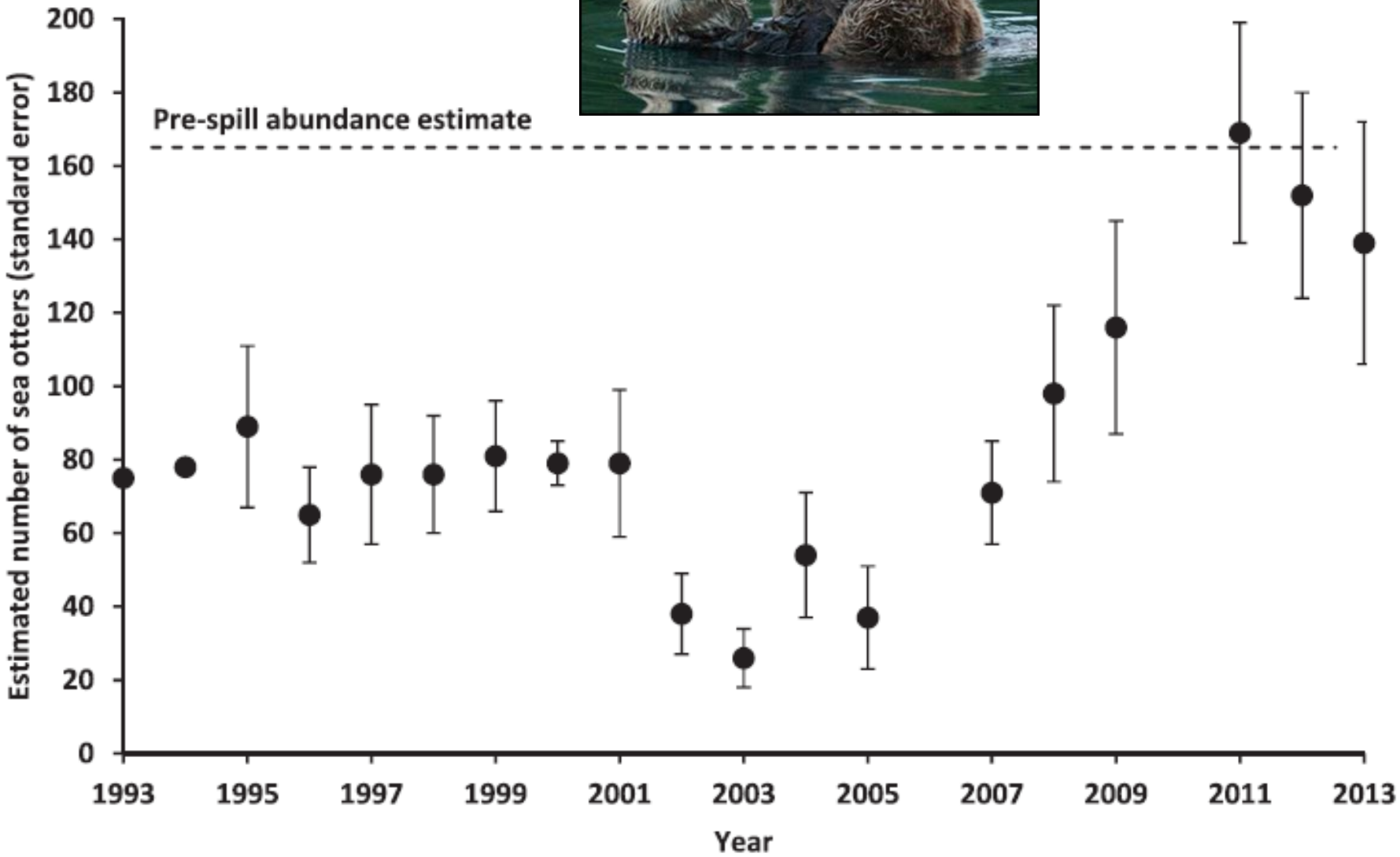

Images source: NOAA

# Population level impacts of EVOS




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

# Sea Otters

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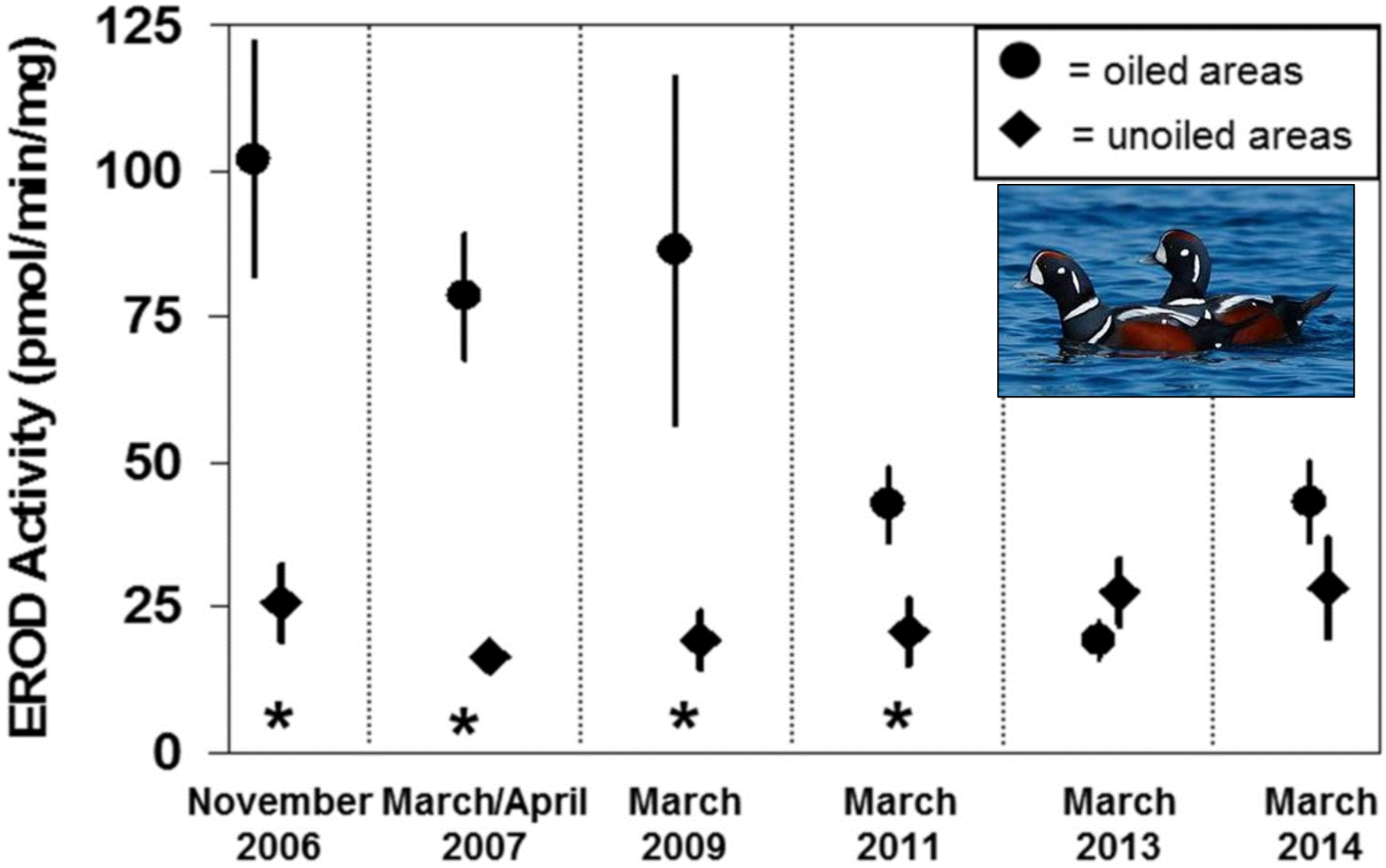
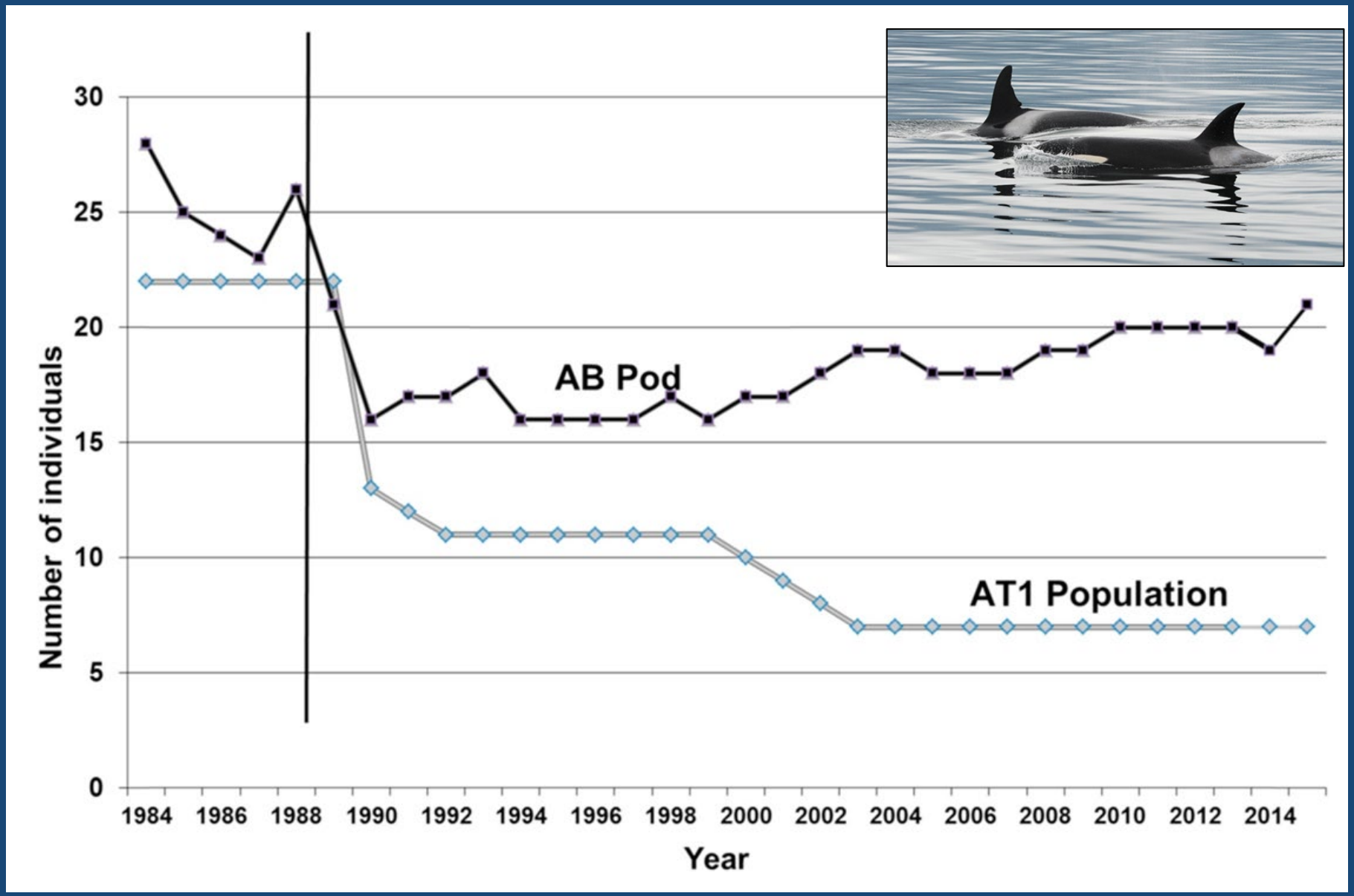
# Harlequin Ducks




