The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Oil in the Sea IV:
Inputs, Fates, and Effects

Committee Meeting 6
February 11, 2021

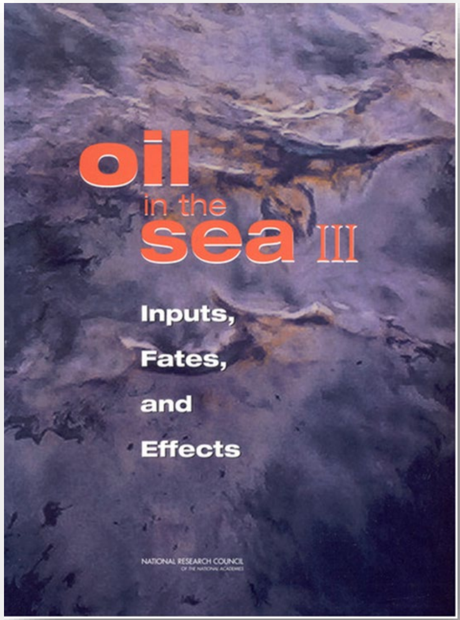
We will start at 11:00am EST

*This meeting will be recorded and posted on our project website

Photo Credit: NOAA

Welcome

- NASEM Consensus Study
- Update to Oil in the Sea III
- Sponsored by:
  - American Petroleum Institute
  - Bureau of Ocean Energy Management
  - Bureau of Safety and Environmental Enforcement
  - Fisheries and Oceans Canada
  - Gulf of Mexico Research Initiative
  - National Academies
- Information Gathering Session



Statement of Task

With regards to inputs:

1. Examine natural and anthropogenic sources of hydrocarbons entering the marine environment.
2. Develop quantitative estimates of hydrocarbon inputs to the marine environment.
3. Review progress in implementing the recommendations from the 2003 report
4. Provide recommendations to improve estimates of inputs and identify focus areas for reducing hydrocarbon inputs from human activities.

Statement of Task

With regards to <u>fates and effects</u>:

1. Assess and discuss the characteristics and behavior of hydrocarbons in the marine environment, the transport and fate in the marine environment, and the effects on marine life and ecosystems.
2. Characterize the risk posed to the marine environment.
3. Review progress in implementing the recommendations from the 2003 report regarding fates and effects.
4. Provide recommendations to improve understanding of the fates and effects of hydrocarbons on the ecosystem.

Committee Membership

- Kirsi Tikka (Chair)
- Ed Levine (Vice-chair)
- Akua Asa-Awaku
- C.J. Beegle-Krause
- Victoria Broje
- Steve Buschang
- Dagmar Etkin-Schmidt
- John Farrington
- Julia Foght
- Bernie Goldstein
- Carys Mitchelmore
- Nancy Rabalais
- Jeff Short
- Scott Socolofsky
- Berrin Tansel
- Helen White
- Michael Ziccardi

Agenda

11:00am	Welcome
11:05am	Human Health: Disaster Mental Health
11:30am	Human Health: Exposure Assessment
12:00pm	Phototoxicity of Hydrocarbons to the Marine Ecosystem
12:30pm	*BREAK*
1:00pm	Modeling Approaches for Toxicity Determination
1:30pm	Population Effects: Dolphin Case Study
2:00pm	Population Effects of Large-scale Oil Spills and Ecological consequences of Produced Waters
3:00pm	*BREAK*
3:30pm	Toxicity of Oil in Estuarine Environments
4:00pm	Case Study: Cosco Busan: Photoenhanced and Embryotoxic Effects

Zooming Guidance

- Please keep your line muted unless talking
- Please keep your video off unless you are talking
- Please raise your virtual hand if you want to comment or ask a question. The chat box will also be open.
- For those logged in to the webinar, use the Q&A function to submit questions or comments
- This meeting is being recorded. Recording will be posted in roughly a week's time

Environmental stressors and population mental health

Sandro Galea

Boston University School of Public Health

"A traumatic event is an experience that causes physical, emotional, psychological distress, or harm. It is an event that is perceived and experienced as a threat to one's safety or to the stability of one's world."

http://www.nlm.nih.gov/medlineplus/ency/article/001924.htm

Levetown M. Communicating with children and families: from everyday interactions to skill in conveying distressing information. Pediatrics. 2008;121:e1441-e1460.

“[A disaster is] a potentially traumatic event that is collectively experienced, has an acute onset, and is time delimited; disasters may be attributed to natural, technological, or human causes.”

McFarlane AC, Norris FH. Definitions and Concepts in Disaster Research. In Norris F, Galea S, Friedman M, Watson P. Methods for Disaster Mental Health Research. Guilford Press; 2006.

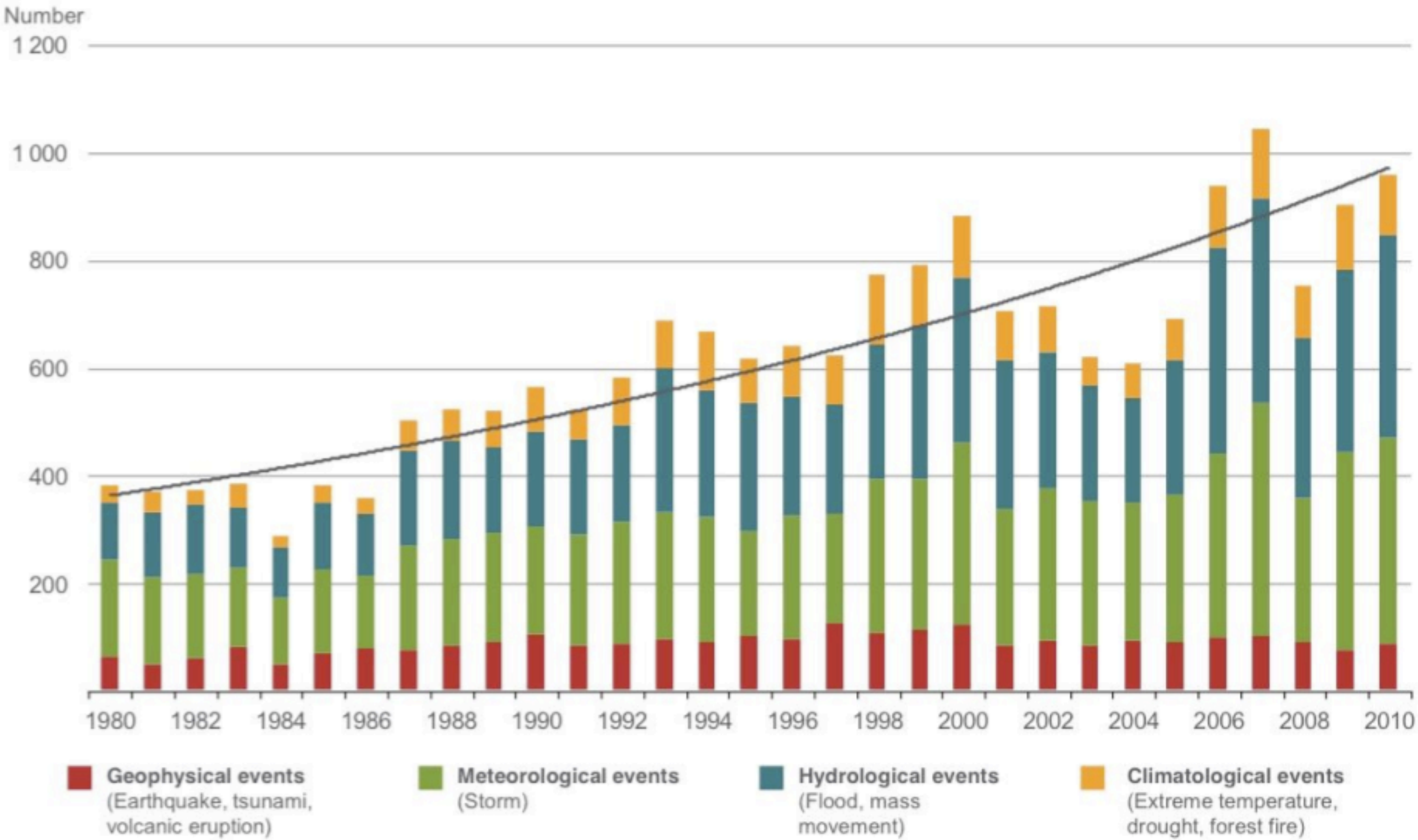
TOP 10 MOST EXPENSIVE MEDICAL CONDITIONS

G·R·A·P·H | cugraph.org

This graphic shows the top 10 most expensive medical conditions in the United States in 2011. On the y-axis of both bar graphs are the top 10 medical conditions ranked from low to high. The condition with the highest expense, any heart condition, is located at the bottom. The condition with the 10th highest expense, hyperlipidemia, is located at the top. The x-axis on the left hand bar graph is millions of dollars. The x-axis of the bar graph on the right is percent of medical expenses. Any heart condition was responsible for $116,308 million or 9.3% of all medical expenses in 2011. Overall, the top 10 medical expenses in 2011 accounted for $691,994 million dollars or 55% of all medical expenses. Chronic conditions such as heart disease and behavioral disorders are the most expensive health conditions in the US.

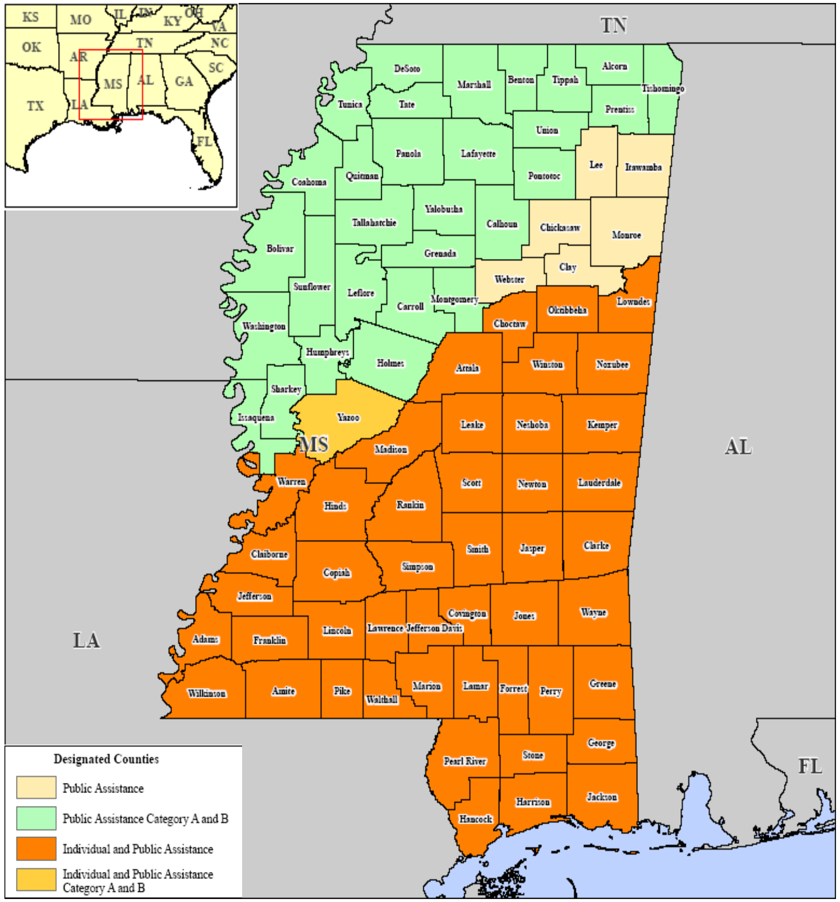
DATA SOURCE: CENTER FOR FINANCING, ACCESS AND COST TRENDS, AGENCY FOR HEALTHCARE RESEARCH AND QUALITY: MEDICAL EXPENDITURE PANEL SURVEY, 2011.

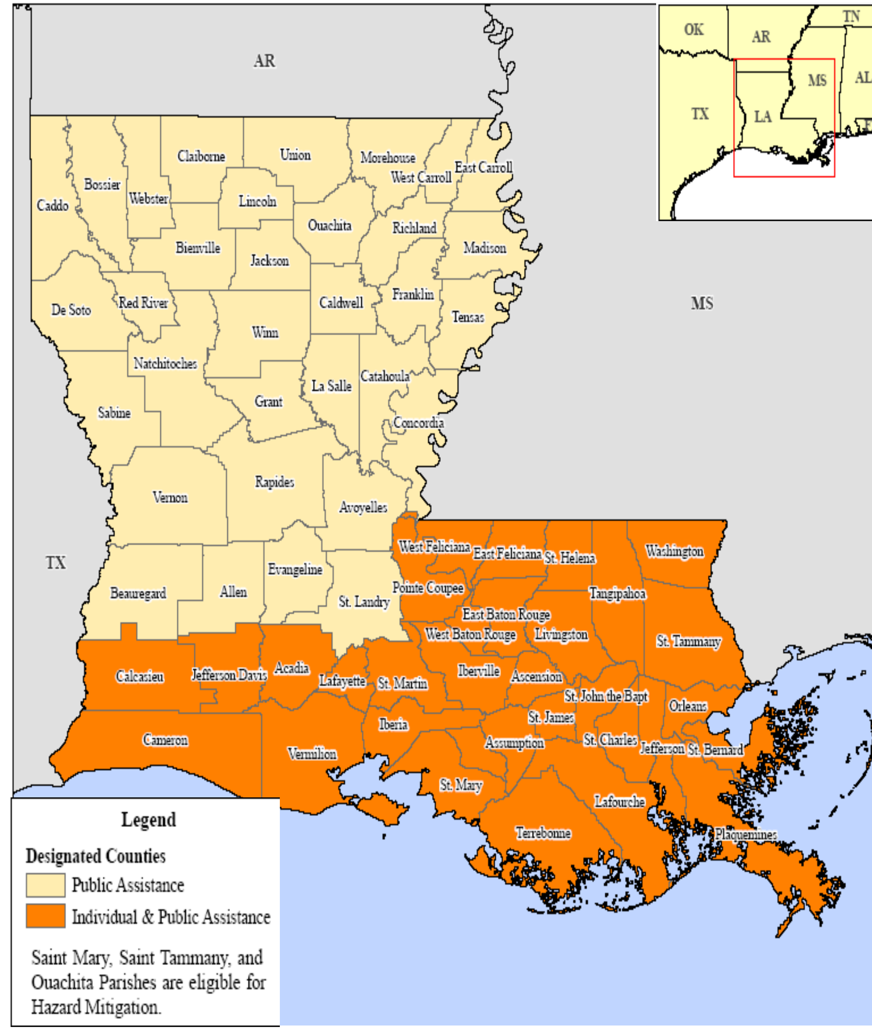
Number of natural disasters worldwide, 1980-2010



Adapted from: Munich Re (2010) "Topics Geo natural catastrophes 2009: Analyses, assessments, positions." Munich: Munich Reinsurance Company, by Jennings, S. "Time's Bitter Flood: Trends in the number of reported natural disasters." Oxfam Research Report 2011.

Mississippi and Louisiana. Area of disaster declaration September 11, 2005…





http://www.gismaps.fema.gov/2005graphics/dr1604/dec_1604.pdf

…equivalent in size to the UK

http://www.lastminute-hotel.co.uk/images/uk_map.gif

1. Disasters and mental health
2. The biological and the social
3. Health inequities
4. The long-term
5. Physical health

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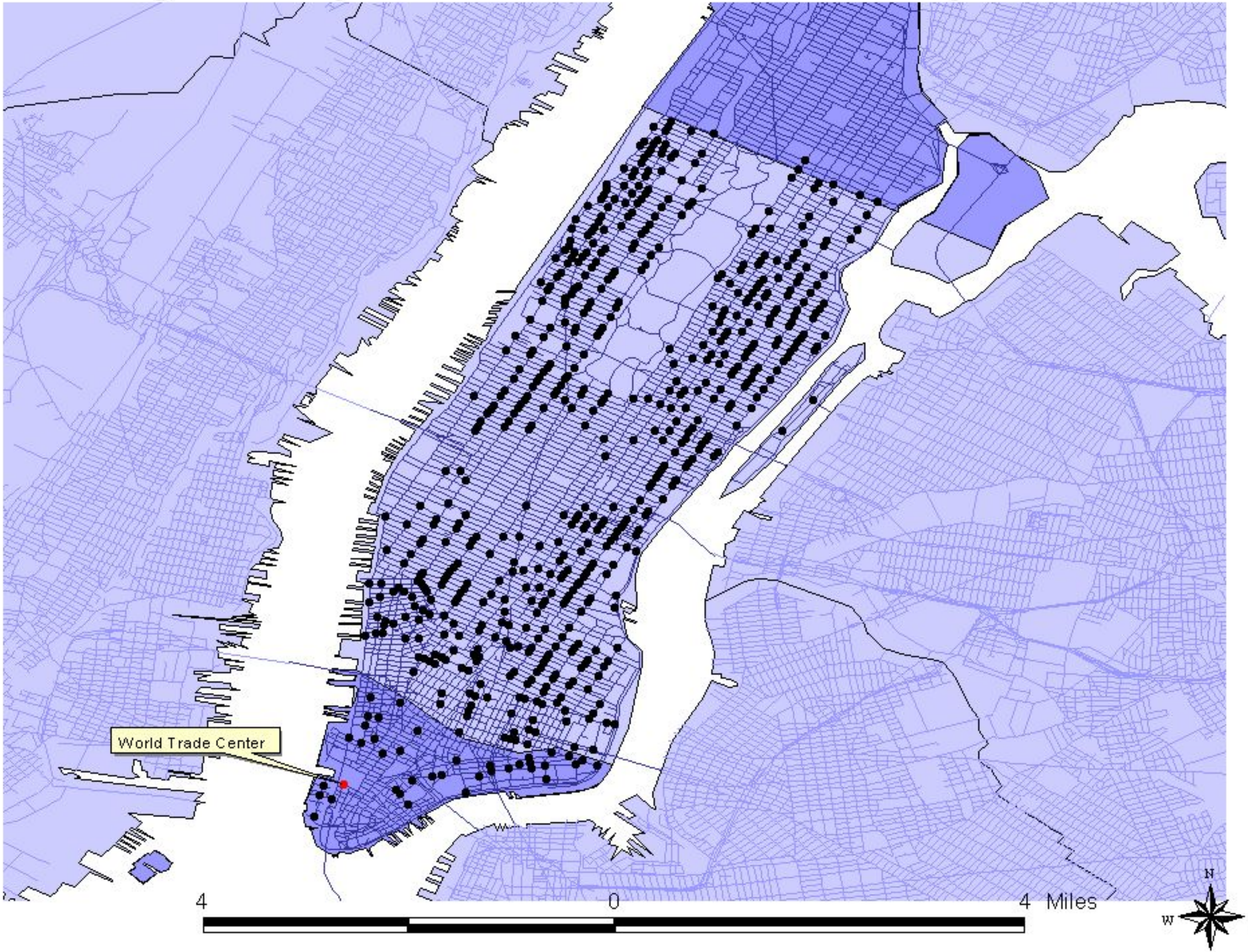
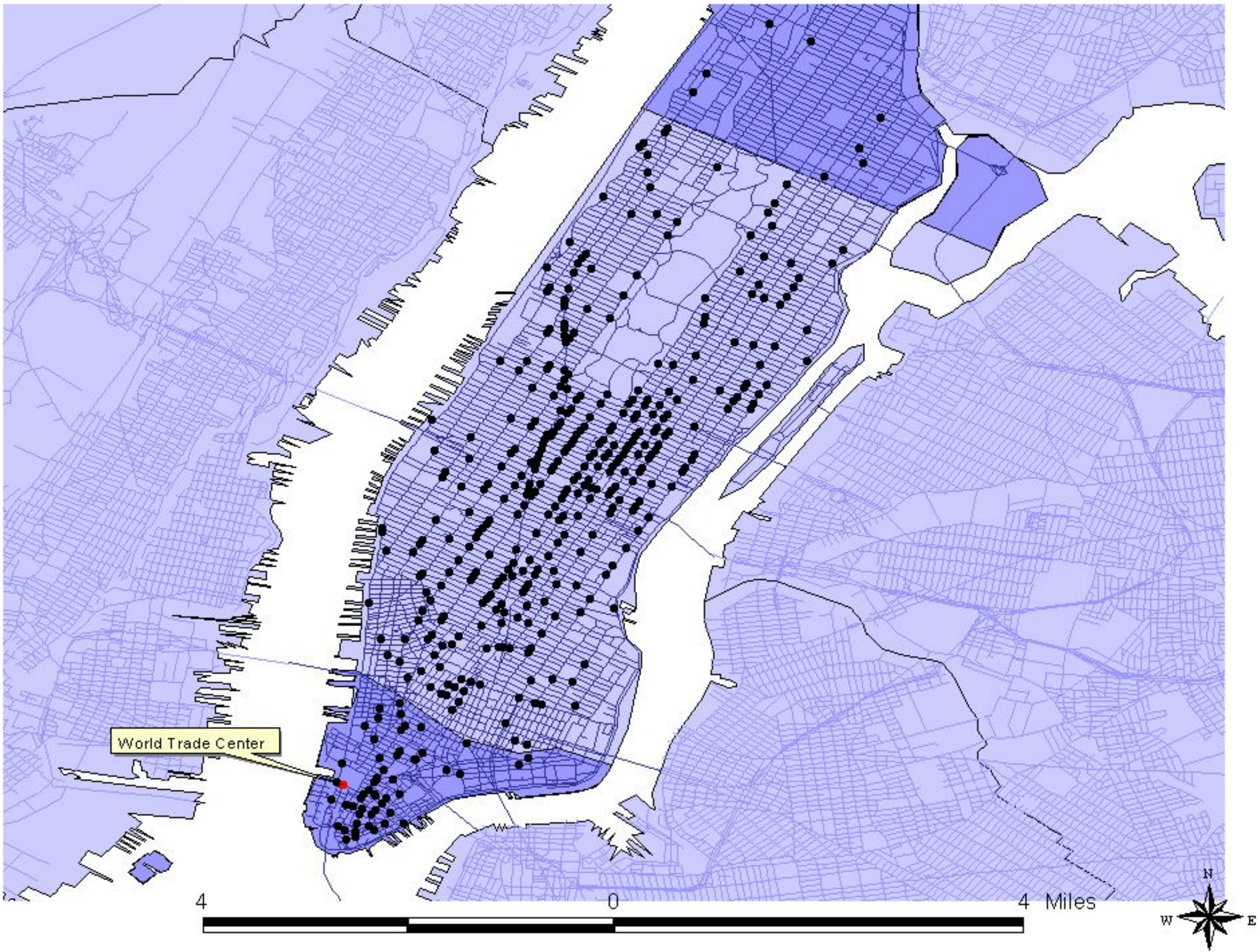
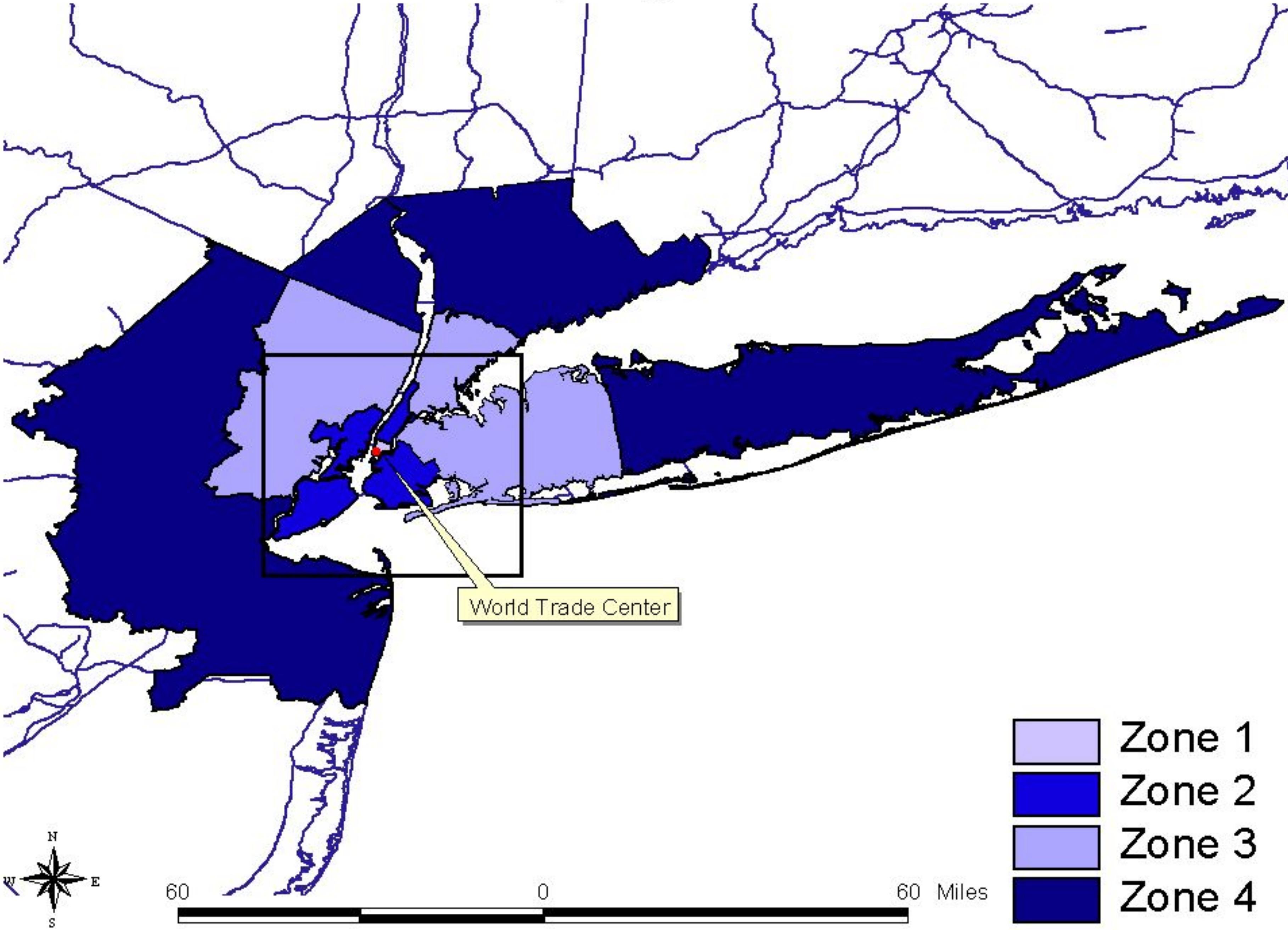
Survey 1: Respondents' residences on September 11