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

# Killer Whales (Orca)




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

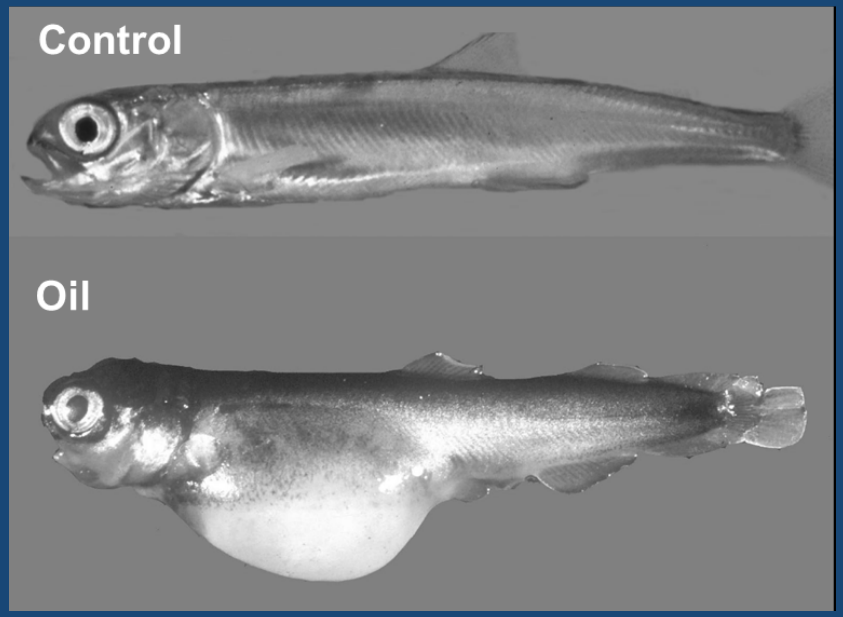
# Salmon and Herring

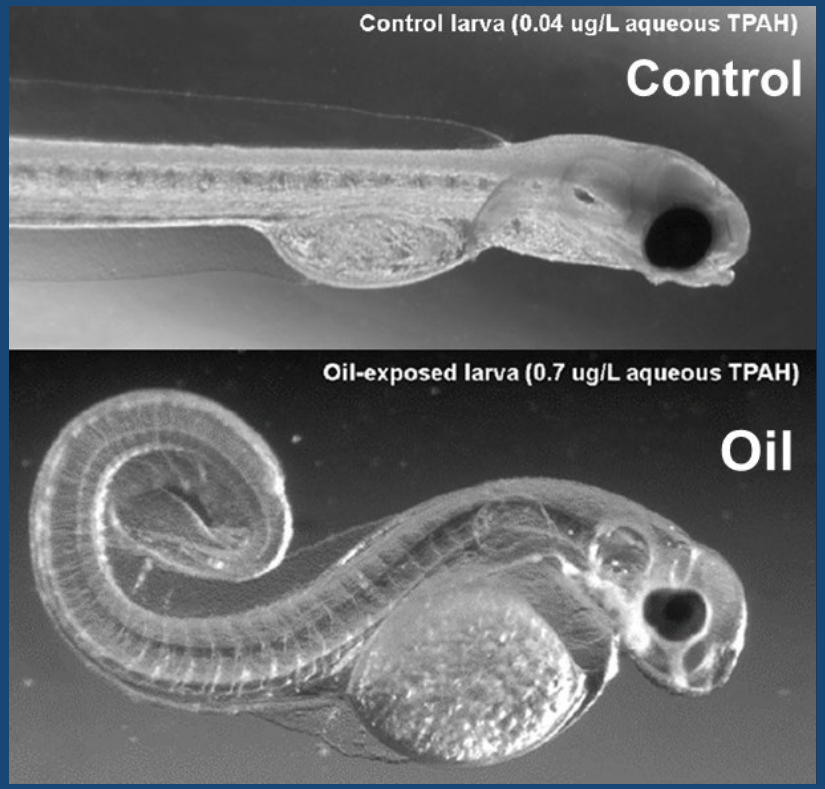
## Pink salmon:

- part per billion PAHs delayed growth and reduced marine survival (Heintz et al. 2000. MEPS 208:205-216)
- Elevated embryo mortality in streams after 2 generations (1989-1993) (Bue et al. 1998. TAFS 127:35-43)

## Pacific herring:

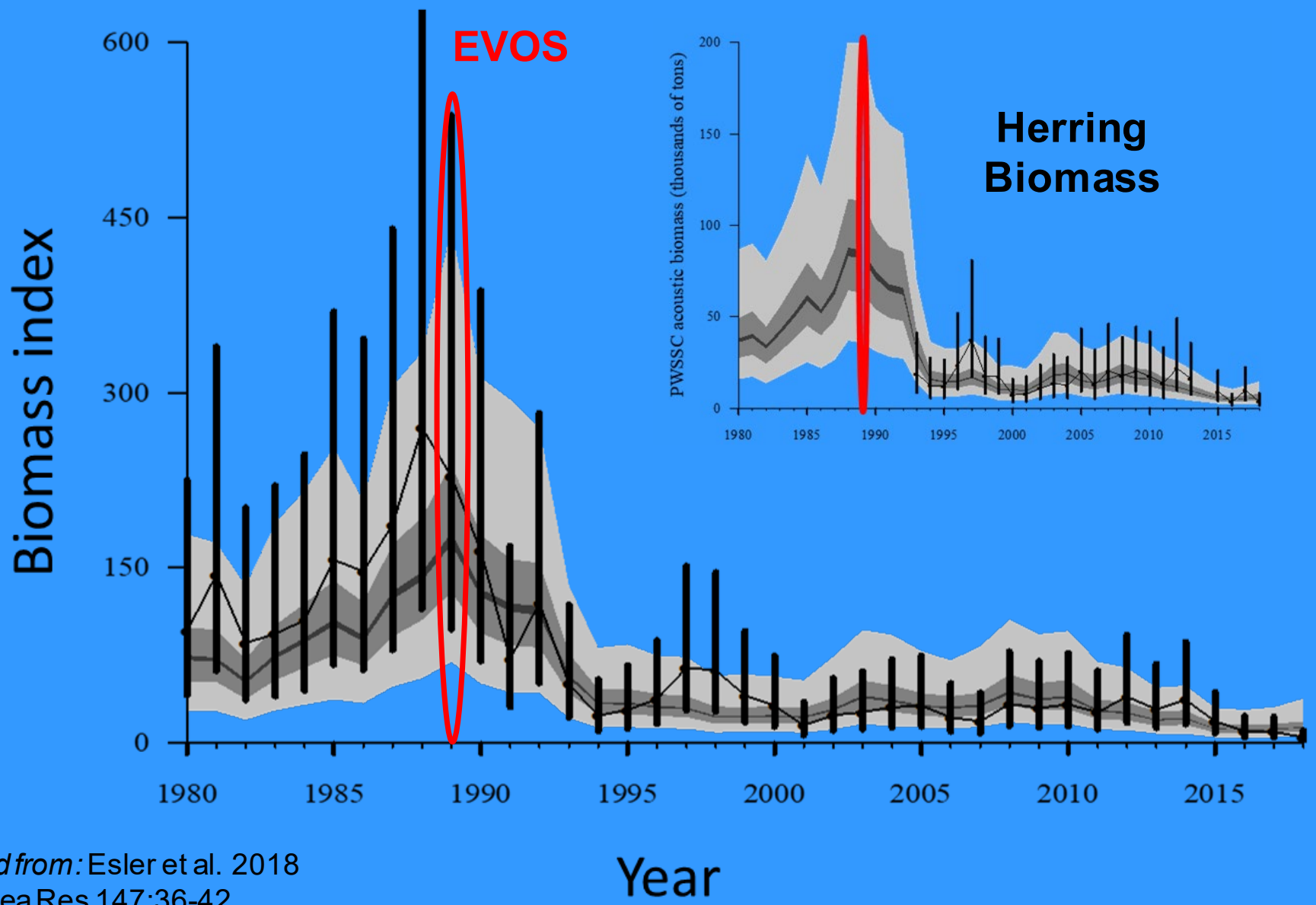
- developmental effects at <10 ppb
- syndrome of edema, malformations




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

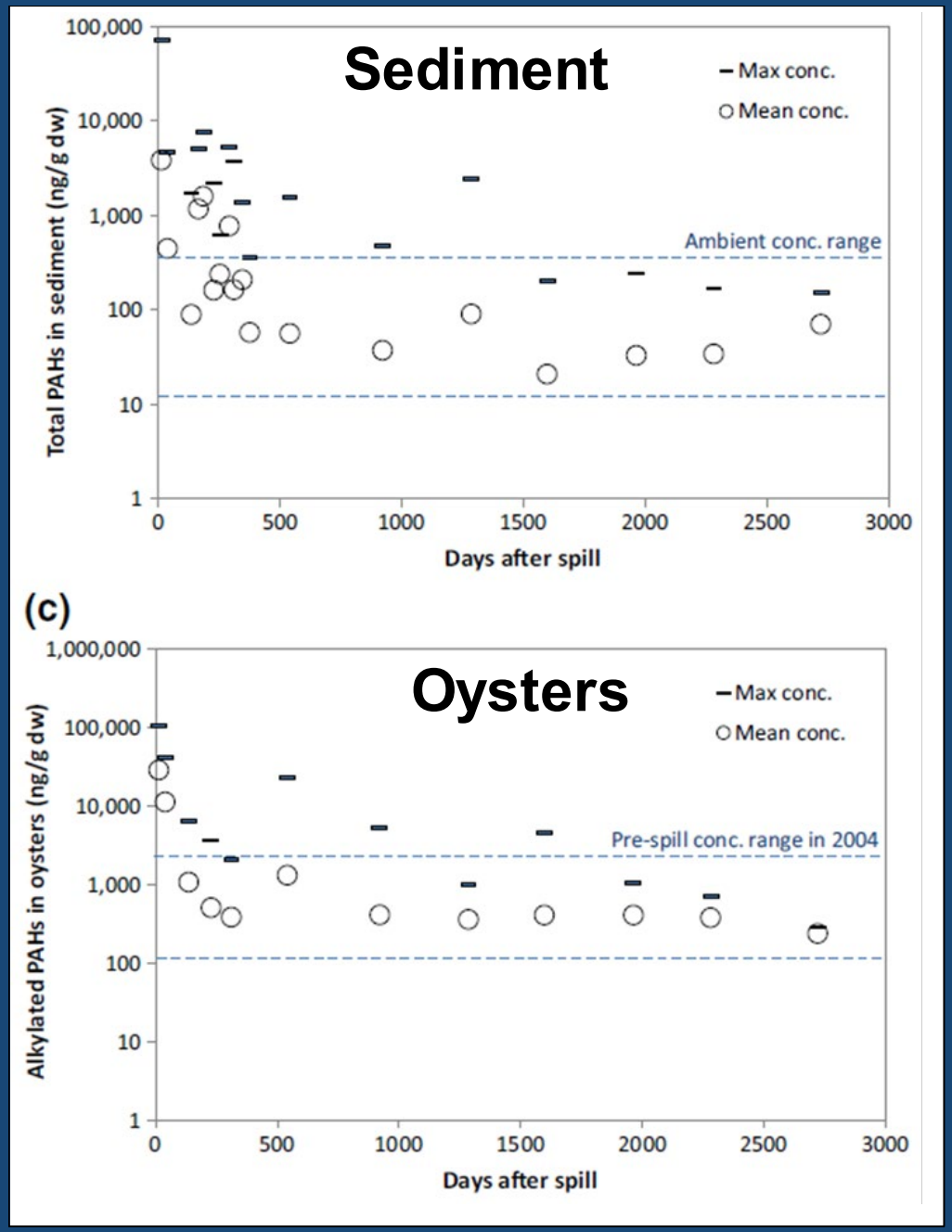
# *Hebei Spirit* Oil Spill (HSOS)