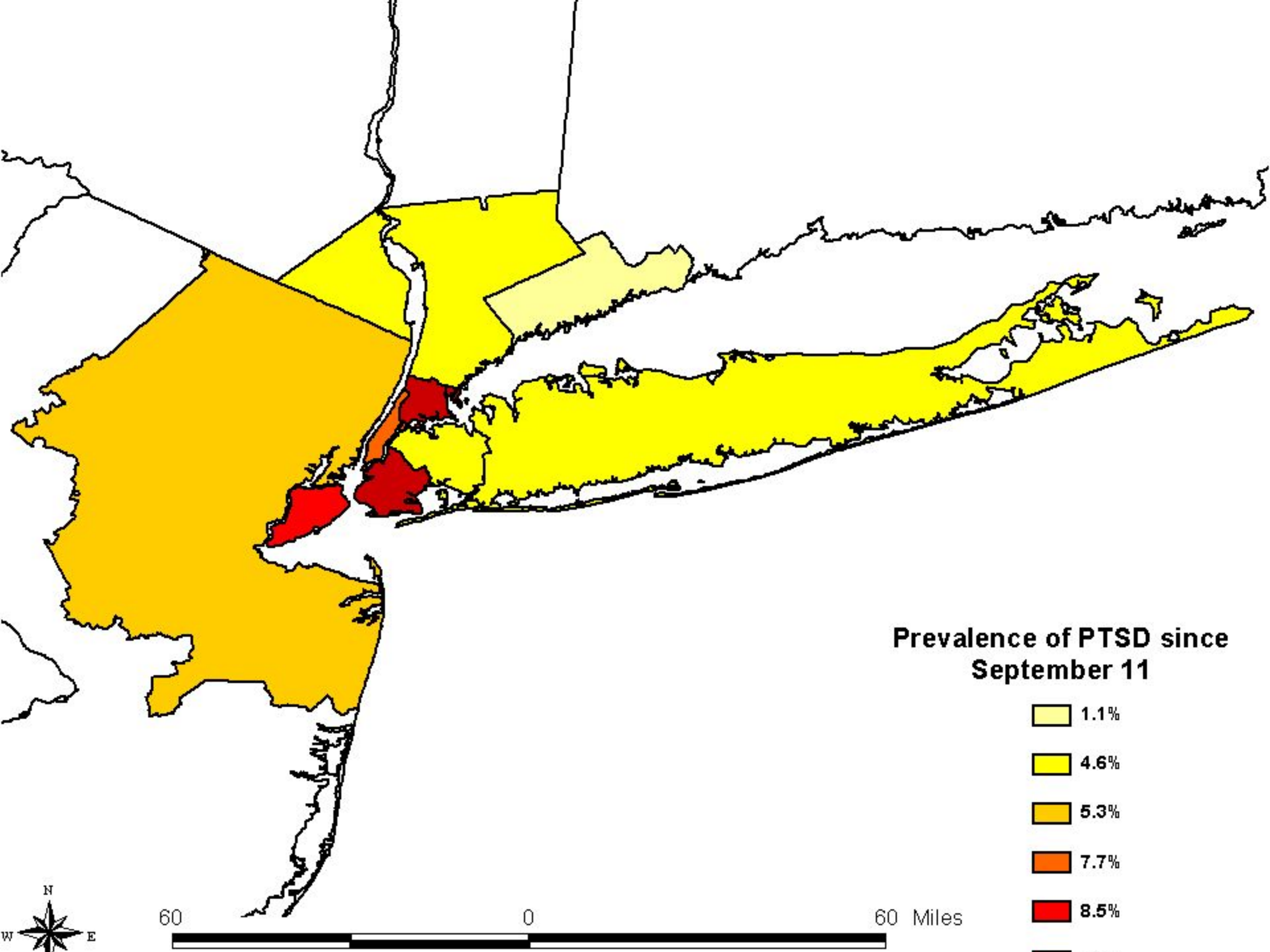


Survey 1: Respondents' locations on September 11



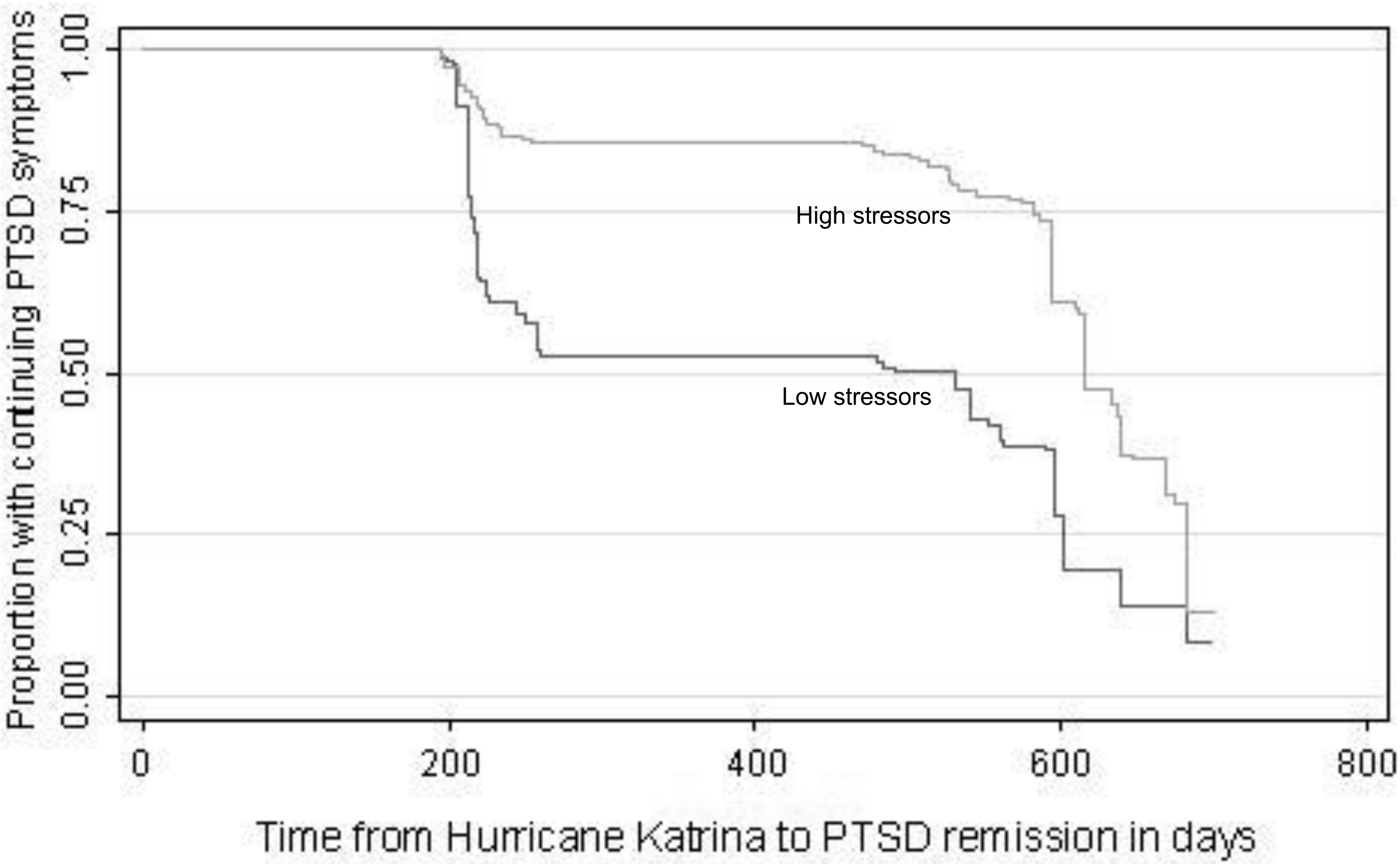
Sampling frames




Prevalence of PTSD since September 11
1.1%
4.6%
5.3%
7.7%
8.5%
N
W
E
60
0
60 Miles

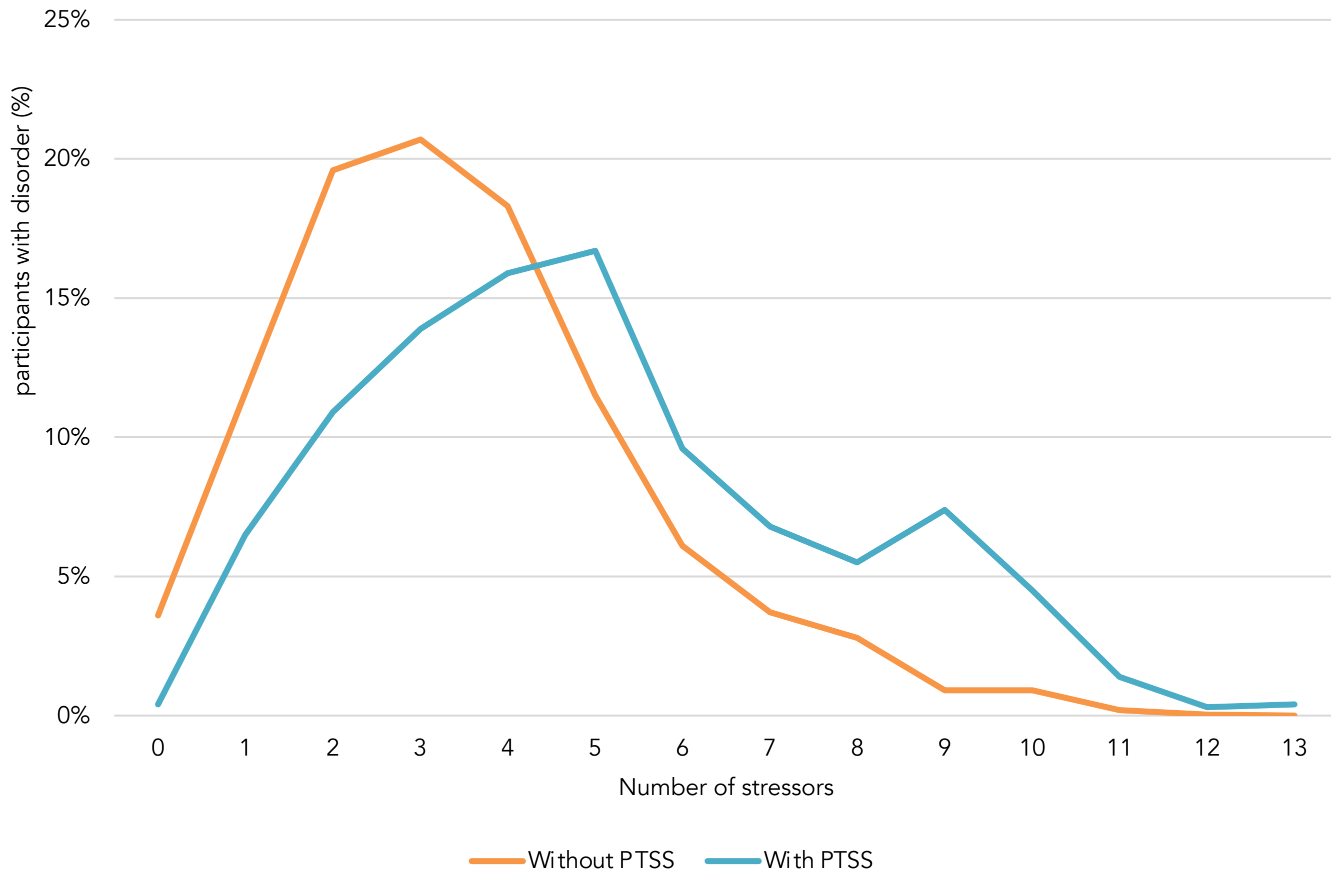

The Water
Is
Rising
Pleas


SIGNS
VERA
GOD HELP U



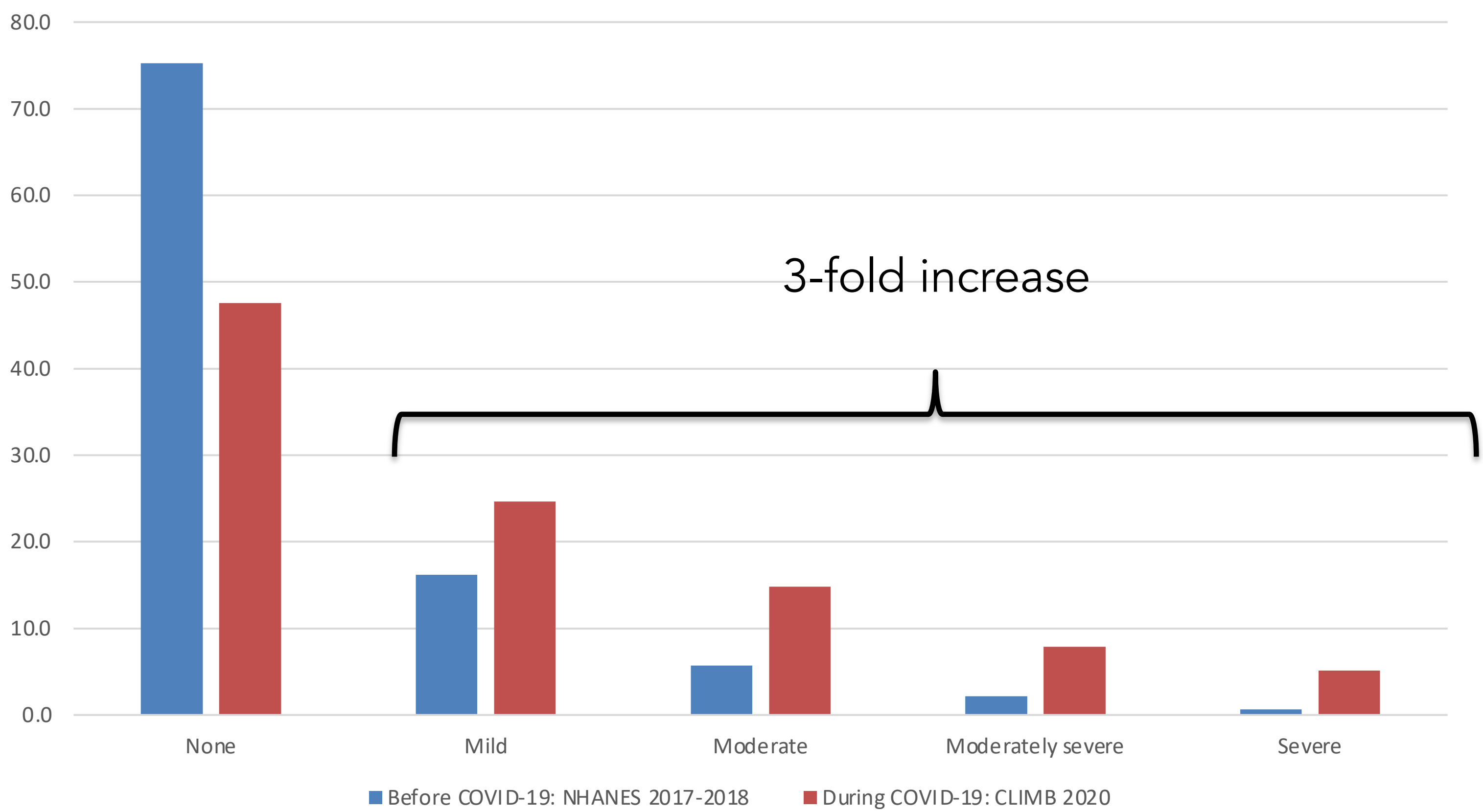
Galea S, Tracy M, Norris F, Coffey S. Financial and social circumstances and the incidence and course of PTSD in Mississippi during the first two years after Hurricane Katrina. Journal of Traumatic Stress. 2008; 21(4):357-68. PMID: 18720399. URL: http://hdl.handle.net/2027.42/60922

Distribution of total number of COVOD-19 stressors by post-traumatic stress symptom status