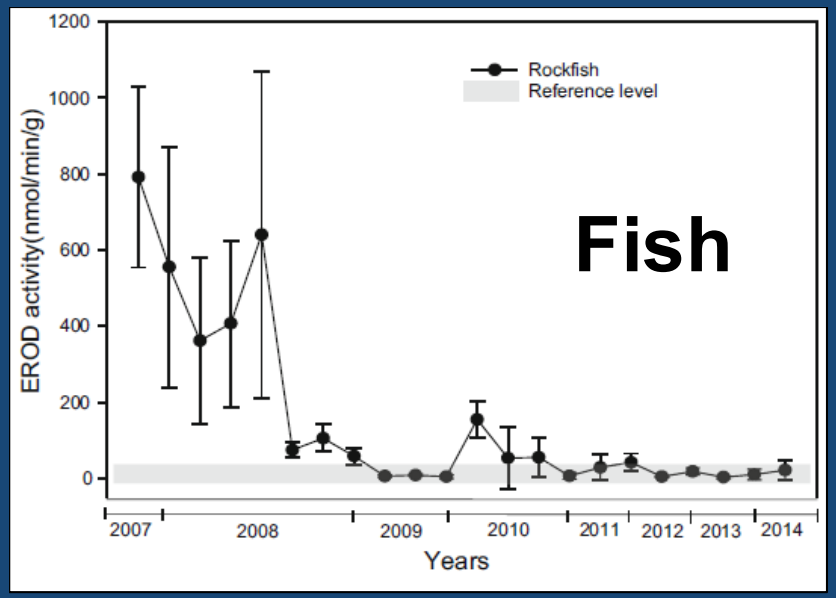
Image source: Korea National Park Service

- 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

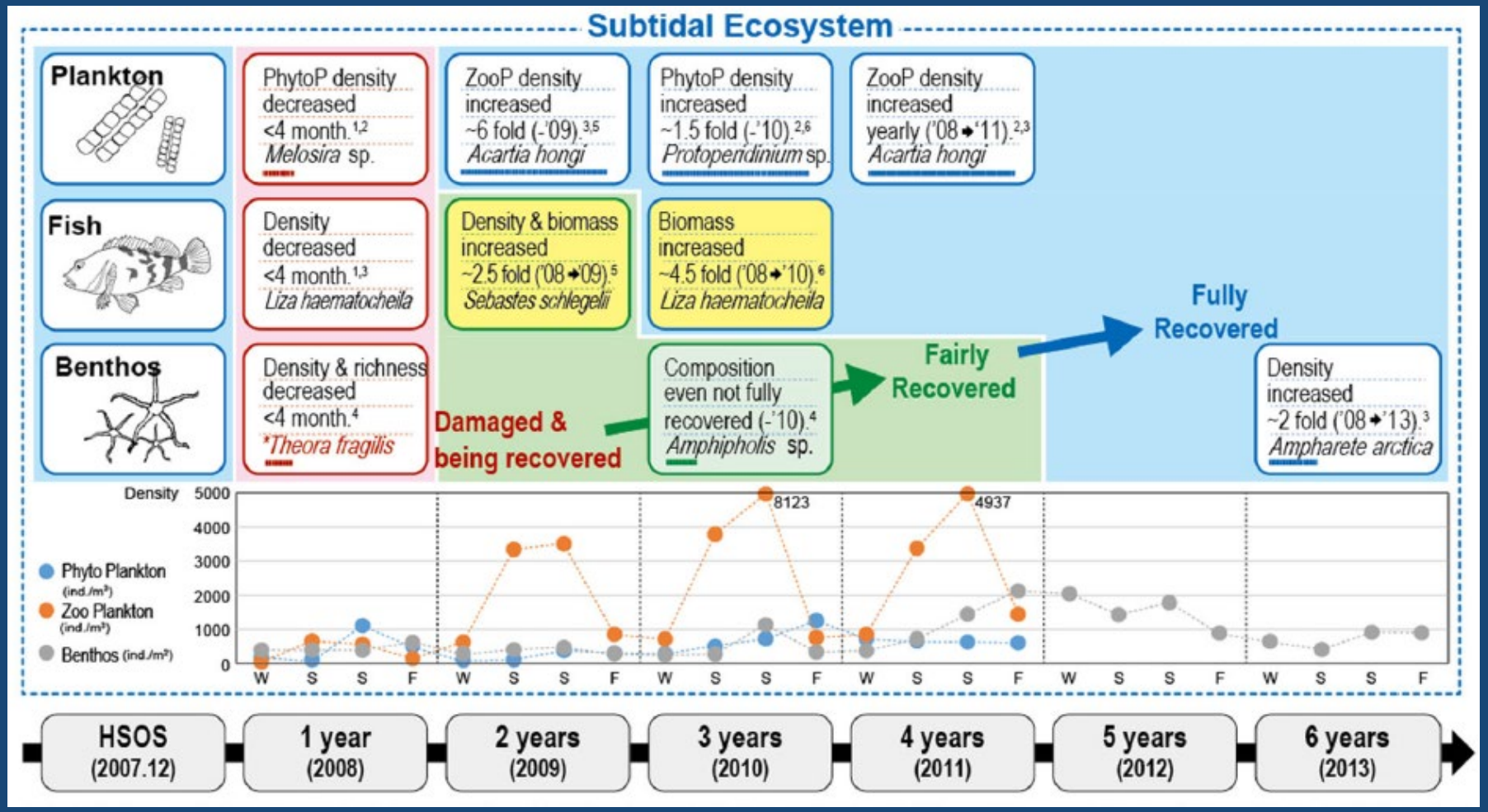
# Oil exposures declined within two years