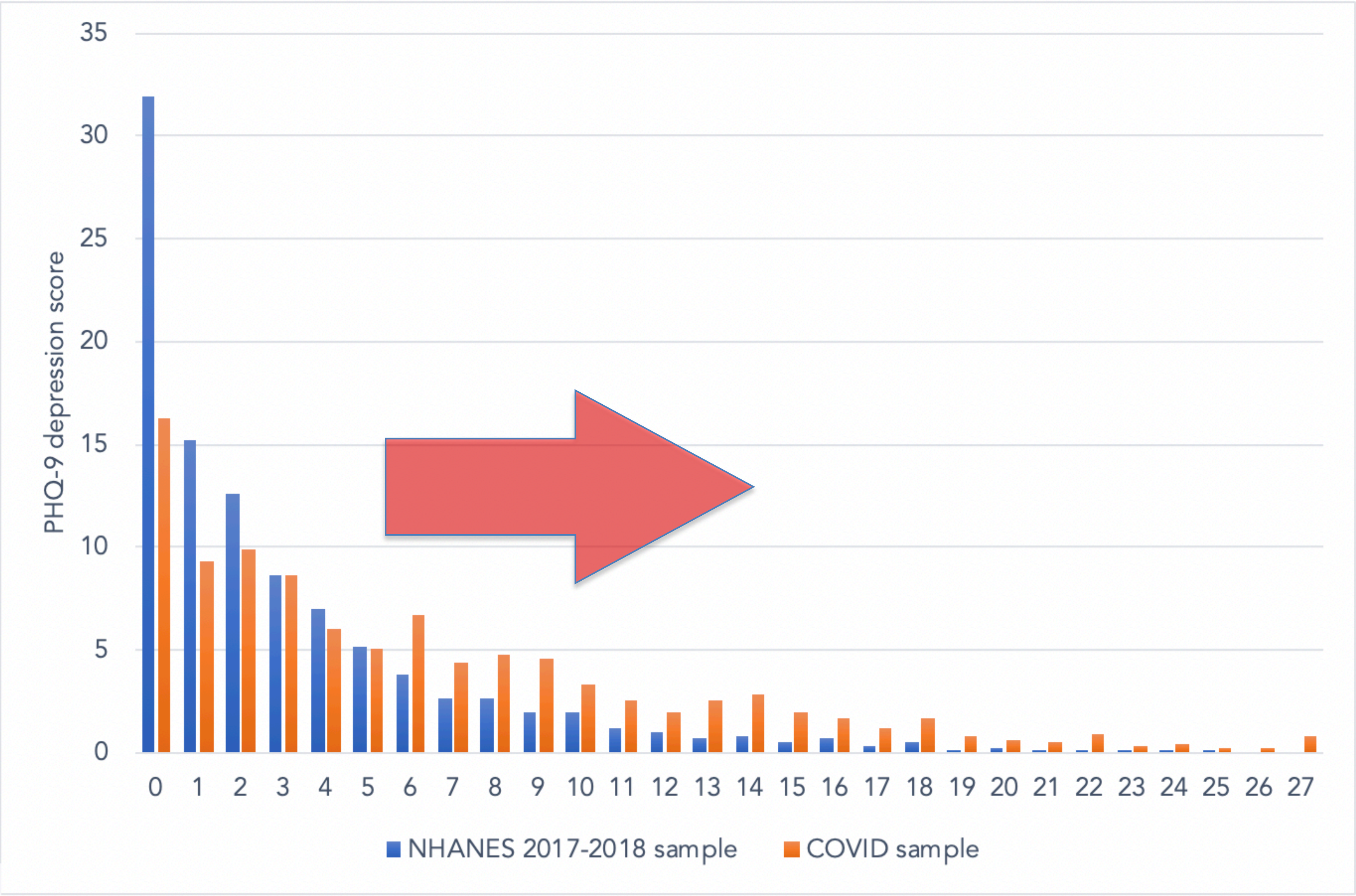


Post-traumatic stress symptoms (PTSS). PTSS defined by a PTSD checklist (PCL) score ≥3. Percentages are weighted to the U.S. population. Abdalla SHM, Ettman CK, Cohen GH, Galea S. The mental health consequences y disorders in the United. Under review.

Depression symptoms in U.S. adults before and during the COVID-19 pandemic



Note: Before COVID-19 estimates from the National Health and Nutrition Examination Survey (NHANES) from 2017-2018 (N=5065). During COVID-19 estimates from the COVID-19 and Life stressors Impact on Mental Health and Well-being Study (CLIMB) collected from March 31, 2020 to April 13, 2020 (N=1441). Depression symptoms categories calculated using the Patient Health Questionnaire-9 (PHQ-9): none (0-4), mild (5-9), moderate (10-14), moderately severe (15-19), and severe (≥20). Percentages weighted to the U.S. adult 18 years or older population. Ettman CK, Abdalla SM, Cohen GH, Sampson L, Vivier PM, Galea S. Prevalence of depression symptoms in US. adults before and during the COVID-19 pandemic. JAMA Network Open 2020; 3(9): e2019686. https://doi:10.1001/jamanetworkopen.2020.20104



Ettman CK, Abdalla SM, Cohen GH, Sampson L, Vivier PM, Galea S. Prevalence of depression symptoms in US. adults before and during the COVID-19 pandemic. JAMA Network Open 2020; 3(9): e2019686. https://doi:10.1001/jamanetworkopen.2020.20104

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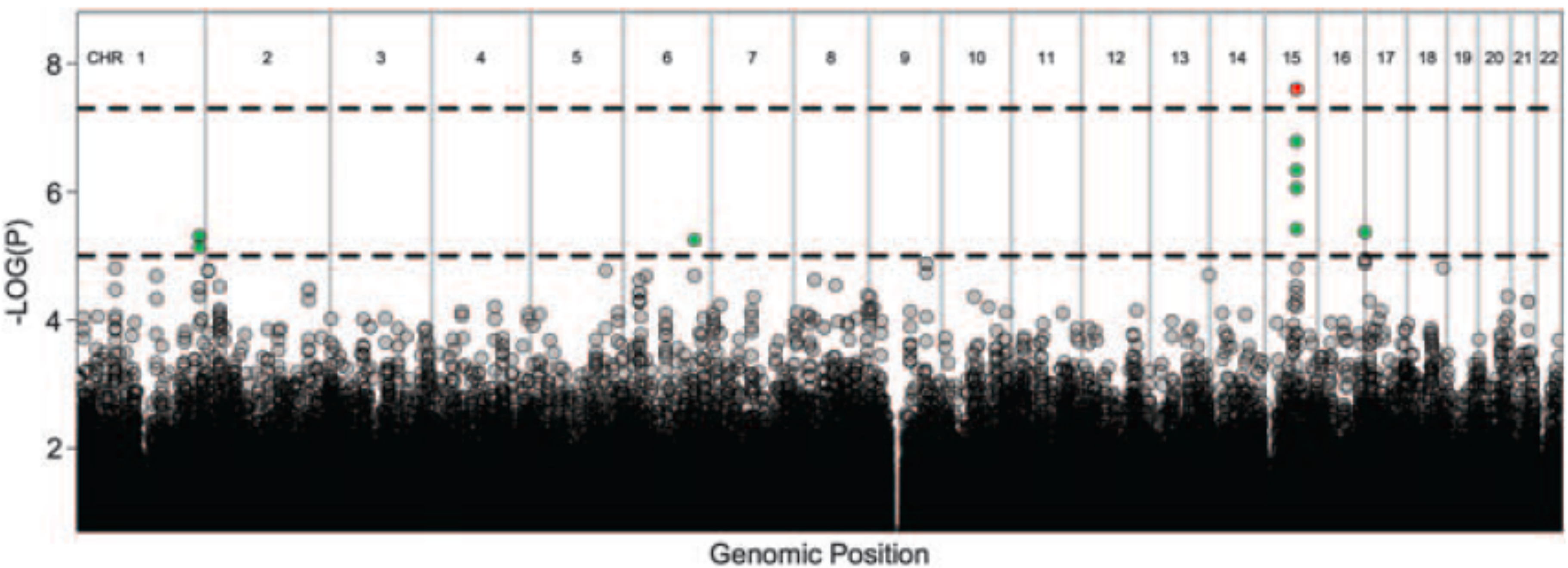
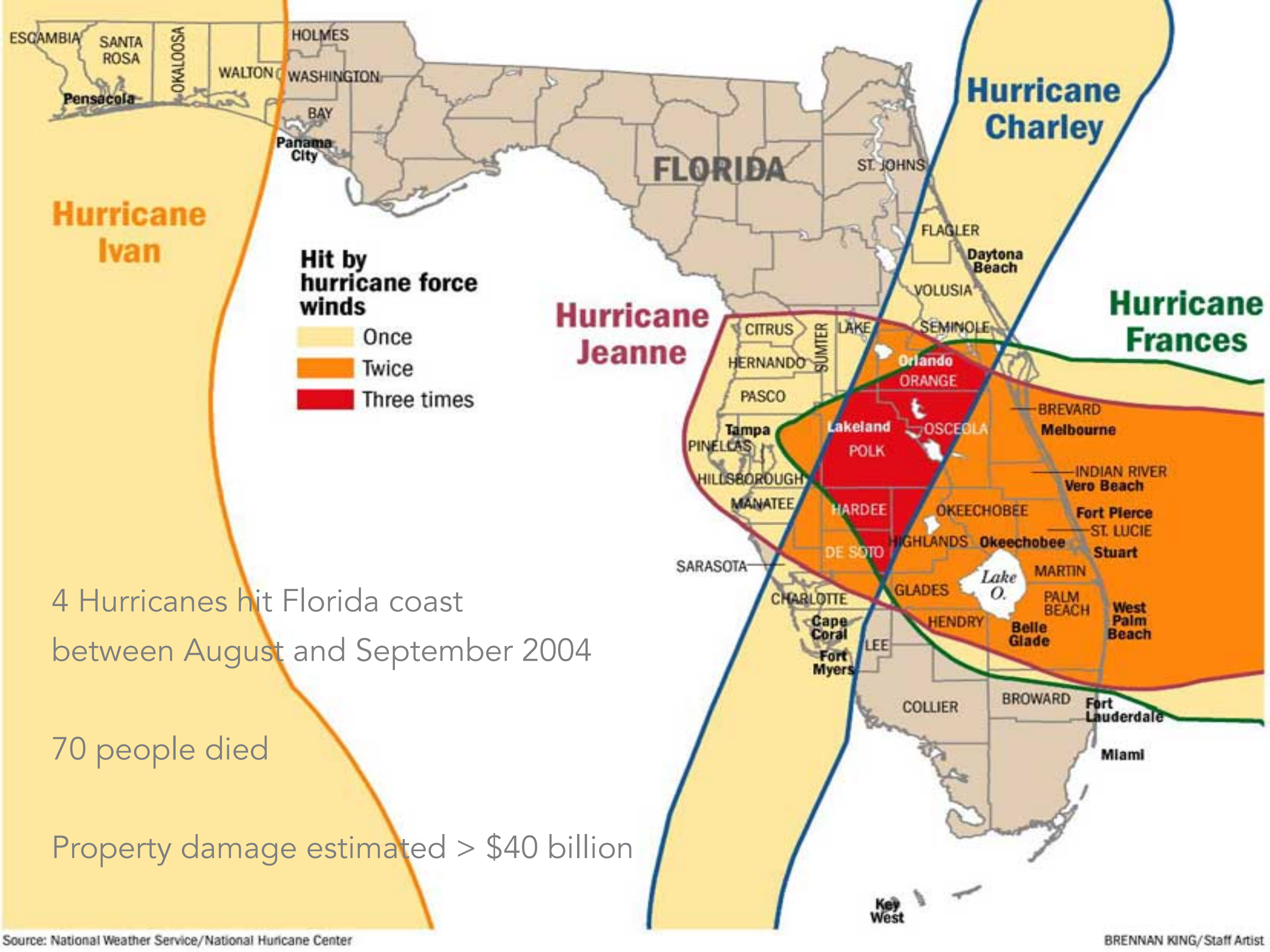


Manhattan plot of genome-wide association results in discovery group. Dashed lines and colors represent suggestive and genomewide significance respectively, with green p<10(-5) and red p<5(-8)

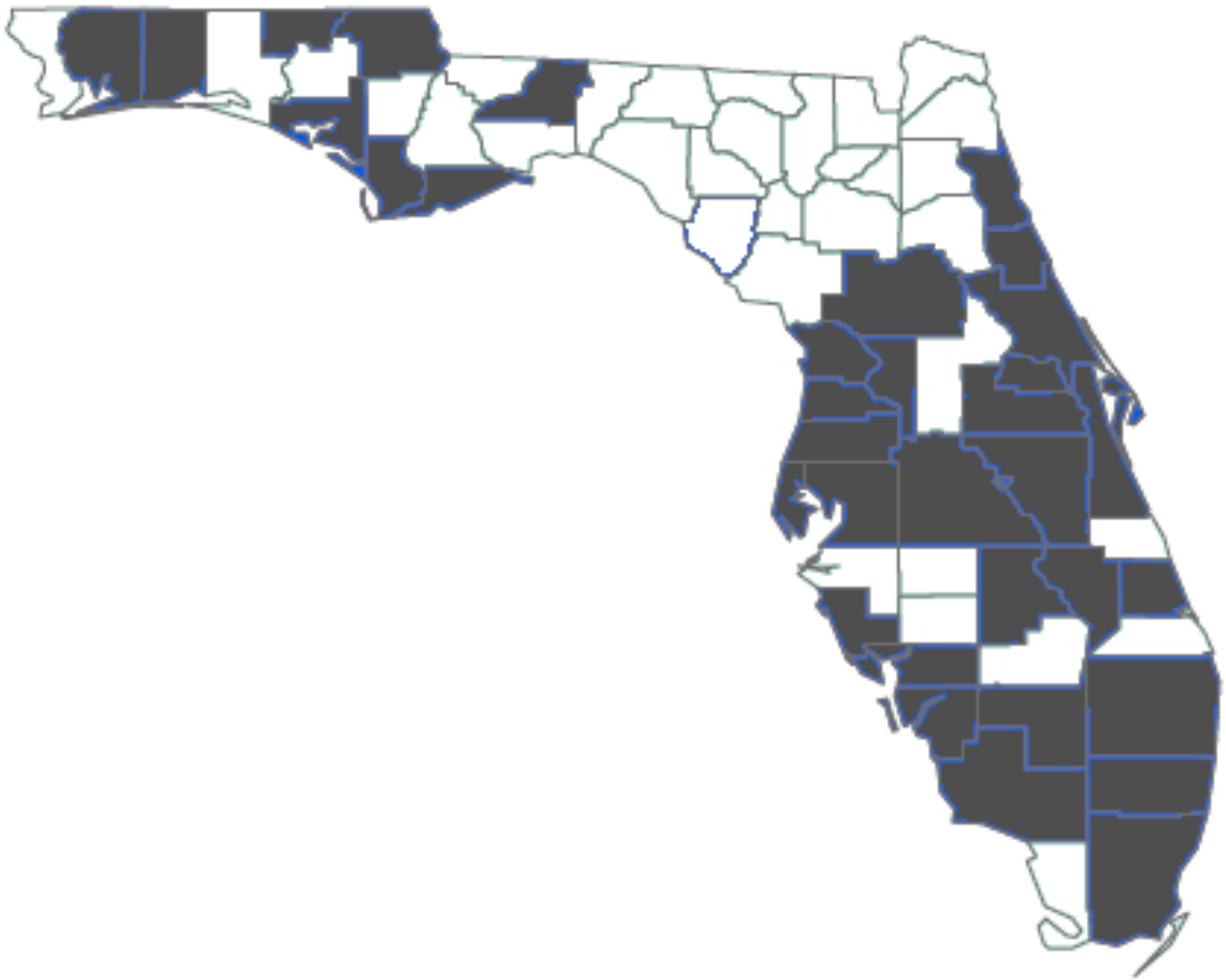
Logue MW, Baldwin C, Guffanti G, Melista E, Wolff EJ, Reardon AF, Uddin M, Wildman D, Galea S, Koenen KC, Miller MW. A Genome-wide association study of posttraumatic stress disorder identifies the retinoid-related orphan receptor alpha (RORA) gene as a significant risk locus. Molecular Psychiatry. 2013;18(8):937-42. PMID: 22869035. PMCID: PMC3494788. http://dx.doi.org/10.1038/mp.2012.113.



4 Hurricanes hit Florida coast between August and September 2004

70 people died

Property damage estimated > $40 billion



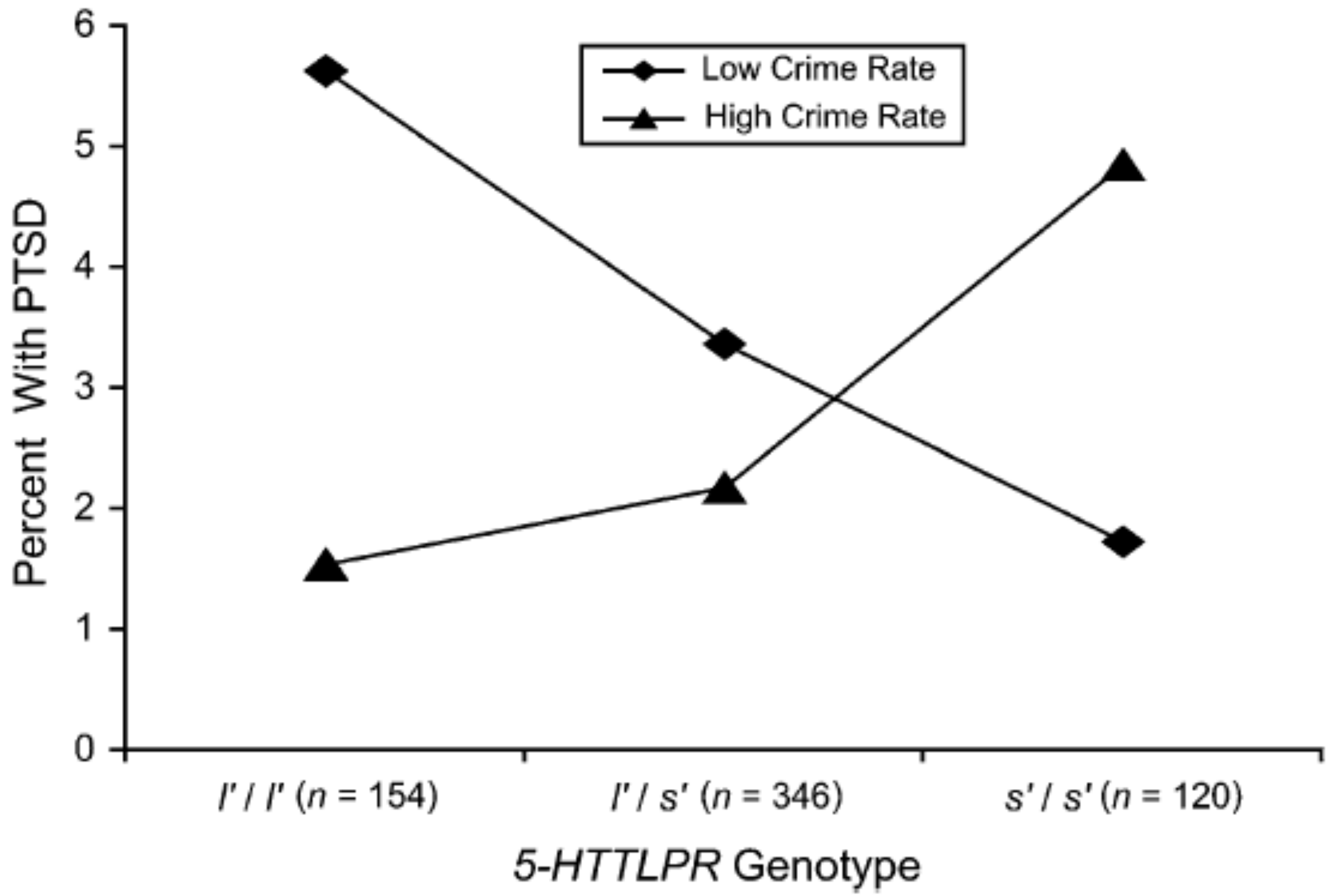


Figure 1. Prevalence of posttraumatic stress disorder (PTSD) by serotonin transporter polymorphism (*5-HTTLPR*) genotype and county-level crime rate (dichotomized as high vs. low), 2004 Florida Hurricane Study, 2005. *l*, long allele; *s*, short allele.

Koenen K, Aiello AE, Bakshis E, Amstadter AB, Ruggiero K, Acierno R, Kilpatrick DG, Gelertner J, Galea S. Modification of the association between serotonin transporter genotype and risk of posttraumatic stress disorder in adults by county-level social environment. American Journal of Epidemiology. 2009;169(6):704-711. PMID: 19228812. URL: http://hdl.handle.net/2027.42/61911

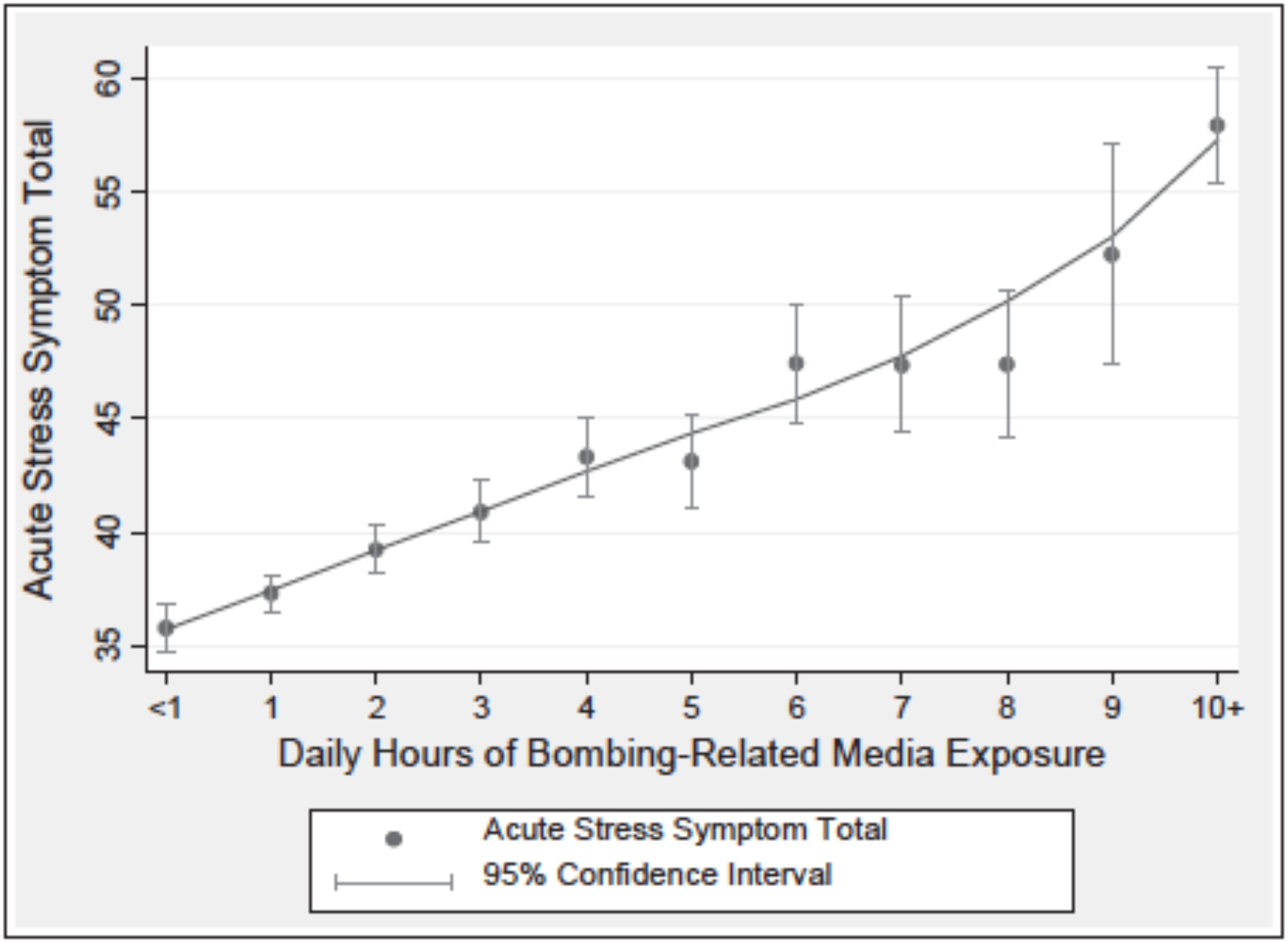
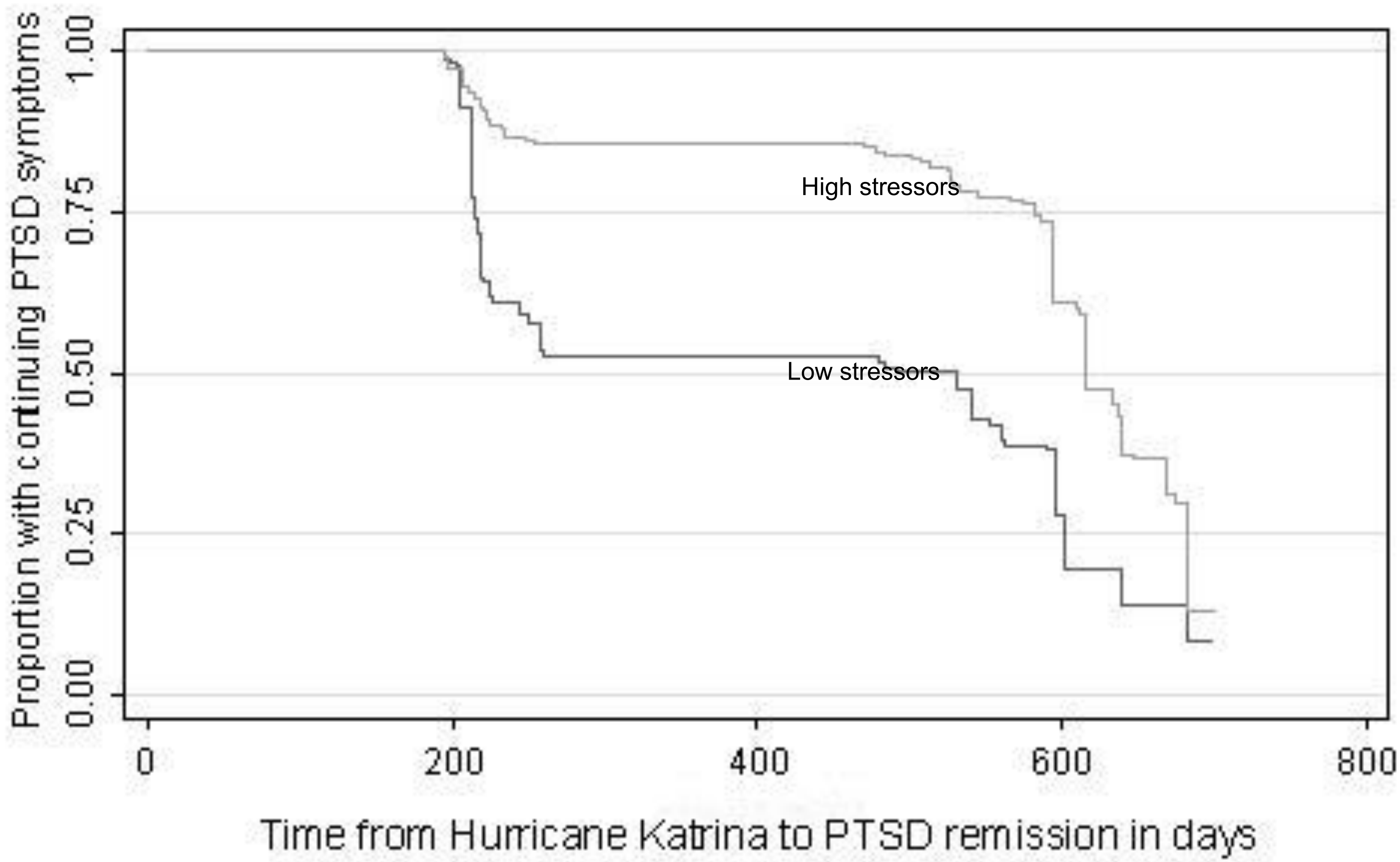


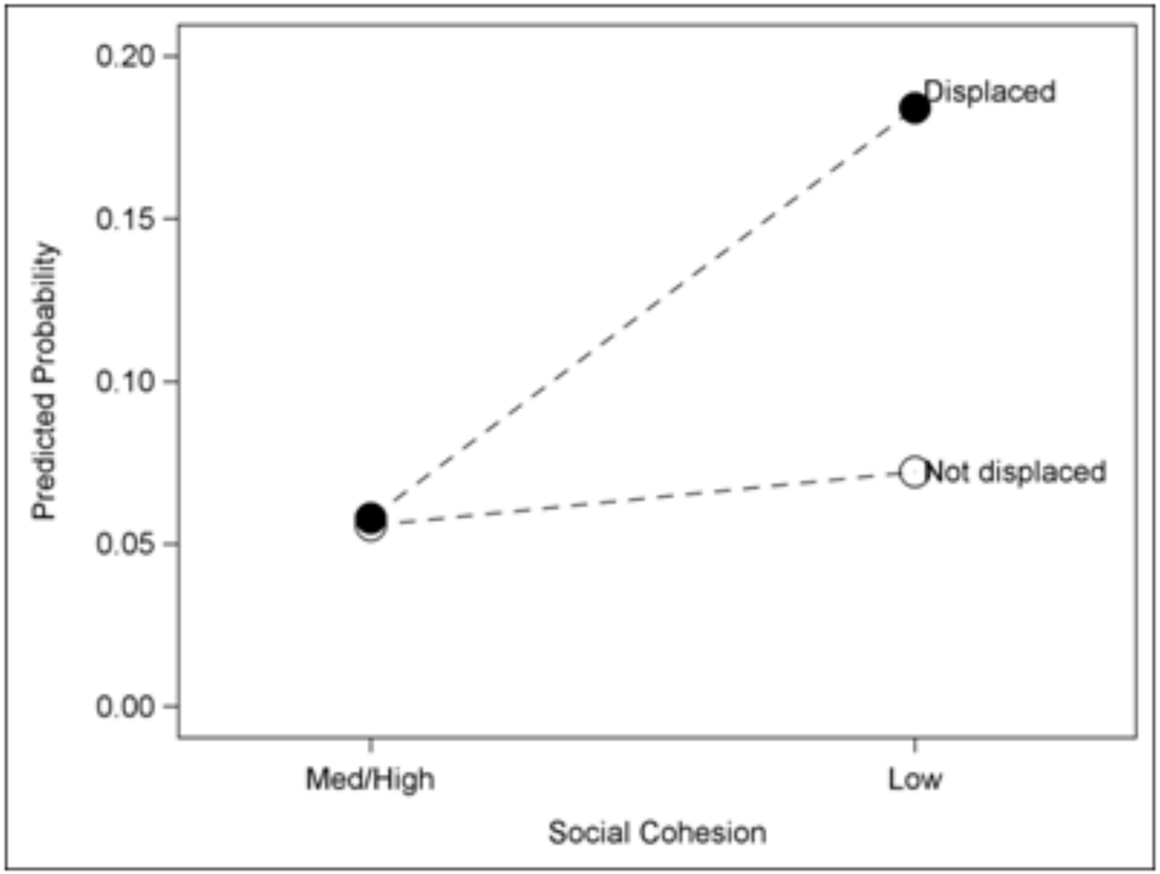
Fig. 1. Acute stress symptom total by the number of hours per day of Boston Marathon bombing media exposure in the week following the Boston Marathon bombings.

Holman EA, Garfin DR, Silver RC. Media's role in broadcasting acute stress following the Boston marathon bombings. Proc Natl Acad Sci U S A. 2014 Jan 7;111(1):93-8. doi: 10.1073/pnas.1316265110



Galea S, Tracy M, Norris F, Coffey S. Financial and social circumstances and the incidence and course of PTSD in Mississippi during the first two years after Hurricane Katrina. Journal of Traumatic Stress. 2008; 21(4):357-68. PMID: 18720399. URL: http://hdl.handle.net/2027.42/60922

Community social cohesion, population displacement, and depression after Hurricane Katrina



Le F, Tracy M, Norris FH, Galea S. Displacement, county social cohesion and depression after a large-scale traumatic event. Social Psychiatry and Psychiatric Epidemiology. 2013;48(11):1729-41.

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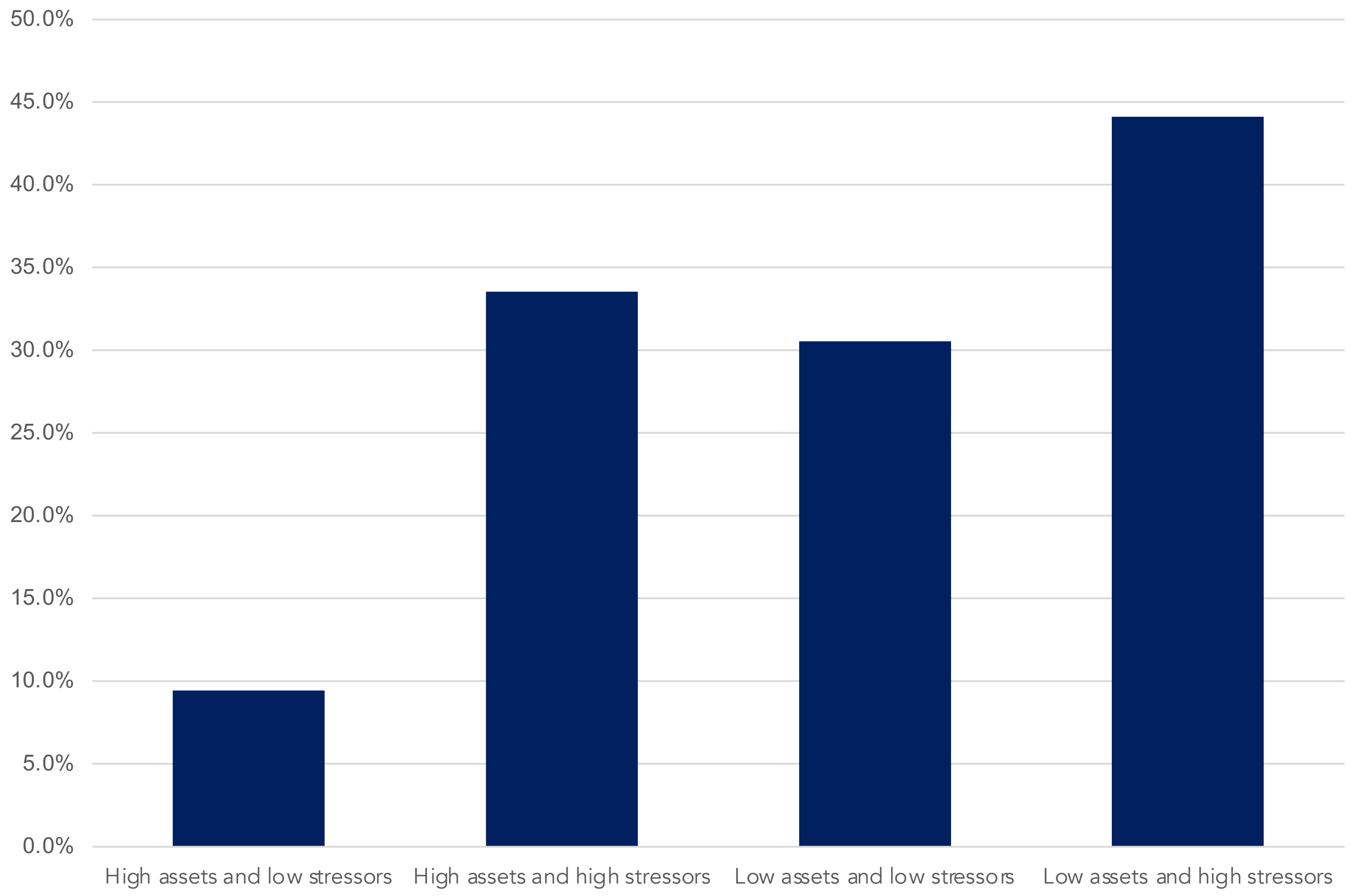
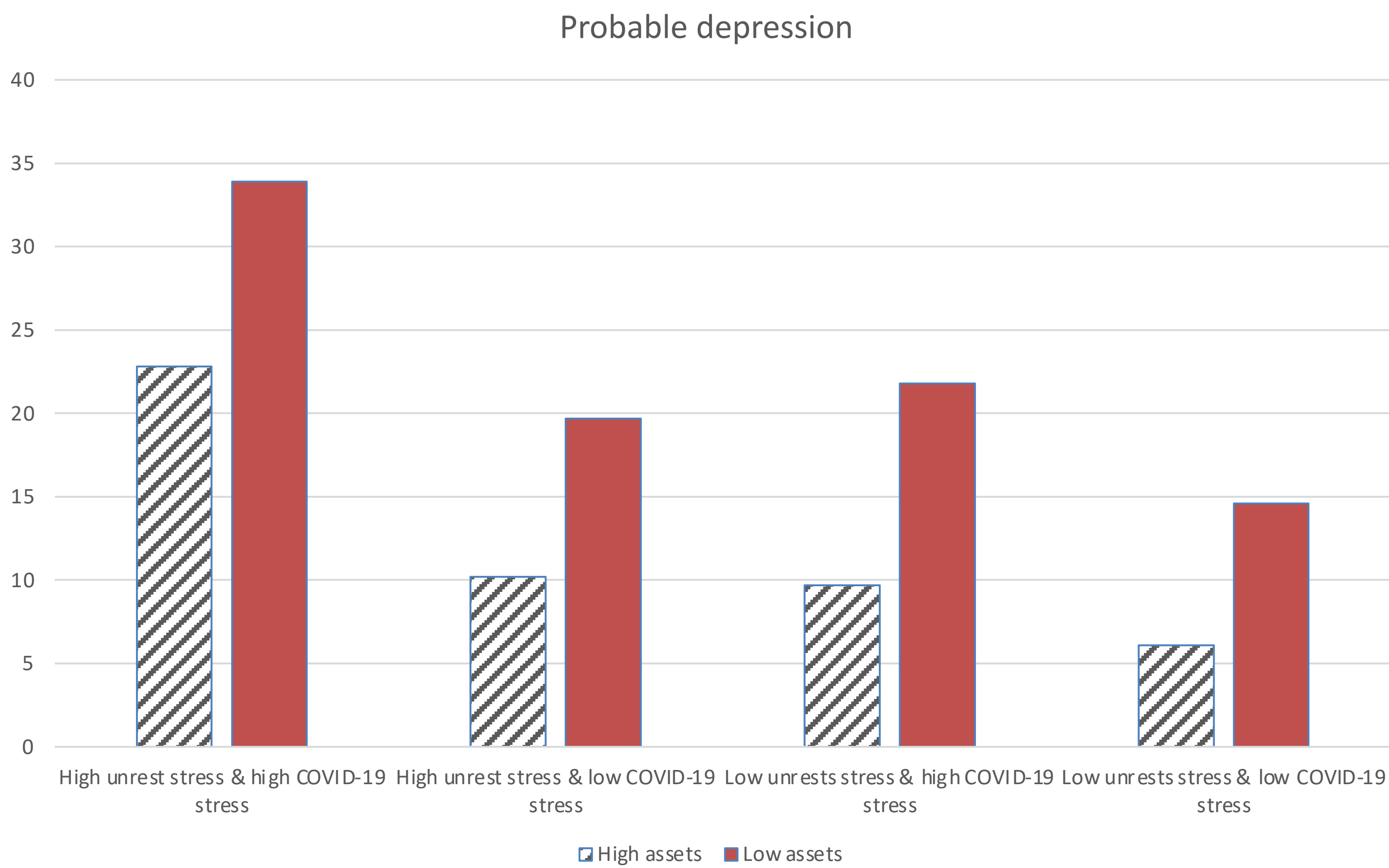
Assets, stressors, and depression during COVID-19



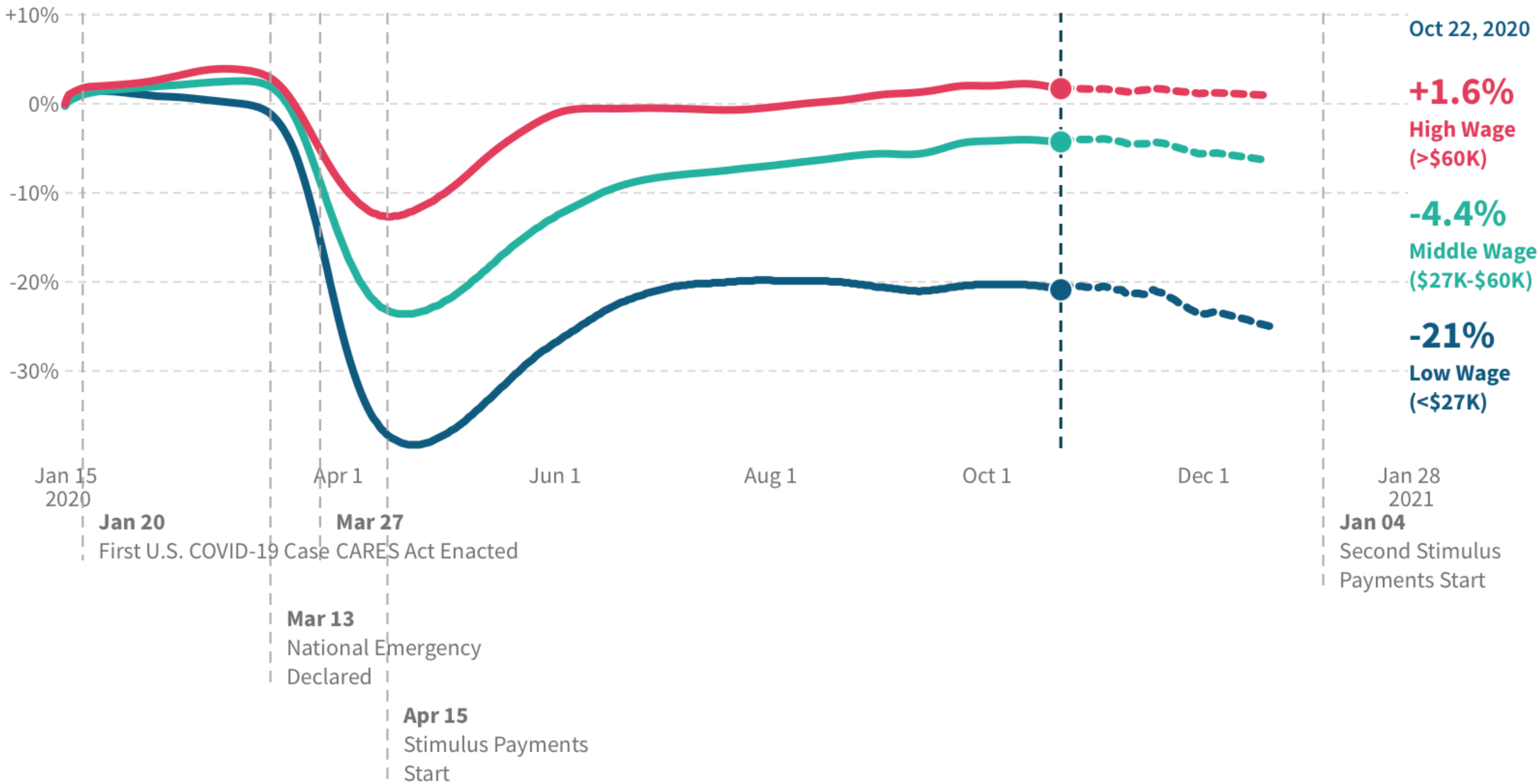
Ettman et al. COVID-19 stressors together with limited assets increase risk for depression. Under review.