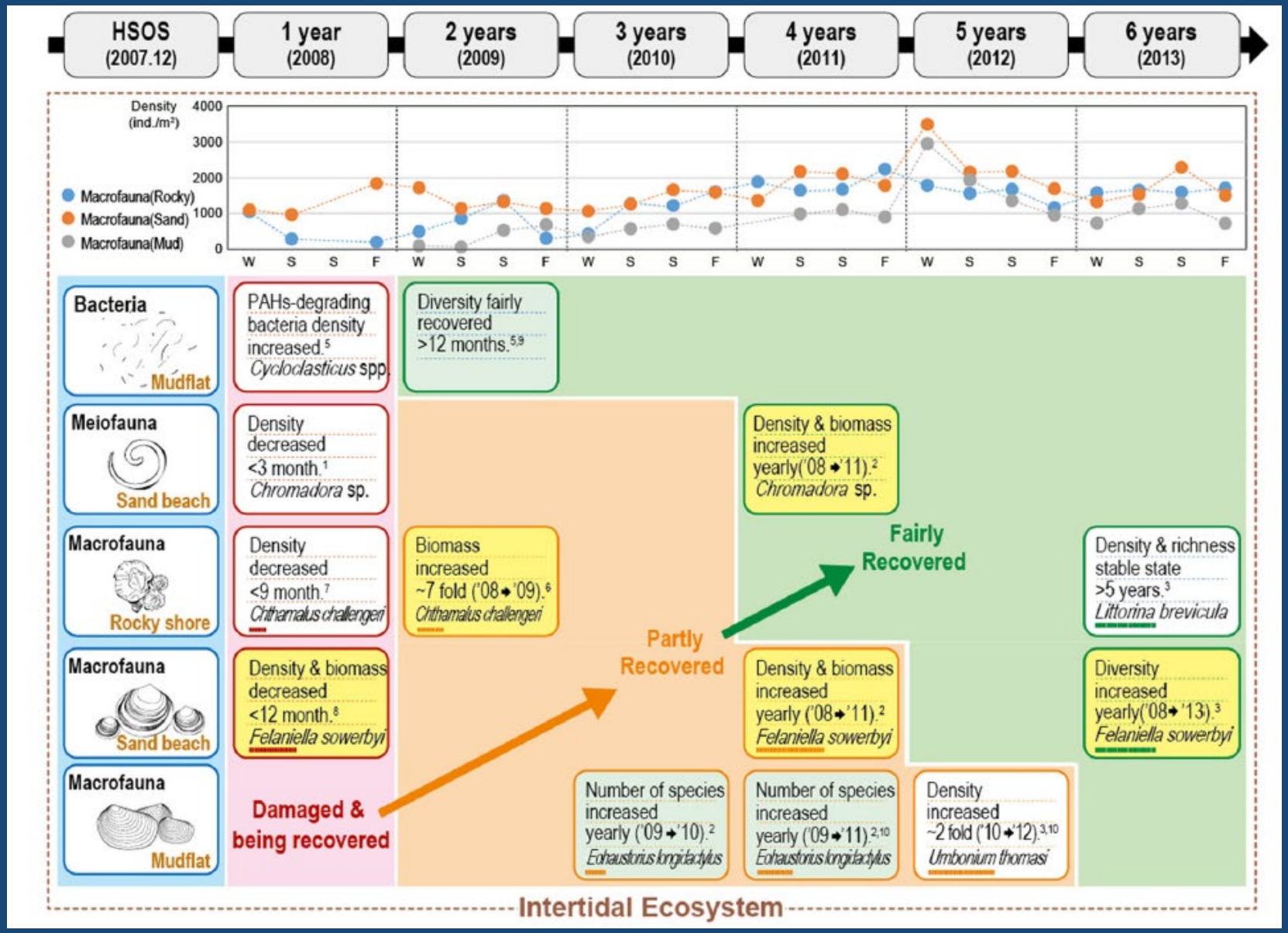

*Adapted from:* Yim et al. 2017. AECT 73:47-54

# 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:

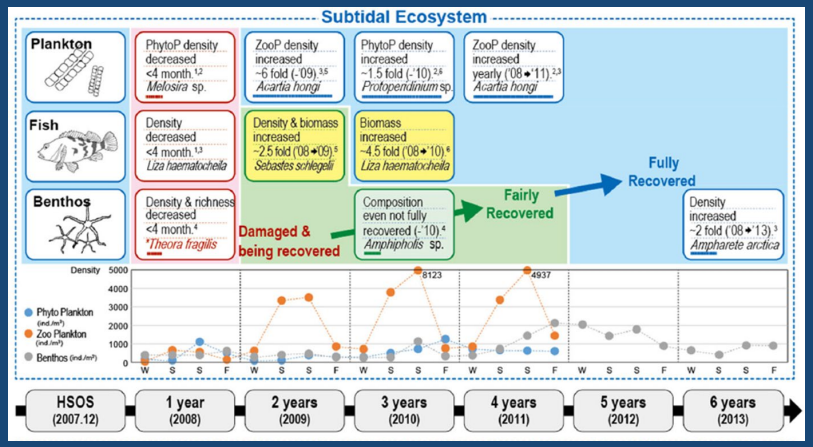
- hydrocarbons declined in most areas within first year
- some lingering oil in some areas

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)

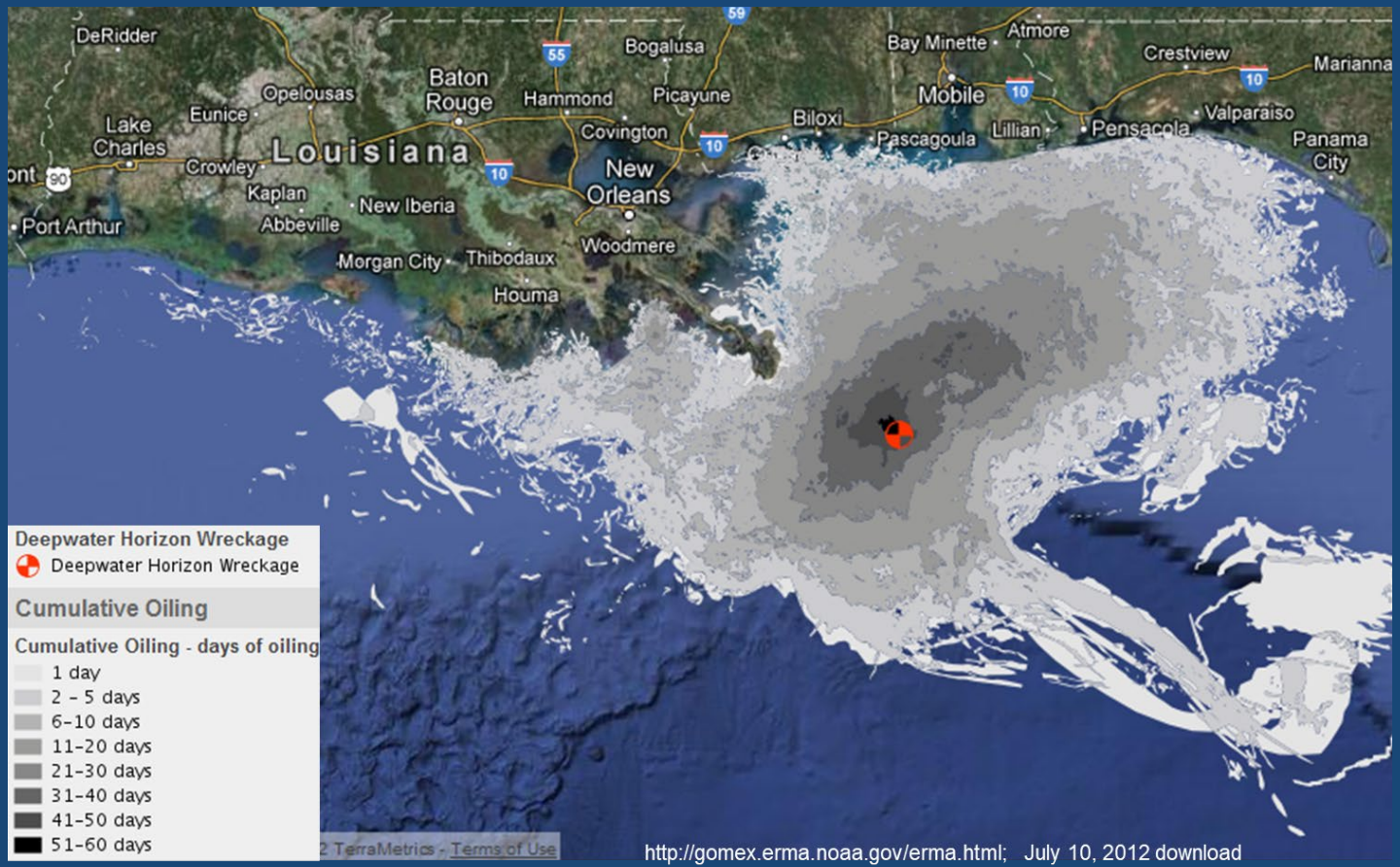



Images source: KNPS

# Deepwater Horizon (DWH)

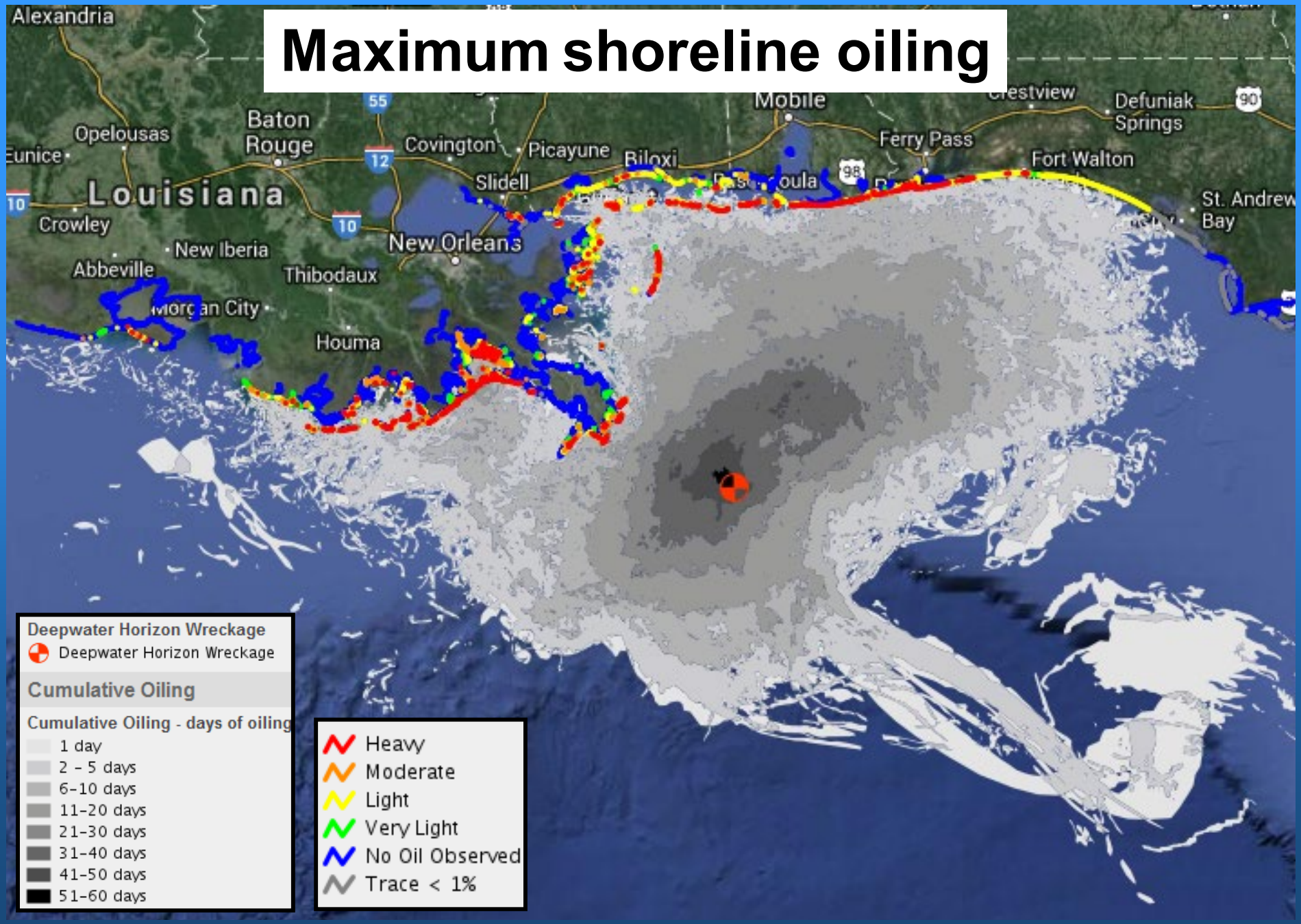
Source: USCG

- 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



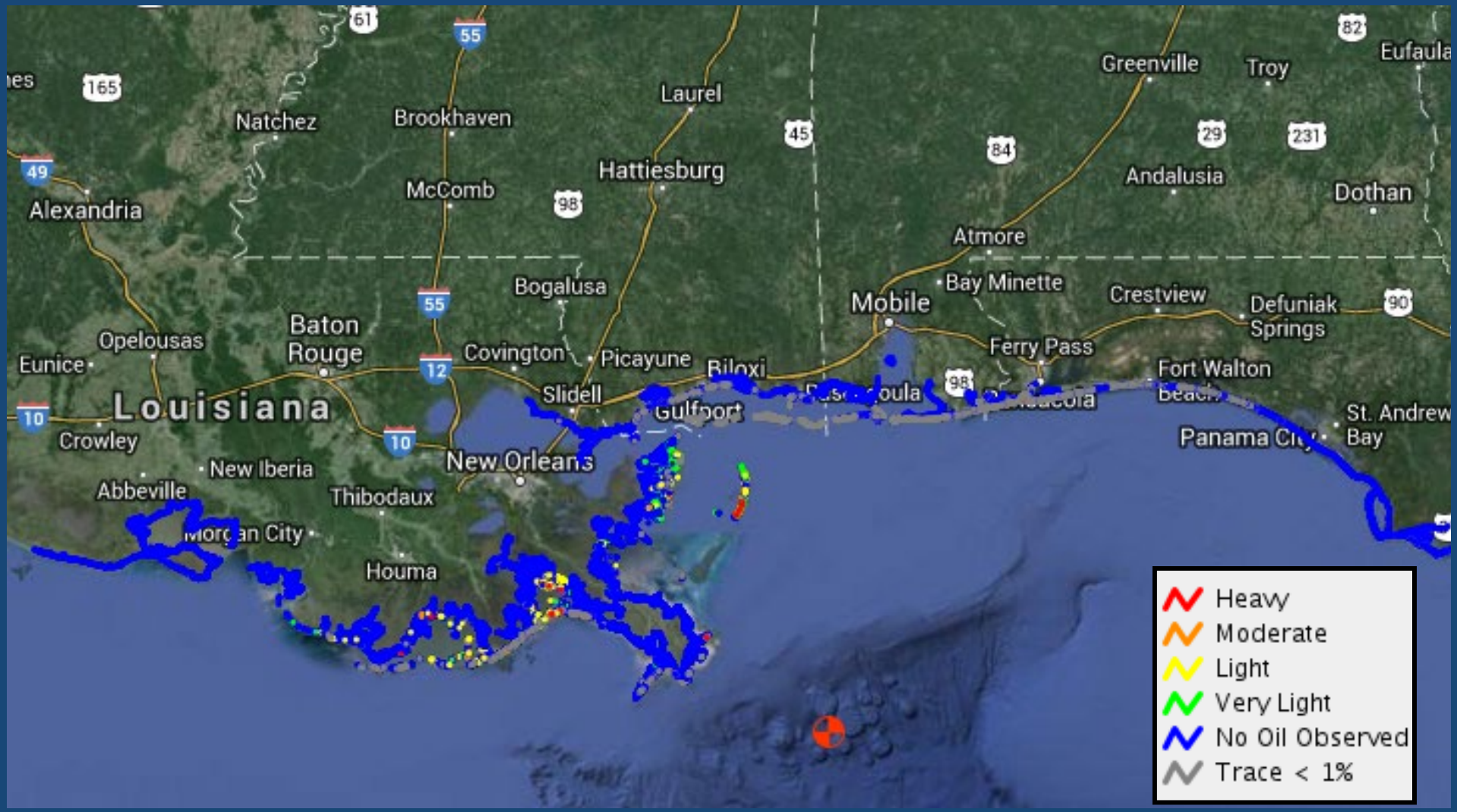

http://gomex.erma.noaa.gov/erma.html; July 10, 2012 download

# Maximum shoreline oiling



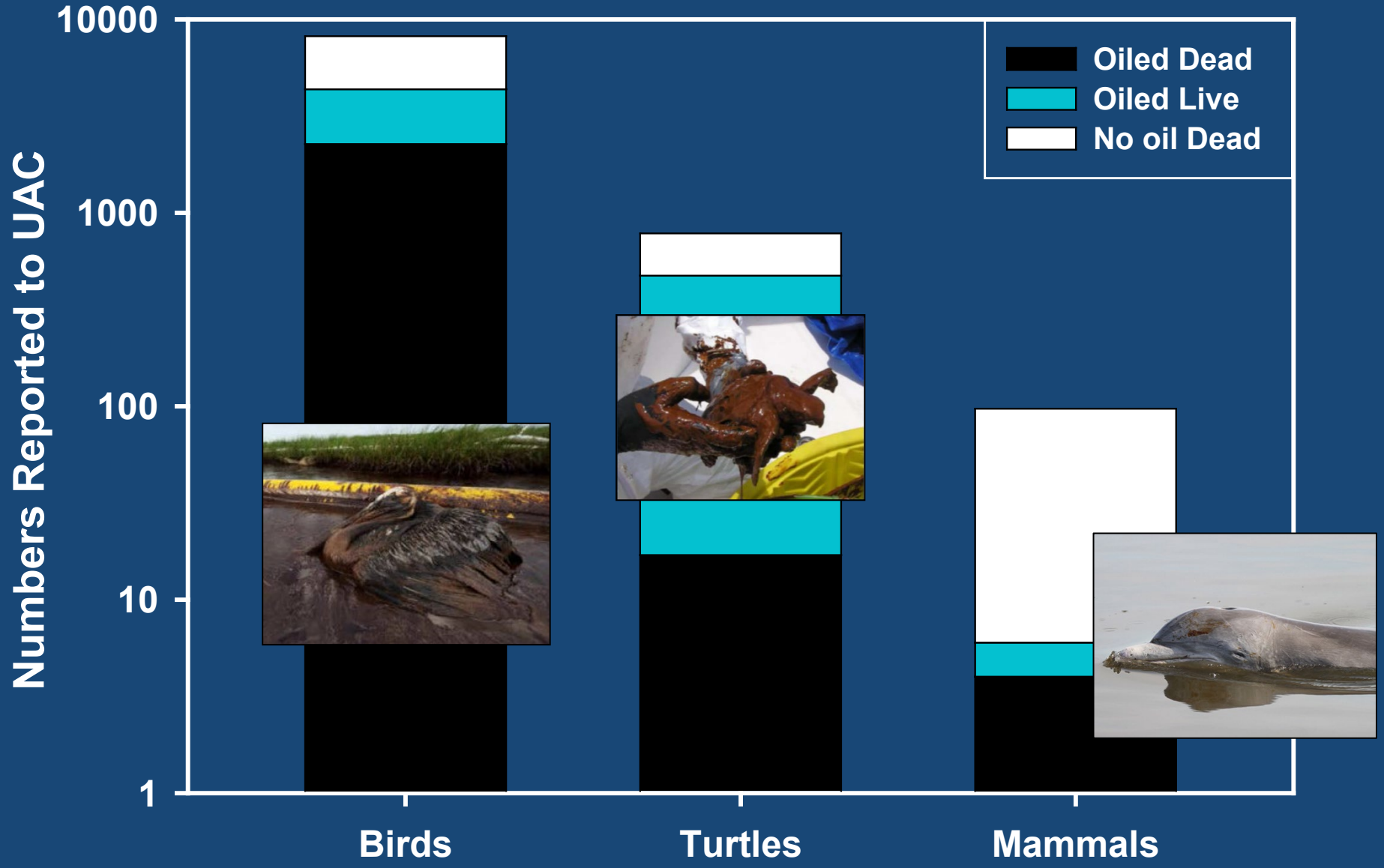