Prevalence of probable depression across different stressors among people with high and low assets, Hong Kong



Wai Kai Hou et al. Civil unrest, COVID-19 stressors, anxiety, and depression in the acute phase of the pandemic: A population-based study in Hong Kong. SPPE. In press.

In **the United States**, as of October 22 2020, employment rates among workers in the bottom wage quartile decreased by **21%** compared to January 2020 (not seasonally adjusted).



https://tracktherecovery.org

FIGURE E

Black workers are far more likely to be unemployed than white workers at every level of education

Unemployment rates by race and education, 2019

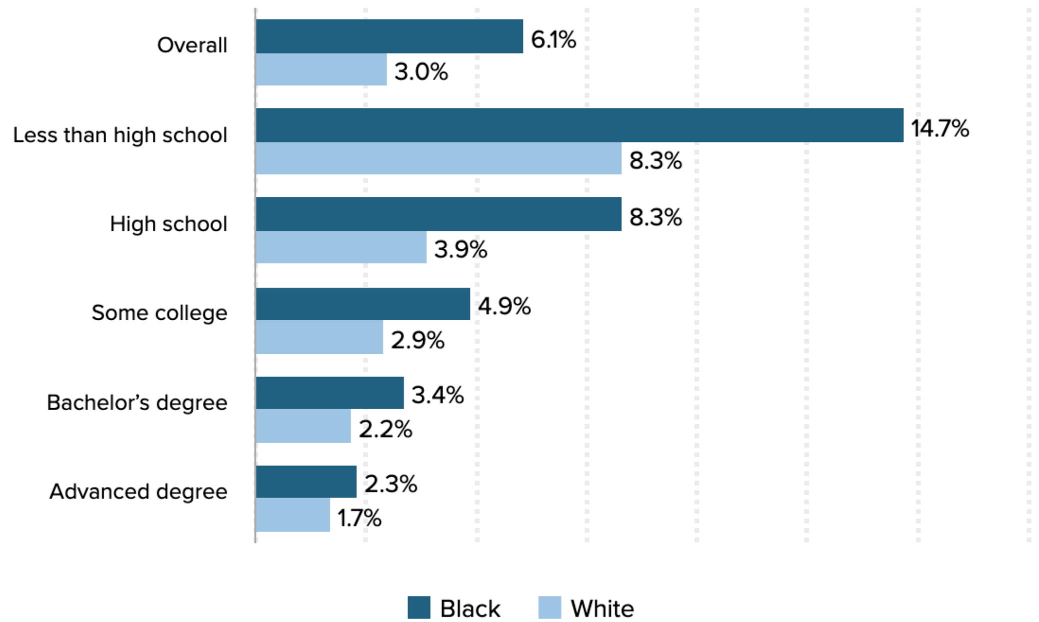


Chart Data

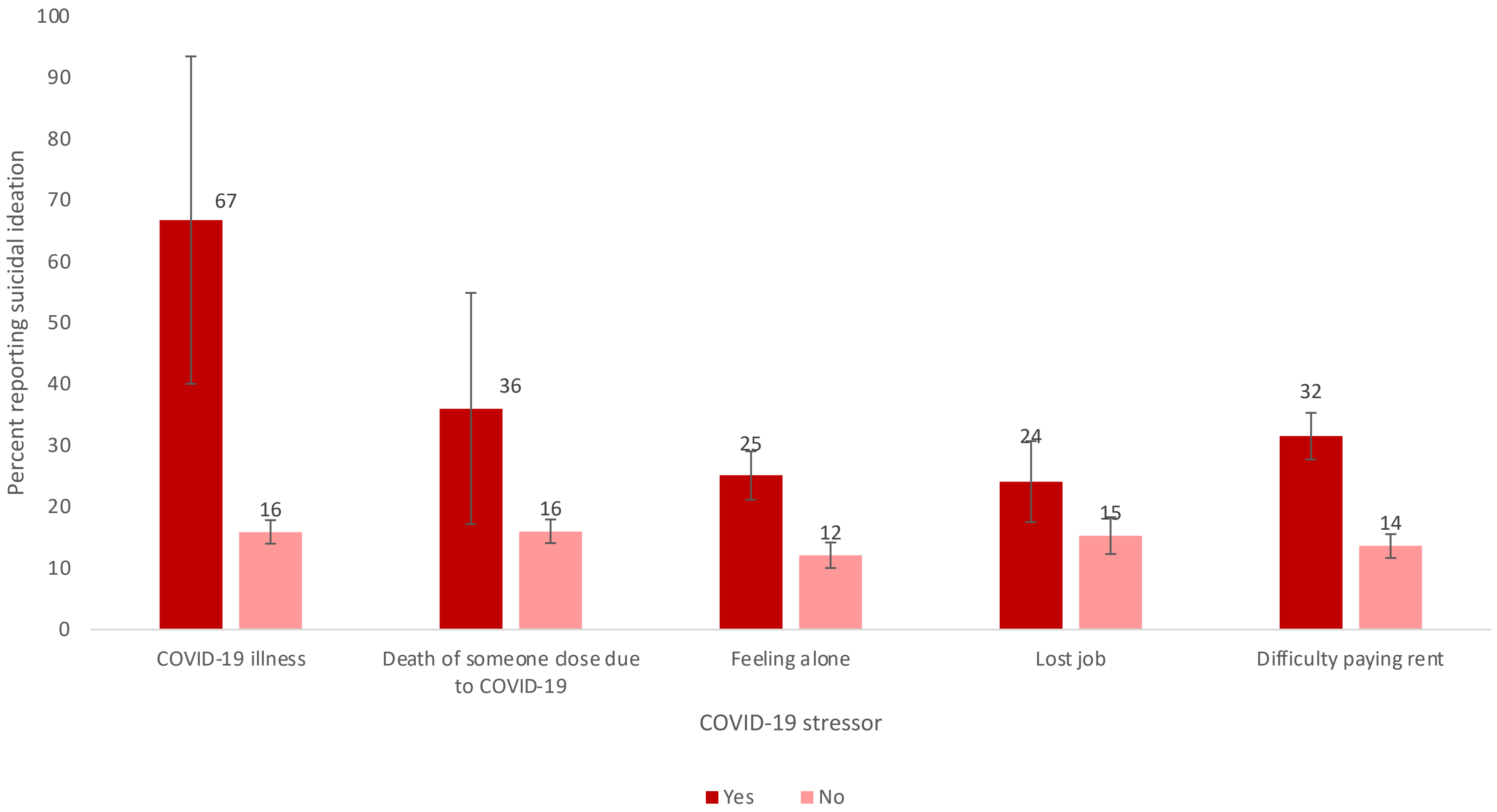
Notes: White refers to non-Hispanic whites, black refers to blacks alone. Educational categories are mutually exclusive and represent the highest education level attained for all individuals ages 16 and older.

Source: Economic Policy Institute, *State of Working America Data Library*, [Unemployment by race and education], 2019.

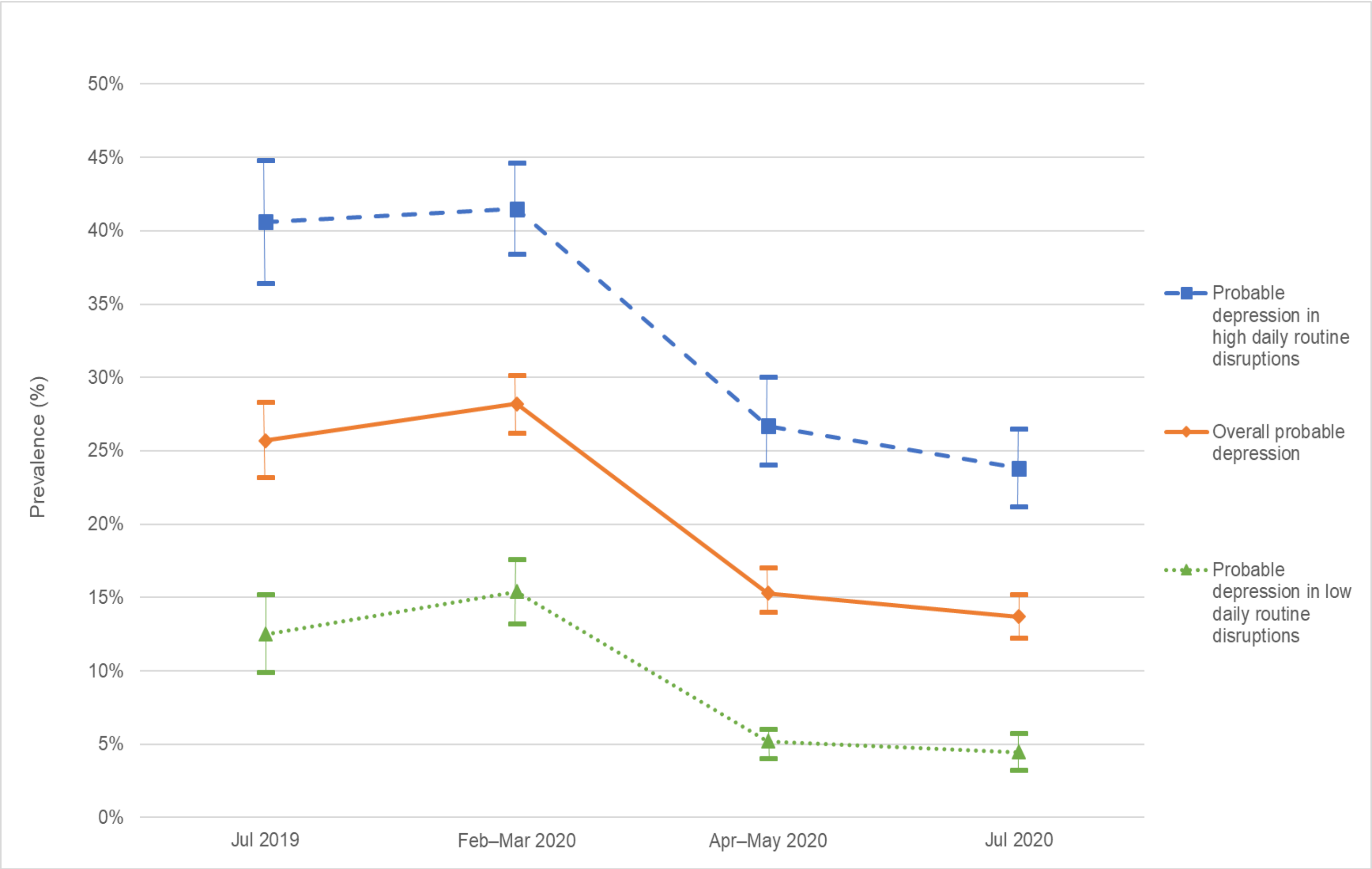
Economic Policy Institute

Gould E, Wilson V. Black workers face two of the most lethal preexisting conditions for coronavirus—racism and economic inequality. Economic Policy Institute. June 1, 2020. https://www.epi.org/publication/black-workers-covid/

Covid-19 stressors and suicidal ideation



Raifman J, Ettman CK, Dean L, Barry C, Galea S. Stressors and suicidal ideation during the COVID-19 pandemic. Under review.



Hou WK, Li TW, Liang L, Liu H, Lee TM-C, Galea S. Trends of probable depression and anxiety during massive civil unrest and COVID-19 in Hong Kong, 2019-2020. Under review.

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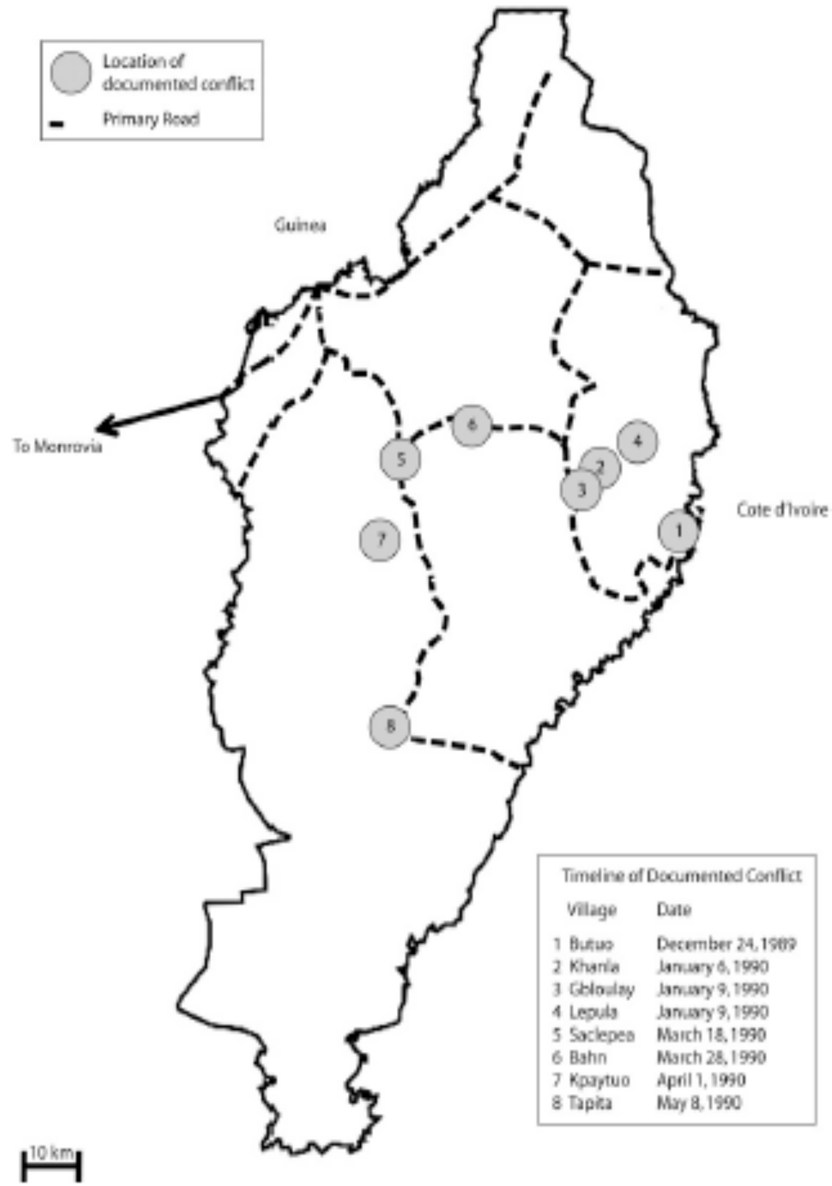
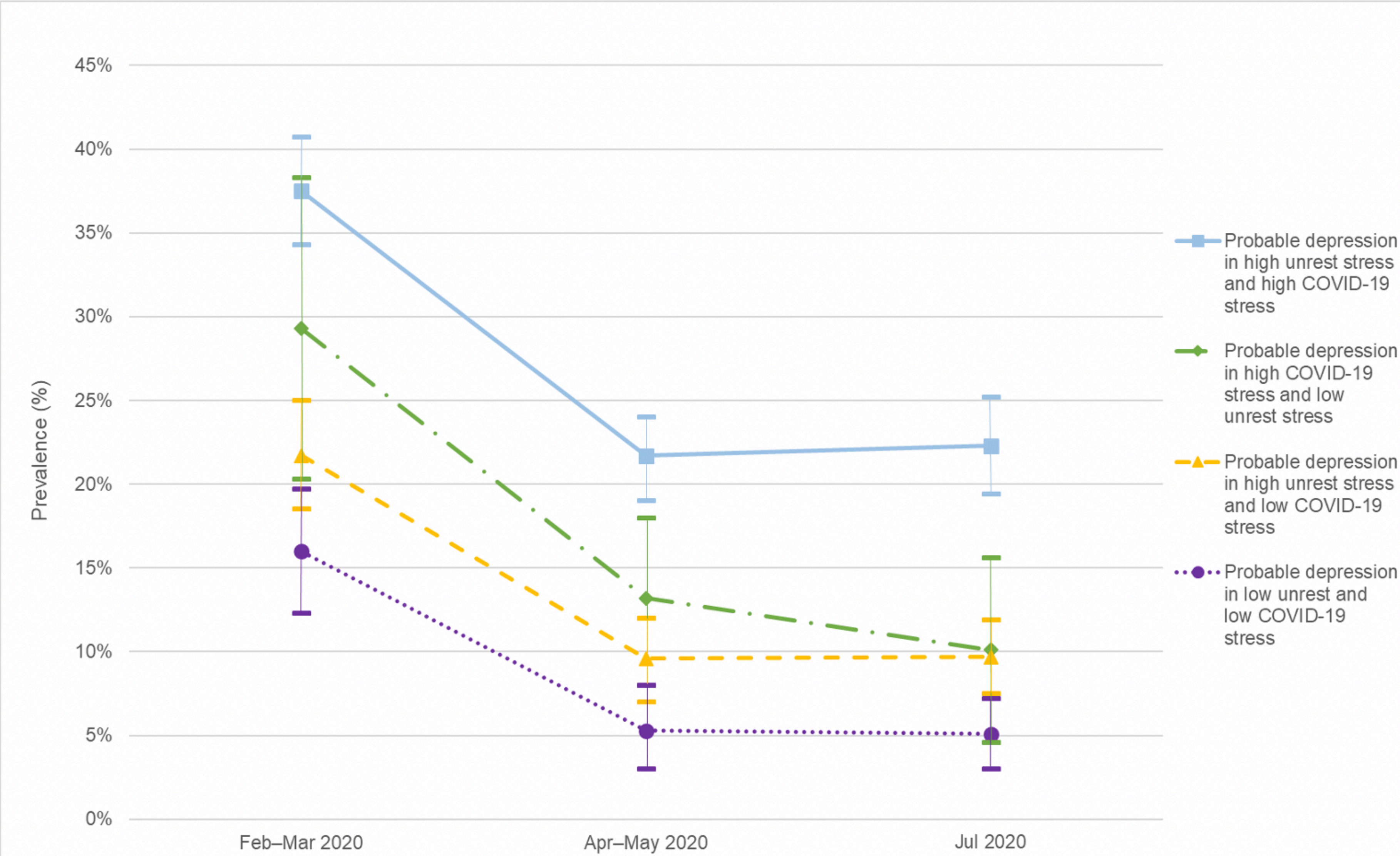


FIGURE 1—Documented instances of civil conflict in Nimba County, Liberia, between December 1989 and May 1990.