http://gomex.erma.noaa.gov/erma.html

# Shoreline oiling conditions: 3.5 years later
## (Aug-Nov 2013 SCAT surveys)



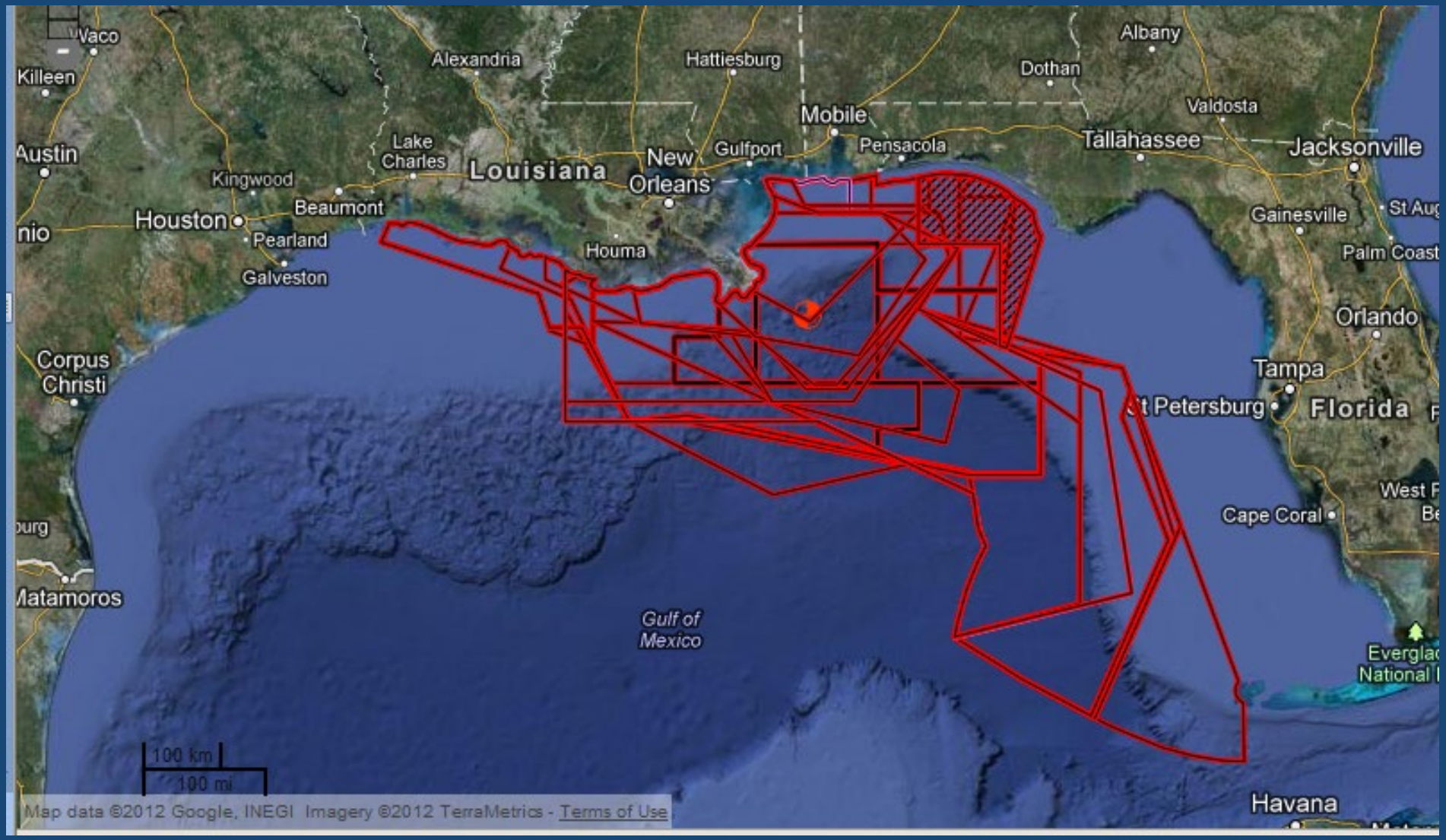

http://gomex.erma.noaa.gov/erma.html; Nov 14, 2013 download

# Reported Wildlife Oiling




Source: USDOJ www.fws.gov/home/dhoilspill/pdfs/ConsolidatedWildlifeTable042011.pdf; April 20, 2011 cumulative