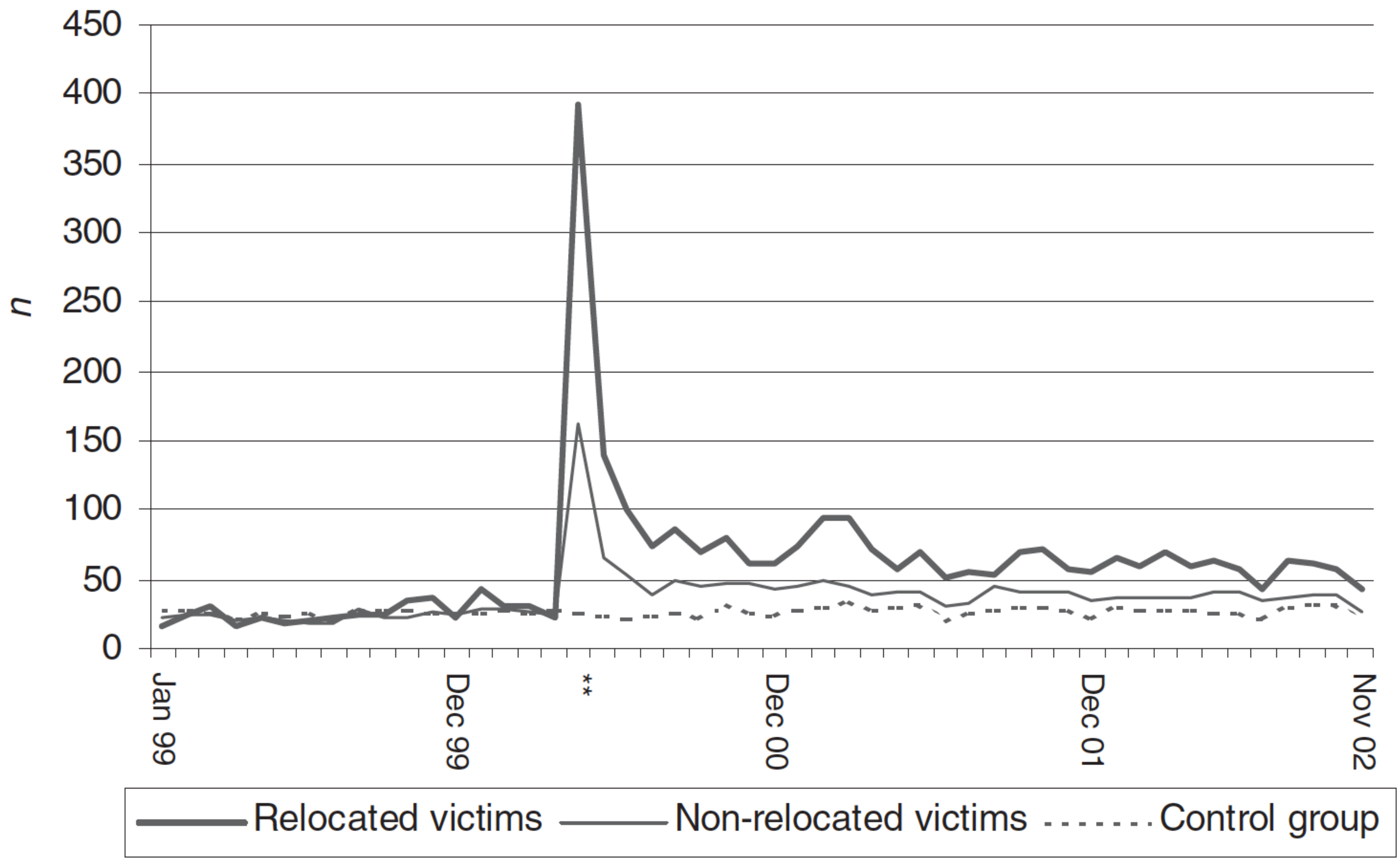
Galea S, Rockers PC, Saydee G, McCauley R, Varpilah ST, Kruk ME. Persistent psychopathology in the wake of civil war: the path of long-term post-traumatic stress disorder in Nimba County, Liberia. American Journal of Public Health. 2010;100(9):1745-51. PMID: 20634461. URL: http://dx.doi.org/10.2105/AJPH.2009.179697

FIGURE 3—Geographical distribution of symptoms consistent with posttraumatic stress disorder in sampled villages: Nimba County, Liberia, 2008.

Galea S, Rockers PC, Saydee G, McCauley R, Varpilah ST, Kruk ME. Persistent psychopathology in the wake of civil war: the path of long-term post-traumatic stress disorder in Nimba County, Liberia. American Journal of Public Health. 2010;100(9):1745-51. PMID: 20634461. URL: http://dx.doi.org/10.2105/AJPH.2009.179697



Hou WK, Li TW, Liang L, Liu H, Lee TM-C, Galea S. Trends of probable depression and anxiety during massive civil unrest and COVID-19 in Hong Kong, 2019-2020. Under review.



**Date of disaster.

Yzermans CJ, Donker GA, Kerssens JJ, Dirkzwager AJ, Soeteman RJ, ten Veen PM. Health problems of victims before and after a disaster: a longitudinal study in general practice.Int J Epidemiol. 2005 Aug;34(4):820-6. doi: 10.1093/ije/dyi096. Epub 2005 Apr 28

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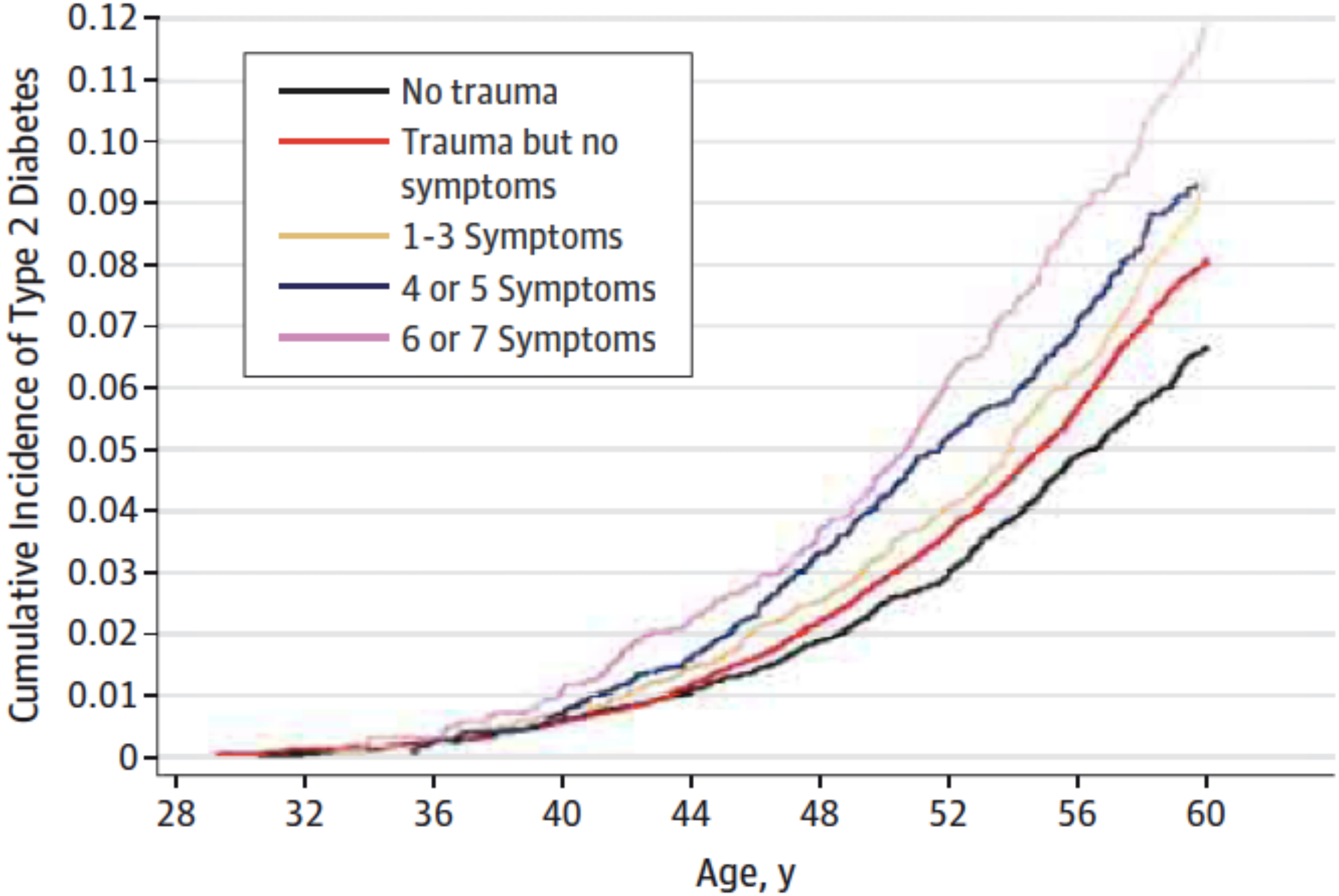
Figure. Cumulative Incidence of Type 2 Diabetes, Stratified by Number of Posttraumatic Stress Disorder Symptoms (Nurses' Health Study II, 1989-2011)



Roberts AL, Agnew-Blais J, Spiegelman D, Mason SM, Galea S, Hu F, Rich-Edwards JW, Koenen KC. Posttraumatic stress disorder and type 2 diabetes incidence in women: A 22-year longitudinal study. JAMA Psychiatry. 2015;72(3):203-10. PMID: 25565410. https://dx.doi:10.1001/jamapsychiatry.2014.2632

Some concluding thoughts

1. Disasters are ineluctably linked to mental health
2. Biological and social factors influence mental health
3. Health inequities are a consistent characteristic
4. Mental health consequences linger in the long-term
5. Physical health is shaped by mental health

Disaster recovery efforts should have a formal mandate to systematically mitigate the mental health consequences of these events

Goldstein BD. Broadening the Mandate of the Incident Command System to Address Community Mental and Behavioral Health Effects as Part of the Federal Response to Disasters. Current Environmental Health Reports (2020) 7:282–291

sandrogalea.substack.com

sgalea@bu.edu

Human Health:
A holistic approach to exposure assessment

Maureen Lichtveld, MD, MPH
Dean, Graduate School of Public Health
Professor, Environmental and Occupational Health
Jonas Salk Chair in Population Health

University of Pittsburgh | Graduate School of Public Health

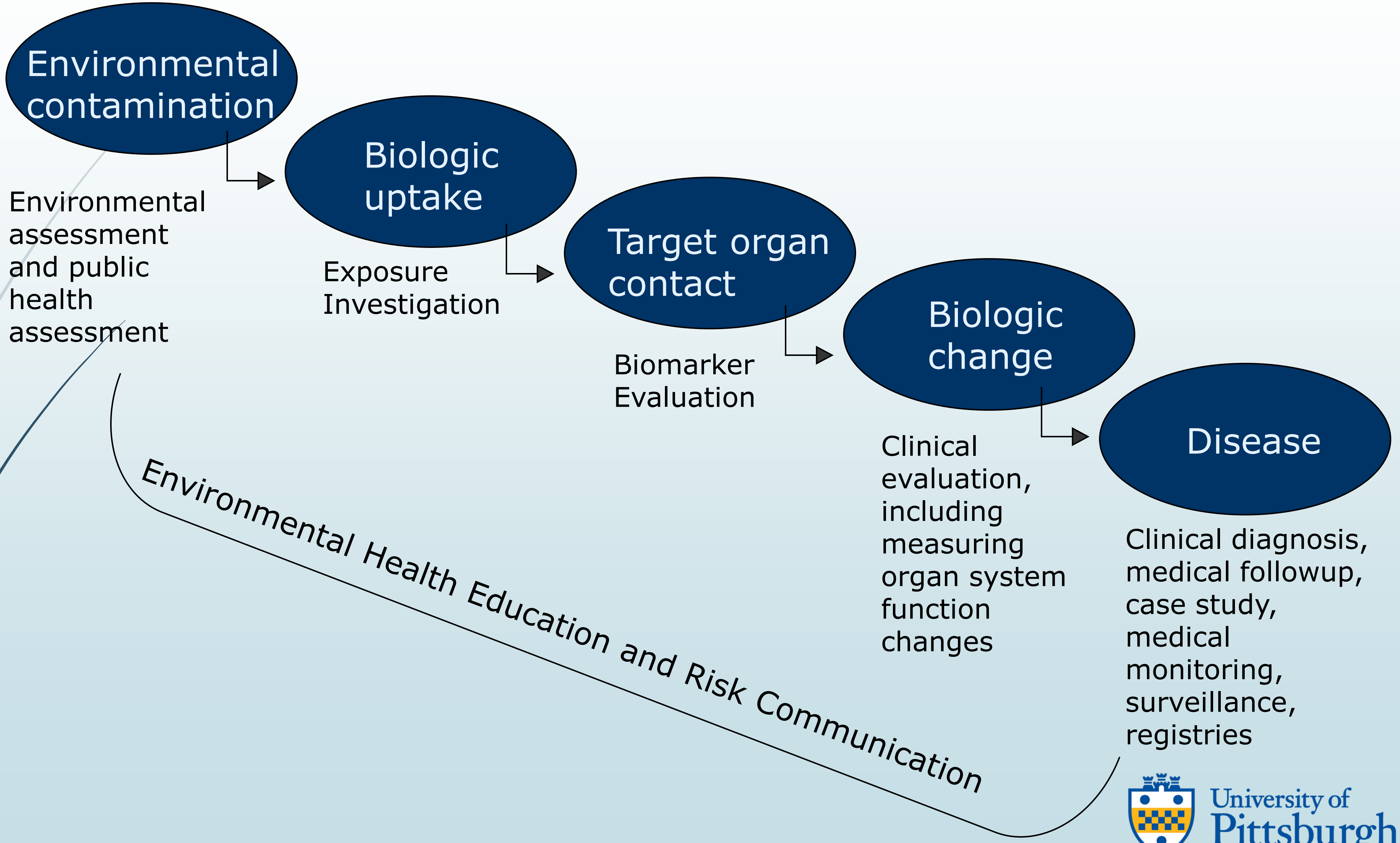
Hierarchy of Data for Exposure Assessment

1. Quantified individual measurements
2. Quantified ambient measurements
3. Quantified surrogates
4. Distance and duration
5. Distance or duration
6. Residence or employment proximity
7. Residence or employment in geographic area

NRC. 1991.

University of Pittsburgh | Graduate School of Public Health

A Model for the Relationship Between Exposure to Hazardous Substances and Adverse Health Effects



DHHS. *Hazardous Waste: Impacts on Human and Ecological Health*. 1997.

Target Organ Contact: Biomarkers

Three types:

- Markers of **exposure**—measure the level of a specific substance or its metabolites in body fluids or excreta
- Markers of **effect**—measure a biochemical, physiologic or other alteration known to be associated with health impairment or disease process
- Markers of **susceptibility**—measure the inherent or acquired limitation of the body's response to exposures to specific substances

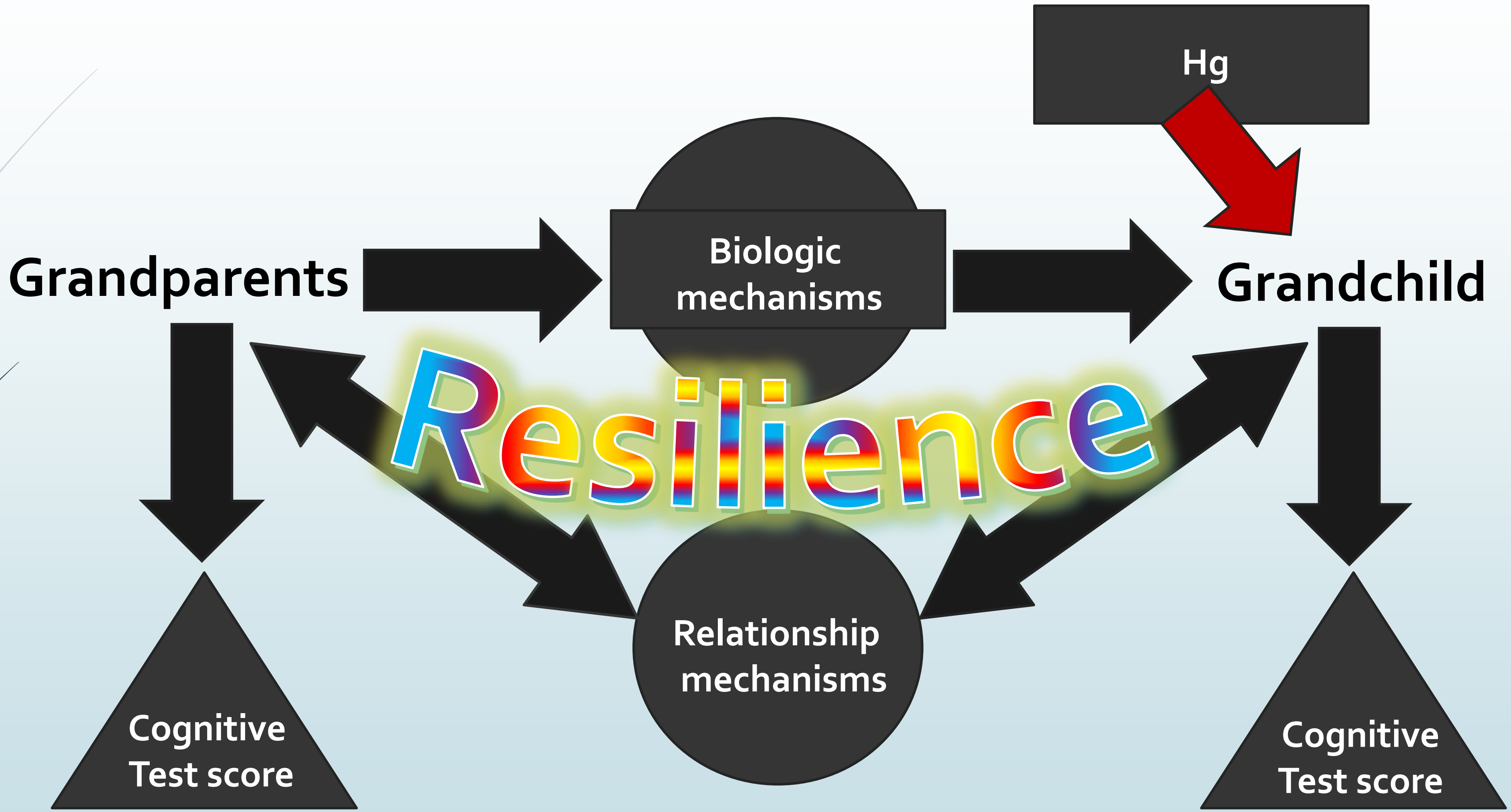
Target Organ Contact: Testing

Biological testing for markers:

- Measure directly a toxicant
- Measure a metabolite of the toxicant
- Measure an effect of the interaction
- Measure indirectly the absorption
- Measure effects on target organs

Exposure Assessment in Environmental Epidemiologic Studies

- Traditional methods -- questionnaires, biomonitoring
- Geographic information systems, modeling, personal sensors, remote sensing, and OMICs technologies
- Non-targeted biomarker assessments; microbiome
- Exposome-life course approach
- Intergenerational factors



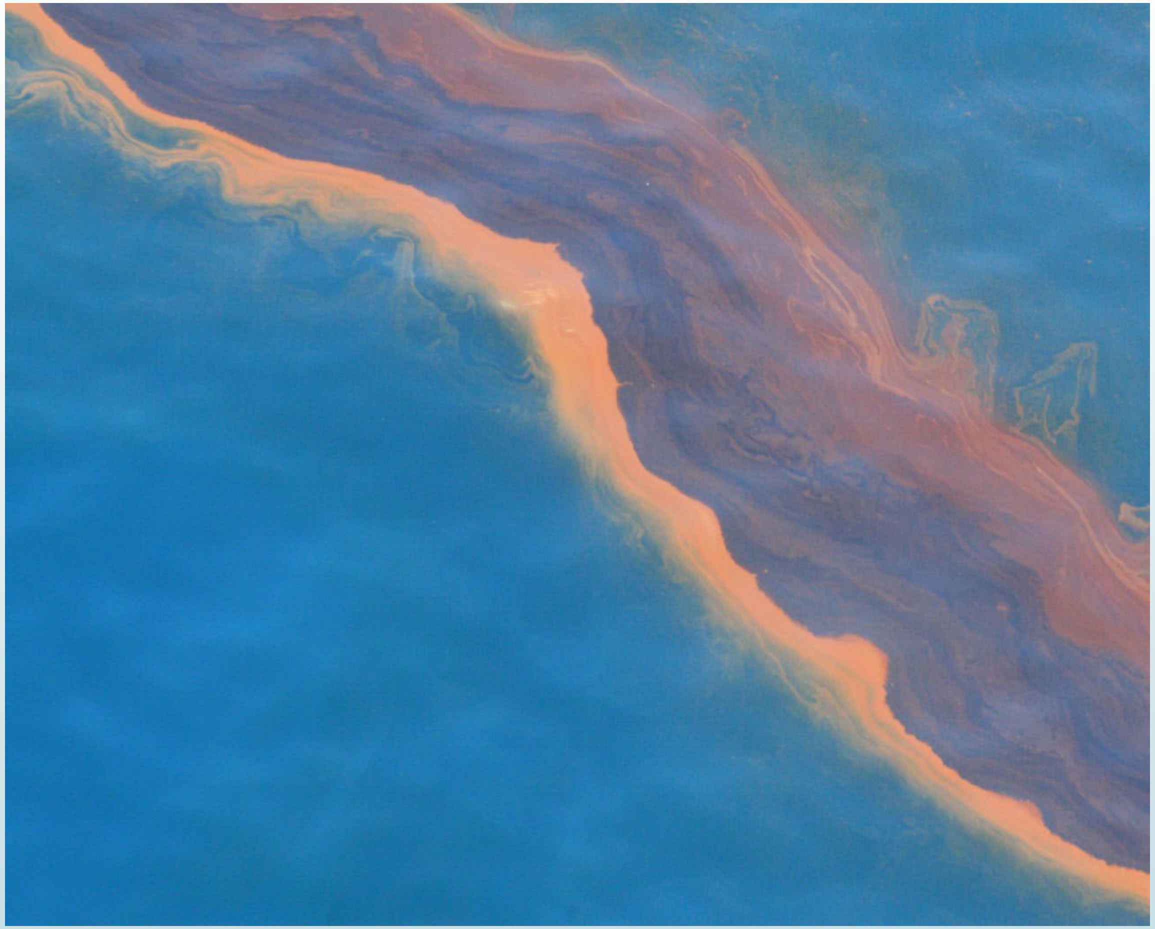
CCREOH

TULANE UNIVERSITY BRAIN INSTITUTE NEW ORLEANS, LA

University of Pittsburgh | Graduate School of Public Health

Example: Deepwater Horizon (DWH) Oil Spill

- April 20, 2010 explosion on DWH - well was not capped until September 19, 2010
  - **206 million** barrels of oil spilled affecting 950 miles of shoreline
    - 11 deaths from explosion
    - Unprecedented use of dispersants
  - Economic impact estimated at $8.7 billion



Source: https://oceanservice.noaa.gov/news/apr17/dwh-protected-species.html

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Mental Health Impacts of DWH Oil Spill

Mental Health impacts

- Income loss
  - Led to anxiety, depression
  - Income loss negatively associated with resiliency
- Media exposure
  - Led to hyperarousal
- Behavioral disengagement in those with income loss
- PTSD symptoms

Source: Reuters

Grattan LM, Roberts S, Mahan WT Jr, McLaughlin PK, Otwell WS, Morris JG Jr. The early psychological impacts of the Deepwater Horizon oil spill on Florida and Alabama communities. *Environ Health Perspect*. 2011;119(6):838-843. doi:10.1289/ehp.1002915

Mental Health Impacts cont.