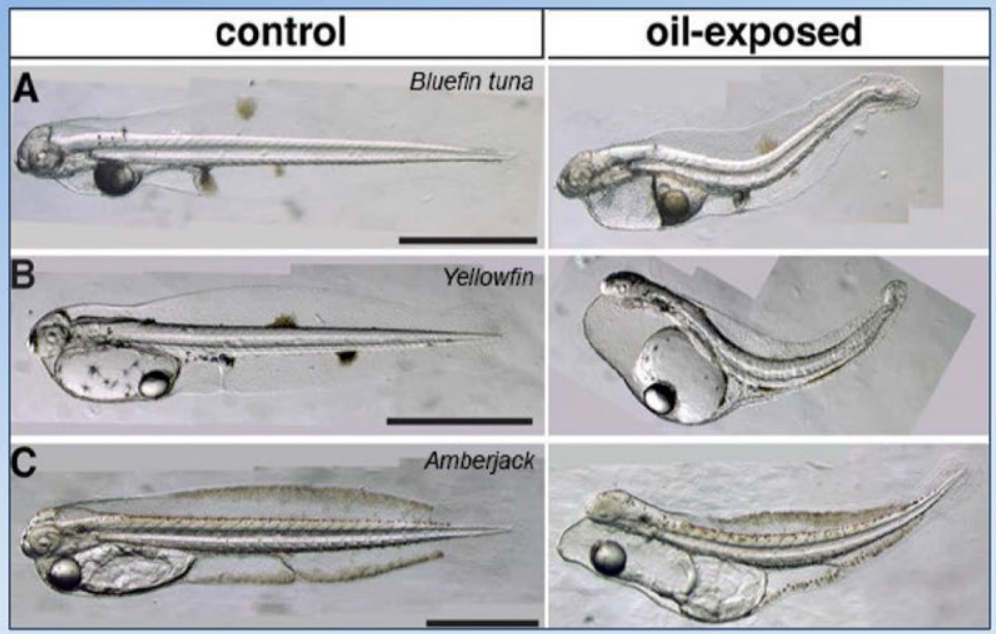
# Federal fishery closures (May 2-Oct 22, 2010)
# 20 million hectares; 37% of Gulf



# EVOS embryotoxicity: demonstrated in 7 Gulf fish species

## DWH EMBRYO TOXICITY STUDIES DEMONSTRATE SIGNIFICANT EFFECTS

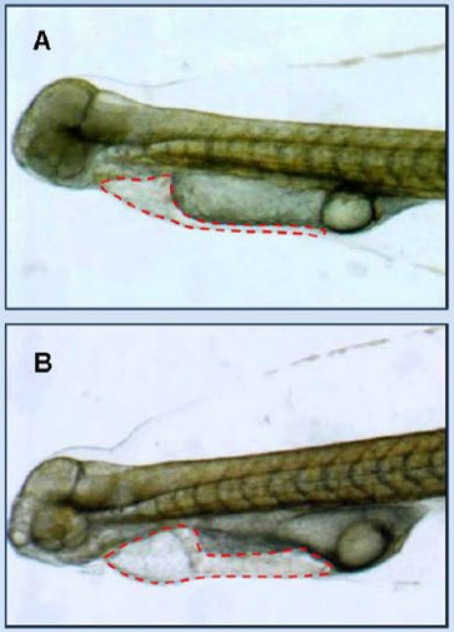
*Incardona et al. (2014)*




*Southern Bluefin Tuna, Yellowfin Tuna, Yellowtail Amberjack*

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

*Mager et al. (2014)*




*Mahi Mahi*

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

TREX-013333; TREX-013338

Source: USDOJ

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

<u>Phototoxicity validated in blue water of Gulf</u>

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

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

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

**Recovery: up to 20 years in highest impact near shore areas**

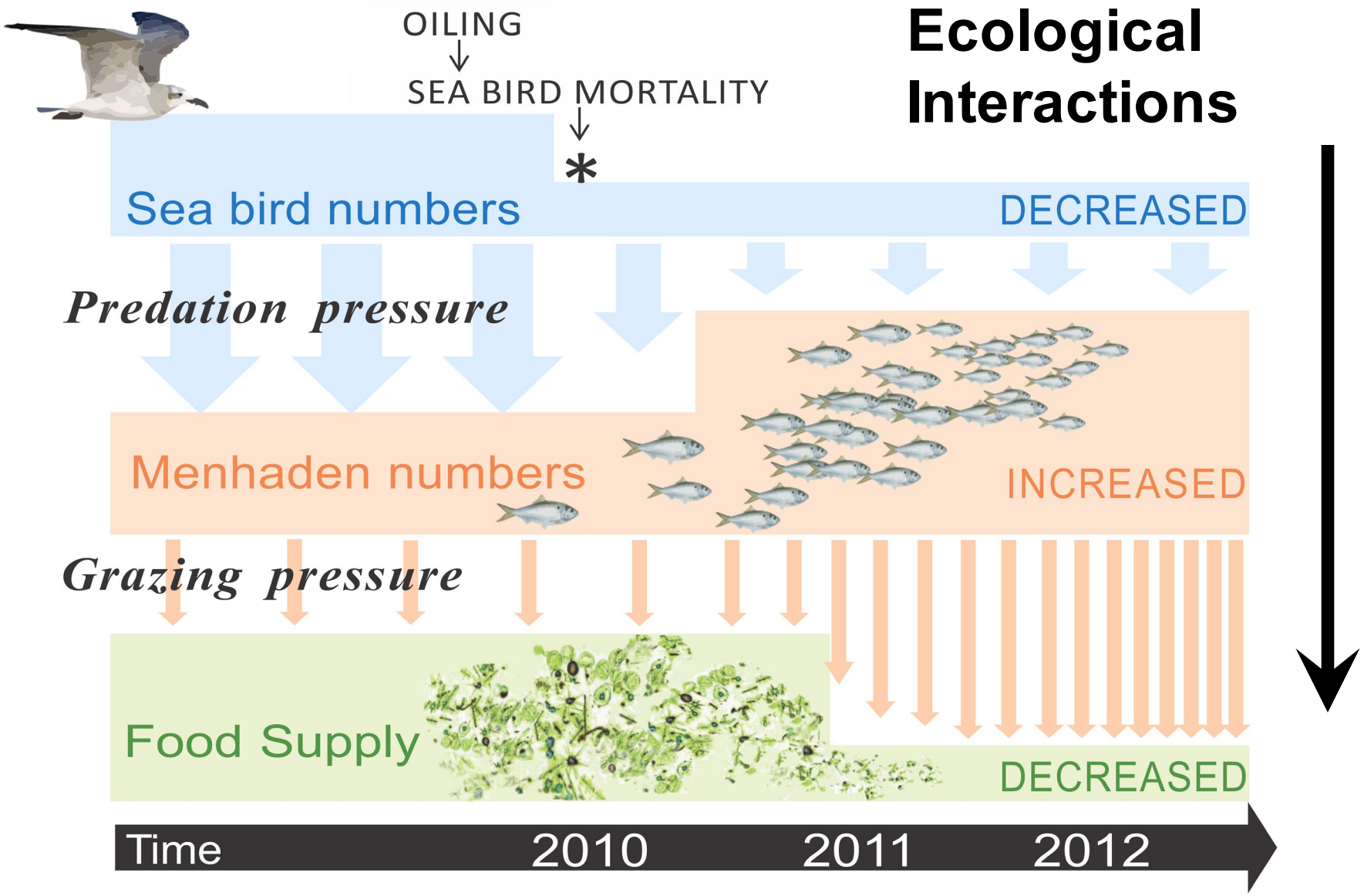
# Large scale persistent ecological impacts from DWH

- 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




*Adapted from:* Short et al. 2017. AECT 73:76-92.

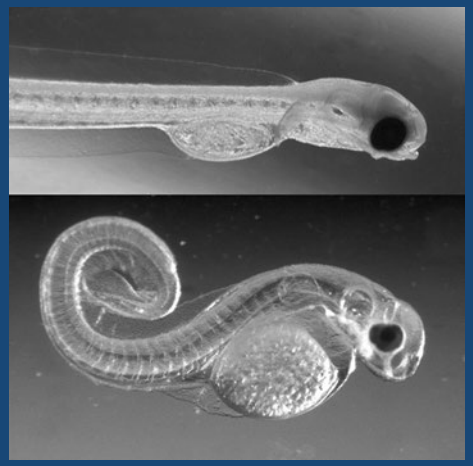
# What have we learned?

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?