Psychosocial measures	Exposure: Indirect (n = 71)	Exposure: Direct (n = 23)	p-Value[a]	Income status: Stable (n = 47)	Income status: Loss (n = 47)	p-Value[a]
POMS						
Tension/anxiety	56.89 ± 17.97	62.44 ± 11.33	0.17	53.23 ± 16.09	63.26 ± 15.94	0.00
Depression	55.70 ± 20.22	57.70 ± 12.99	0.66	51.90 ± 18.37	60.94 ± 18.14	0.02
Anger	56.13 ± 20.63	59.91 ± 13.24	0.41	53.17 ± 19.27	60.49 ± 18.30	0.05
Fatigue	49.41 ± 16.87	55.83 ± 12.95	0.10	47.43 ± 16.55	54.53 ± 15.15	0.03
Confusion	54.92 ± 20.16	60.78 ± 11.62	0.19	52.77 ± 17.93	59.94 ± 18.66	0.06
Vigor	40.44 ± 13.94	41.61 ± 10.16	0.71	40.74 ± 14.33	40.70 ± 11.83	0.99
Total mood disturbance	55.66 ± 20.07	61.13 ± 11.71	0.22	52.93 ± 18.12	61.06 ± 18.10	0.03
POMS suspected clinical impairment						
Tension/anxiety[b,c]	44	48	0.76	24	65	0.00
Depression[b,c]	50	35	0.21	30	62	0.00

Grattan LM, Roberts S, Mahan WT Jr, McLaughlin PK, Otwell WS, Morris JG Jr. The early psychological impacts of the Deepwater Horizon oil spill on Florida and Alabama communities. *Environ Health Perspect*. 2011;119(6):838-843. doi:10.1289/ehp.1002915

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Gulf Resilience on Women's Health (GROWH)

- One of four DWH Research Consortia (NIEHS)
  - Is the seafood safe to eat?, Is the air safe to breathe?, Will our babies be safe?
- Comprehensive set of exposures and outcomes and CBPR approach in reproductive-aged women in SE Louisiana
  - Cumulative risk for mental health effects of multiple disasters
  - Women enrolled in CHW-led intervention had lower average postpartum depression scores (EPDS) 6 months postpartum than comparison population
  - No unacceptable cancer risk from fish and shrimp consumption

Harville EW, Shankar A, et al. Cumulative effects of the Gulf oil spill and other disasters on mental health among reproductive-aged women: The Gulf Resilience on Women's Health study. Psychol Trauma. 2018 Sep;10(5):533-541.
Wickliffe, J., Simon-Friedt, B., Howard, J., et al. (2018). Consumption of fish and shrimp from southeast Louisiana poses no unacceptable lifetime cancer risks attributable to high-priority polycyclic aromatic hydrocarbons. Risk Analysis 38(9):1944-1961.
Mundorf C, Shankar A, et al. (2018). Reducing the risk of postpartum depression in a low-income community through a community health worker intervention. Maternal and Child Health Journal, 22(4): 520-528.

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FDA/NOAA Reopening Protocol & Risk Assessment:

The value of local data collection

- Organoleptic testing
- Chemical analysis
- Assumptions
  - Shrimp consumption rate
    - NHANES 90th percentile:13 grams shrimp/day
    - **Local consumption: 43gr /day**
  - Body weight (standard EPA assumption): 80 kilograms
  - **Local average body weight Vietnamese male: 68 kg**
- Level of concern for PAHs in shrimp

  1 x 10^{-5} Acceptable risk level

  132 µg B[a]P eq per Kg Shrimp

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Environ Health Perspect. 2015 Feb;123(2):152-9. doi: 10.1289/ehp.1408684. Epub 2014 Oct 21

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CCREOH Focus Area: Hg

Gold mining-related Hg contamination of indigenous food sources, specifically fish

CCREOH

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Association Between Hg Exposure and Depression

	EPDS depression score	
Mercury (ug/g)	**0-11 (%)**	**12-30 (%)**
< 1.1 ug/g	324 (77.9)	92 (22.1)
≥1.1 ug/g	144 (71.3)	58 (28.7)
total	468	150

p= 0.073

Gokoel AR, Zijlmans WCWR, Covert HH, Abdoel Wahid F, Shankar A, MacDonald-Ottevanger MS, Hindori-Mohangoo AD, Wickliffe JK, Lichtveld MY, Harville EW. Influence of Prenatal Exposure to Mercury, Perceived Stress, and Depression on Birth Outcomes in Suriname: Results from the MeKiTamara Study. *International Journal of Environmental Research and Public Health*. 2020; 17(12):4444. https://doi.org/10.3390/ijerph17124444

CCREOH

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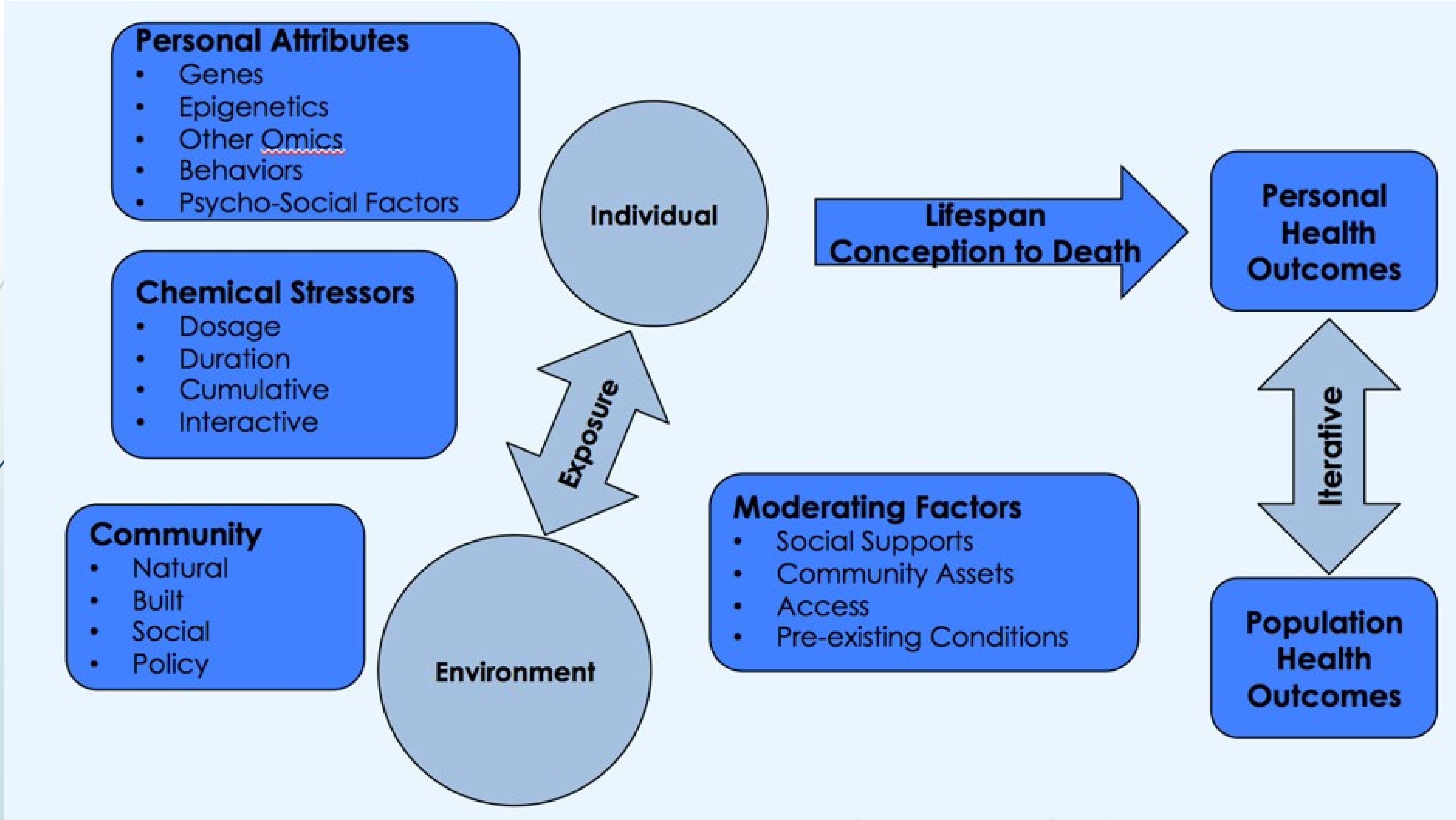
THE PUBLIC HEALTH EXPOSOME:
UNRAVELING CHEMICAL AND NON-CHEMICAL STRESSORS



Juarez, PD, Matthews-Juarez, P, Hood, DB, Im, W, Levine, RS, Kilbourne, BJ, and **Lichtveld, MY.** (2014). The Public Health Exposome: A Population-Based, Exposure Science Approach to Health Disparities Research. *International Journal of Environmental Research and Public Health*, *11*(12), 12866-12895.

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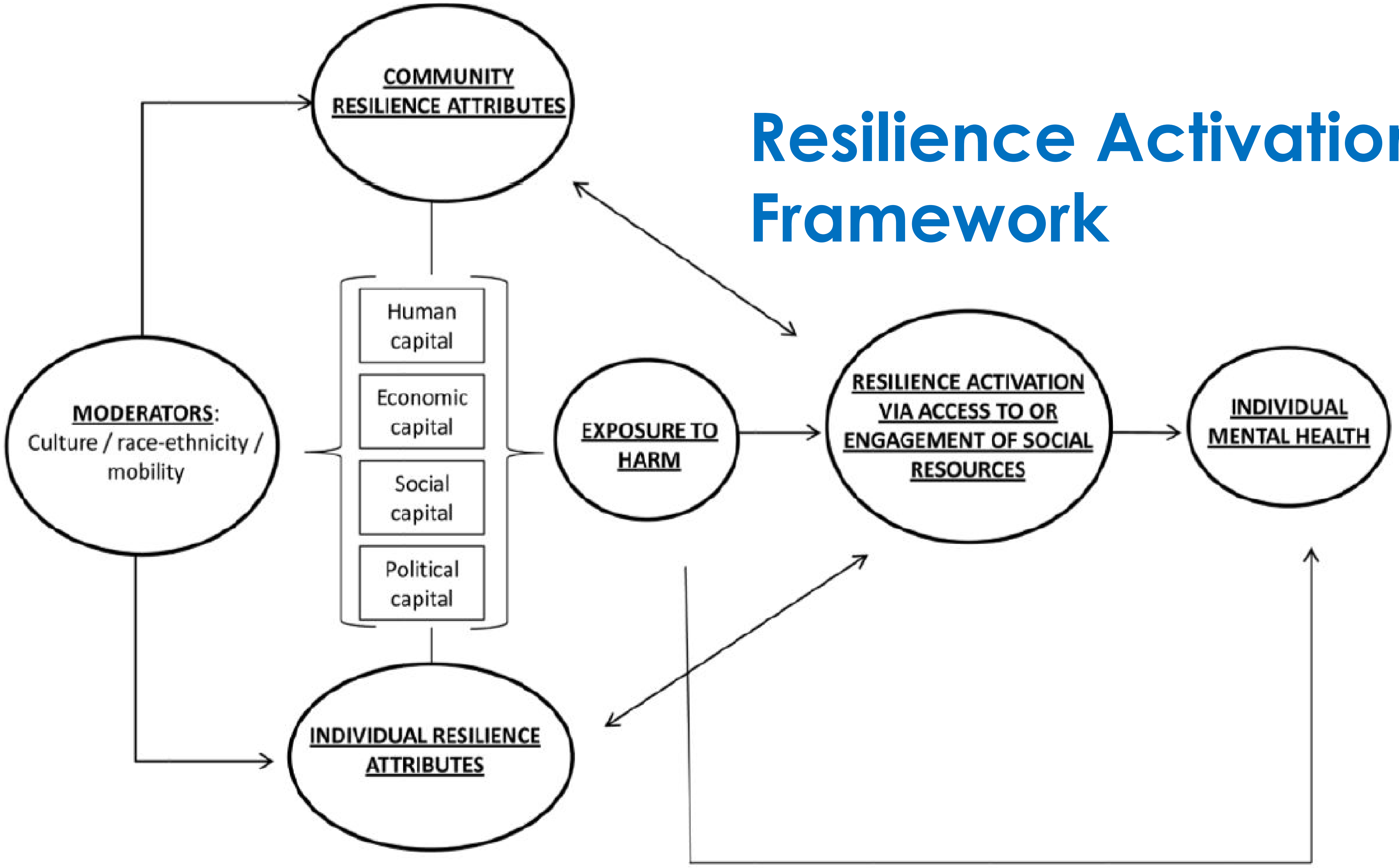
Resilience Activation Framework



Abramson DM, Grattan LM, Mayer B, et al. The resilience activation framework: a conceptual model of how access to social resources promotes adaptation and rapid recovery in post-disaster settings. *J Behav Health Serv Res*. 2015;42(1):42-57. doi:10.1007/s11414-014-9410-2

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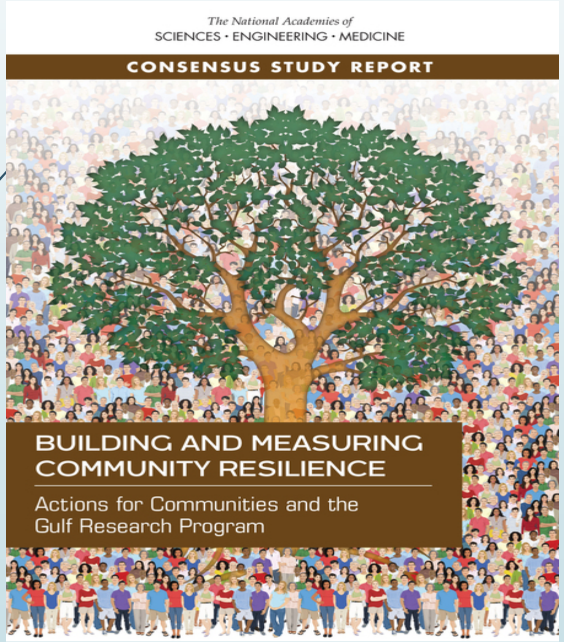
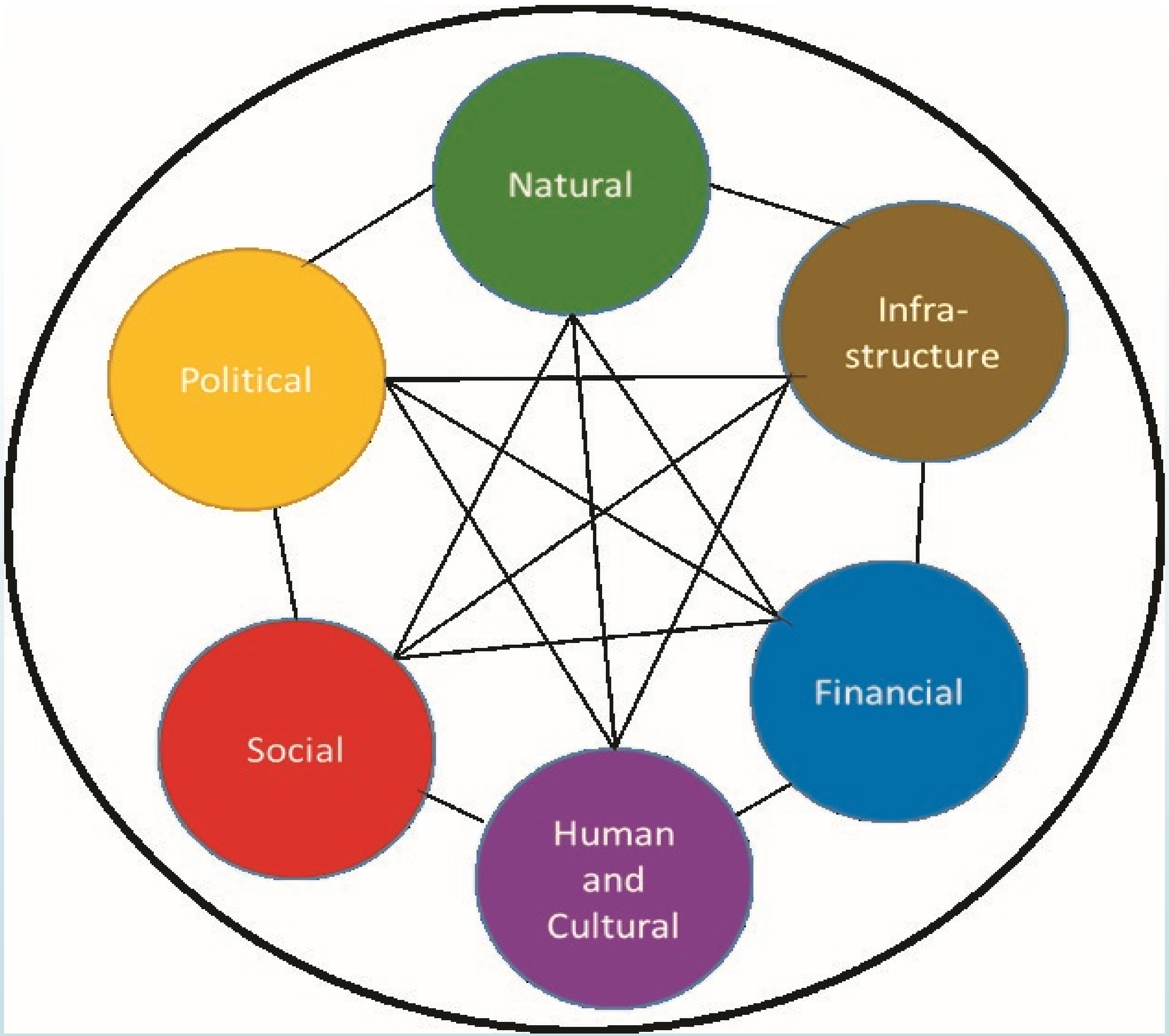
Community Resilience: "Capital Investment"



National Academies of Sciences, Engineering, and Medicine; Policy and Global Affairs; Office of Special Projects; Committee on Measuring Community Resilience. Building and Measuring Community Resilience: Actions for Communities and the Gulf Research Program. Washington (DC): National Academies Press (US); 2019 Mar 20. Introduction. Available from: https://www.ncbi.nlm.nih.gov/books/NBK540795/



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Key Findings

- The health of the environment is inextricably linked to that of people; limiting exposure assessments solely to environmental media precludes a holistic characterization of the true impact on human health
- Significant progress has been made in assessing the impact of exposures to environmental stressors
- Direct exposures provide a limited picture of total human health risk
- Indirect exposures can cause harm overtime and can be measured using an exposomic approach, often in combination with intergenerational studies
- Exposure to non-chemical stressors can last longer and have a greater impact on human health.
- Cumulative risk models taking into account exposures to both chemical and non-chemical stressors can result in a more holistic exposure assessment
- Community resilience can be measured by the strength and the interconnectedness of the "capitals" and influences resilience at the individual level

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Recommendations

- Exposure assessments of oil contamination should take a *one health* approach
- Integrating *local data* is critical to accurately conduct exposure assessments
- Exposure assessments should include examining both chemical *and* non-chemical stressors
- Environmental epidemiologic *longitudinal cohort* studies should deploy an exposomic approach and integrate exposures to chemical and non-chemical stressors
- *Integrated* exposure assessments of chemical and non-chemical stressors can aid predictive risk modeling and inform public health interventions
- Strengthening *community resilience* should be embedded in exposure mitigation and risk reduction strategies
- *Community engagement* should be integral to actions aimed at achieving sustained health protection.

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Acknowledgements

- Firoz Abdoel Wahid, MD, MPH, PhD
- Jeffrey Wickliffe, PhD
- Anisma Gokoel, MS, PhD (c)

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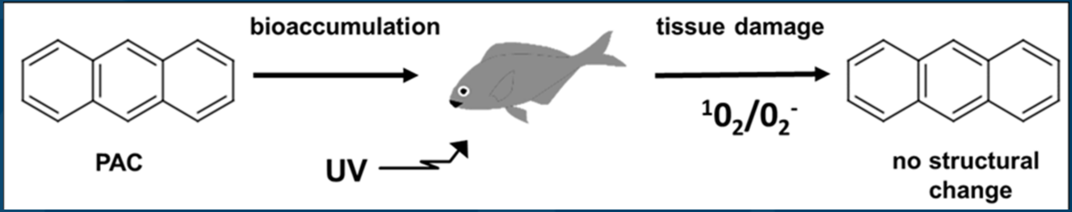
United States Environmental Protection Agency

Oil and UV interactions

Mace G. Barron

U.S. EPA Gulf Ecology Division, Gulf Breeze, FL USA



Office of Research and Development
NHEERL, Gulf Ecology Division, Gulf Breeze, FL 32561

Outline

- Phototoxic crude and refined oils
- Phototoxic components of oil
- Mechanism of petroleum phototoxicity
    - photo-oxidation
    - photosensitization
- Environmental and biological modulation of phototoxicity
- Conclusions and recommendations

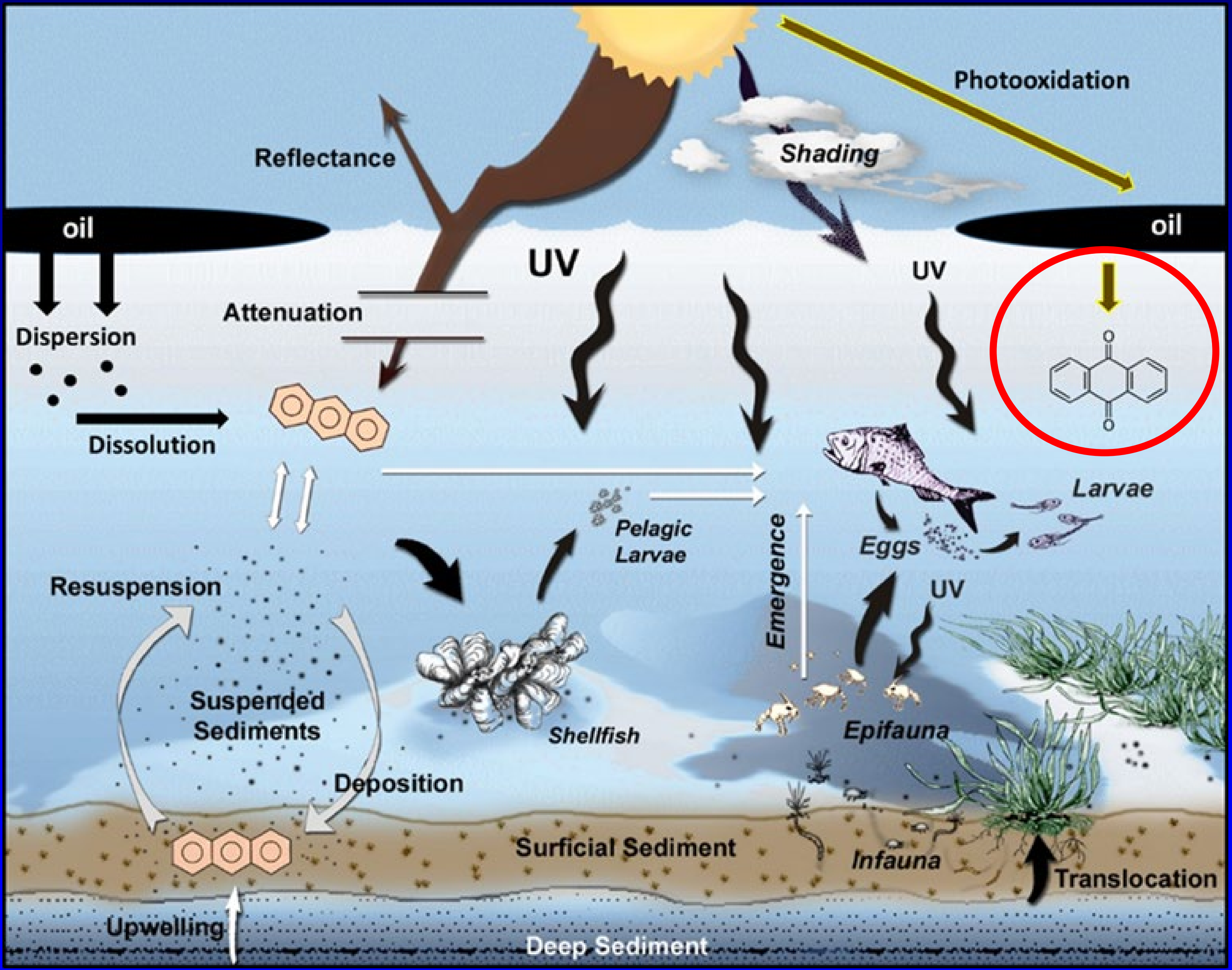
Phototoxicity:
Adverse reaction to ultraviolet light (UV) following chemical exposure

Photoenhanced toxicity of oil:

Increase in petroleum toxicity under natural sunlight

- laboratory: > tox under UV
- standard lab conditions: no UV

Oil and UV



Barron (2017) AECT 73:40-46

Photoenhanced Toxicity

Petroleum is phototoxic

- demonstrated in >20 fresh and weathered oils and oil products
- 2 to >100 fold increase in toxicity compared to no UV
- phototoxity is synergistic: not cumulative UV damage + oil tox
- demonstrated in >30 species of aquatic organisms
- most at risk: translucent early life stages

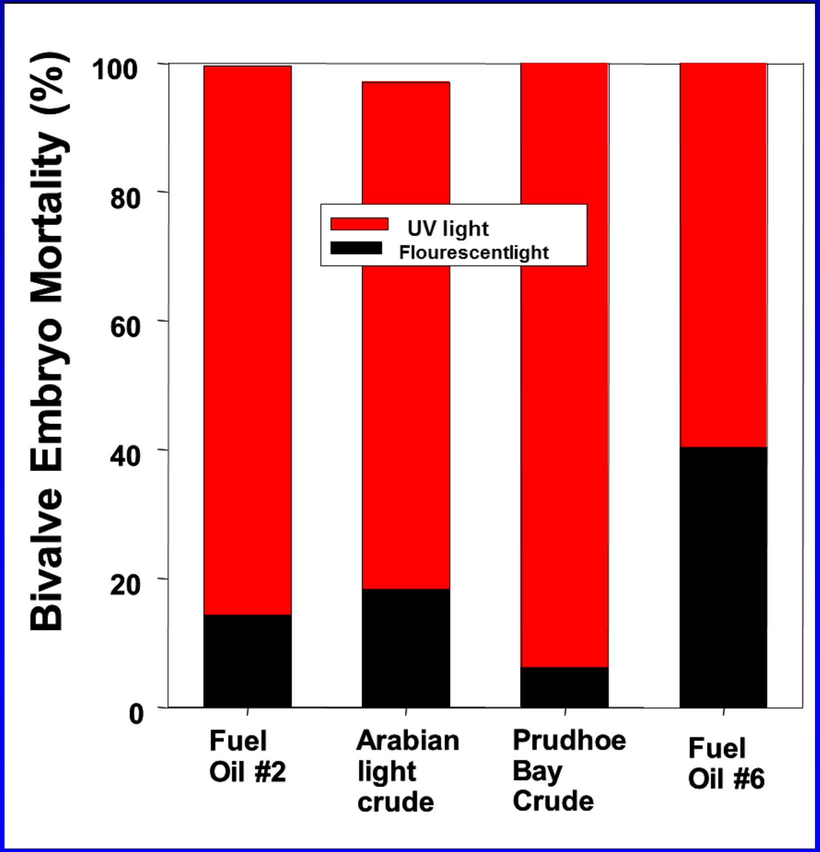
Not traditionally considered in oil spill response and impact assessment

- majority of toxicity tests and bioassays conducted under fluorescent lighting
- standard tox tests do not have ecologically relevant levels of UV
- photoxicity assessed post-Exxon Valdez
- extensive investigation in DWH

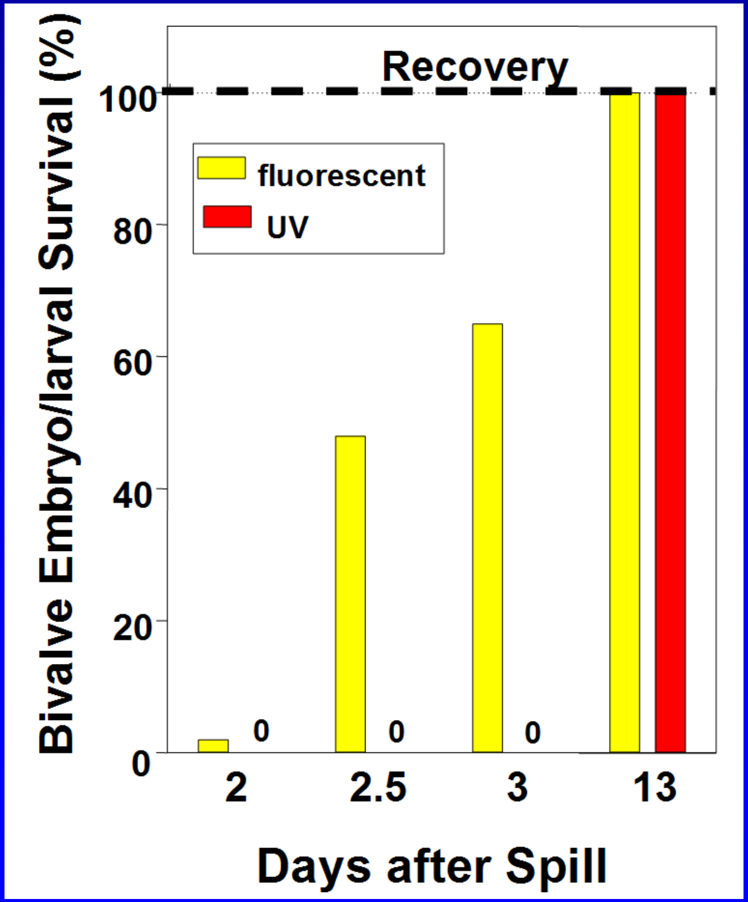
For more information: Barron. 2017. *Arch Env Contam Tox* 73:40-46

Oil is more toxic with UV

- demonstrated with over 20 oils:
  - crudes, middle distillates, heavy fuel oils
- fresh and weathered oils; chemically dispersed oil
- lab water accommodated fractions (WAF), field collected samples



Pelletier et al. (1997) ETC 16:2190

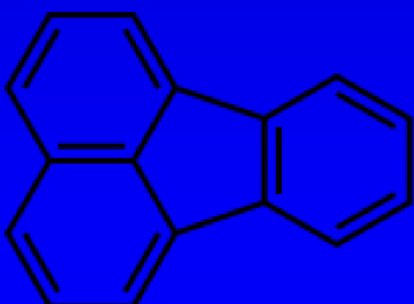


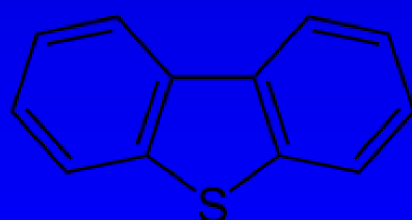
Ho et al. (1999) MPB 38:314

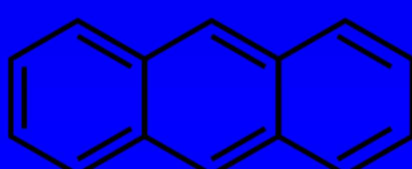
Phototoxic components of oil

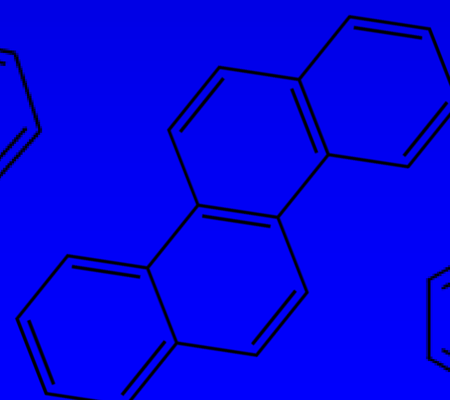
Polycyclic aromatic compounds (PACs) are the phototoxic components of oil

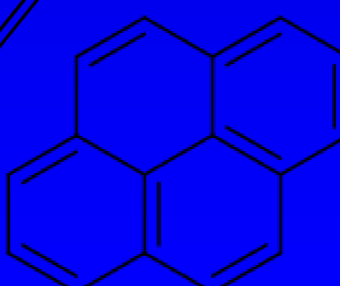
- specific 3 to 5 ring PAHs and heterocycles are phototoxic (single compound tests; QSAR)
- phototoxic PAHs and heterocycles occur in oils and WAF
- other major hydrocarbons lack phototoxicity (aliphatics; mono-,di-aromatics; asphaltenes)
- oil phototoxicity correlated with petrogenic PACs in water and tissue
- most phototoxic oils have higher phototoxic PAC composition



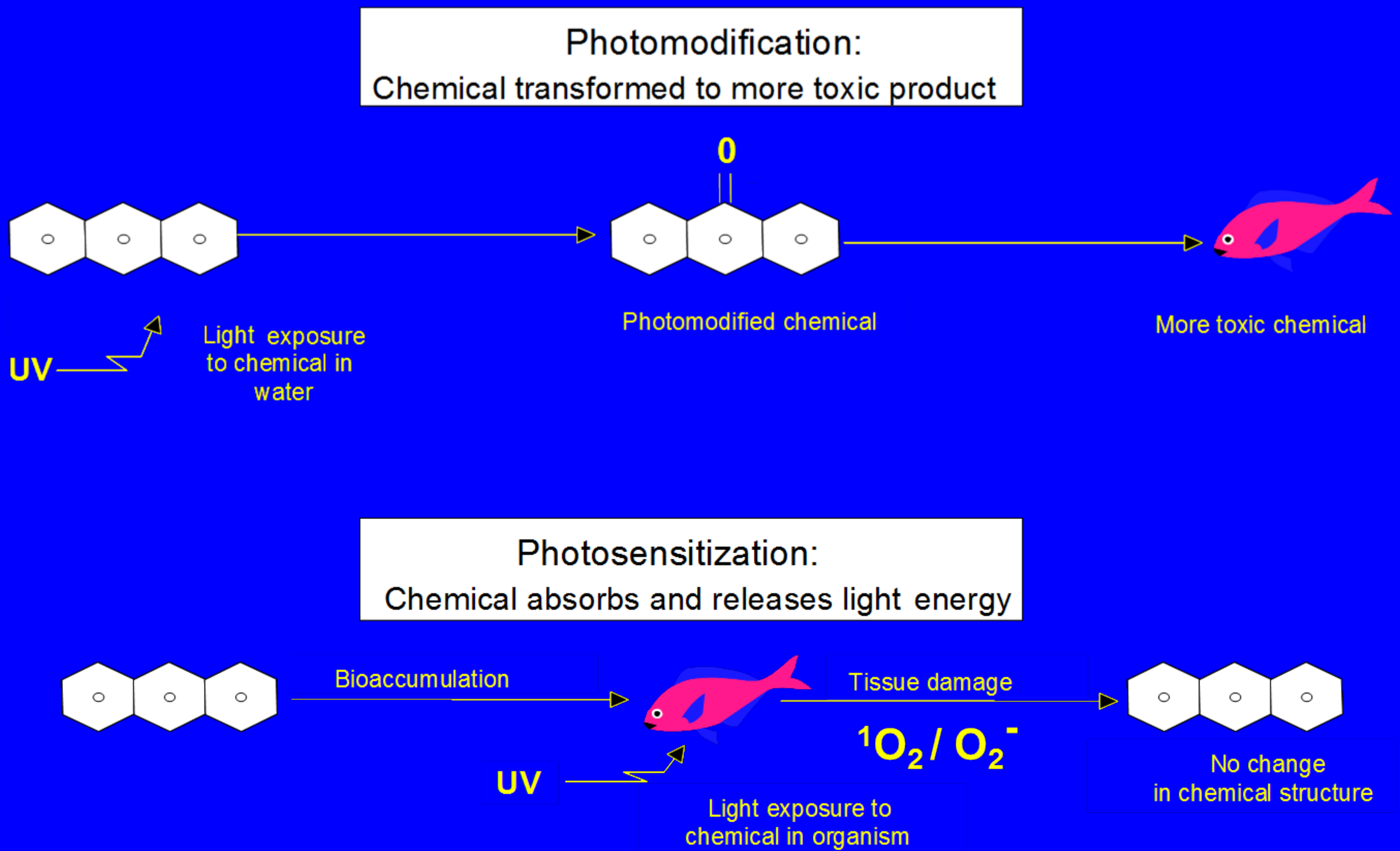




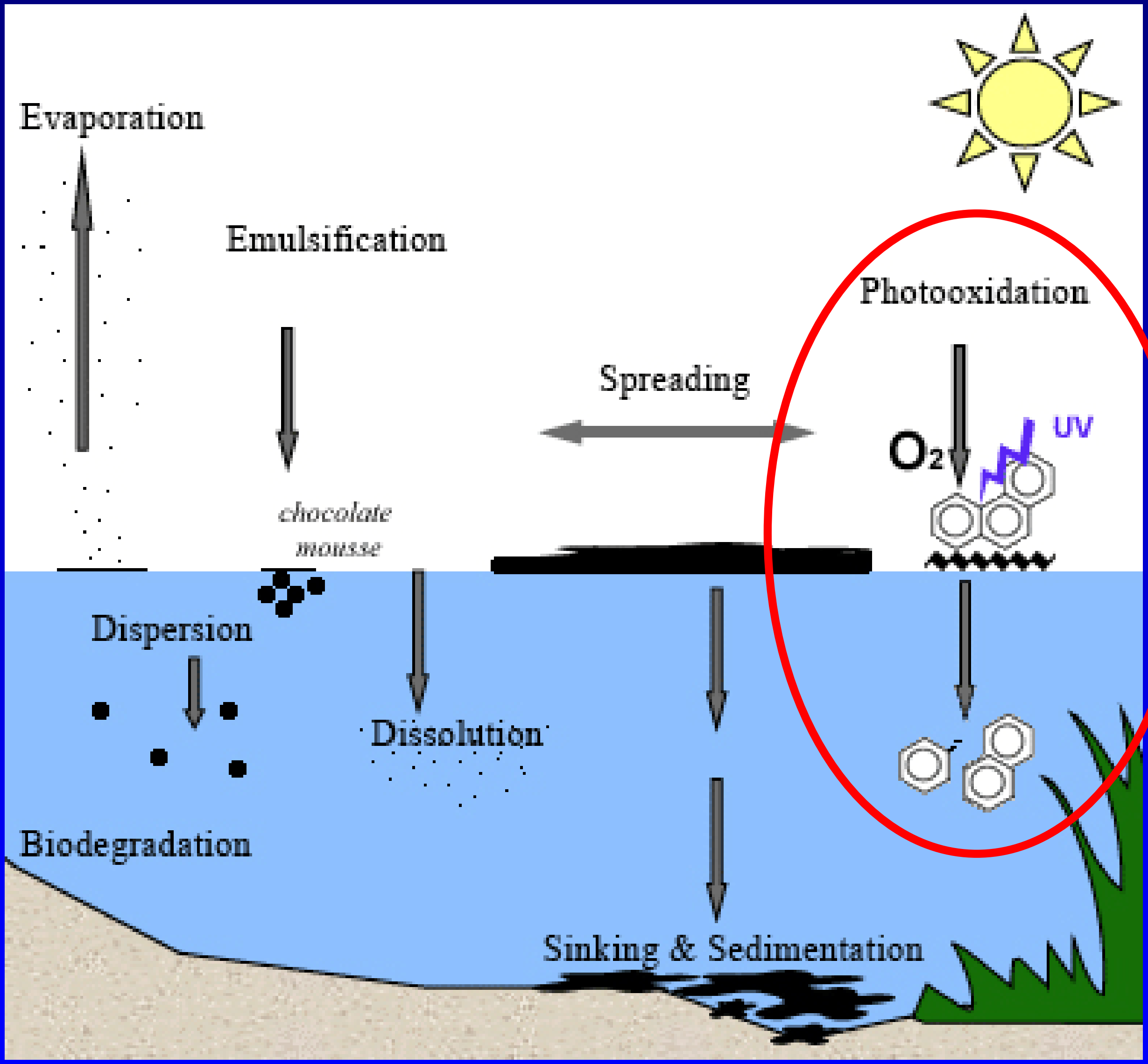




Mechanism of petroleum phototoxicity

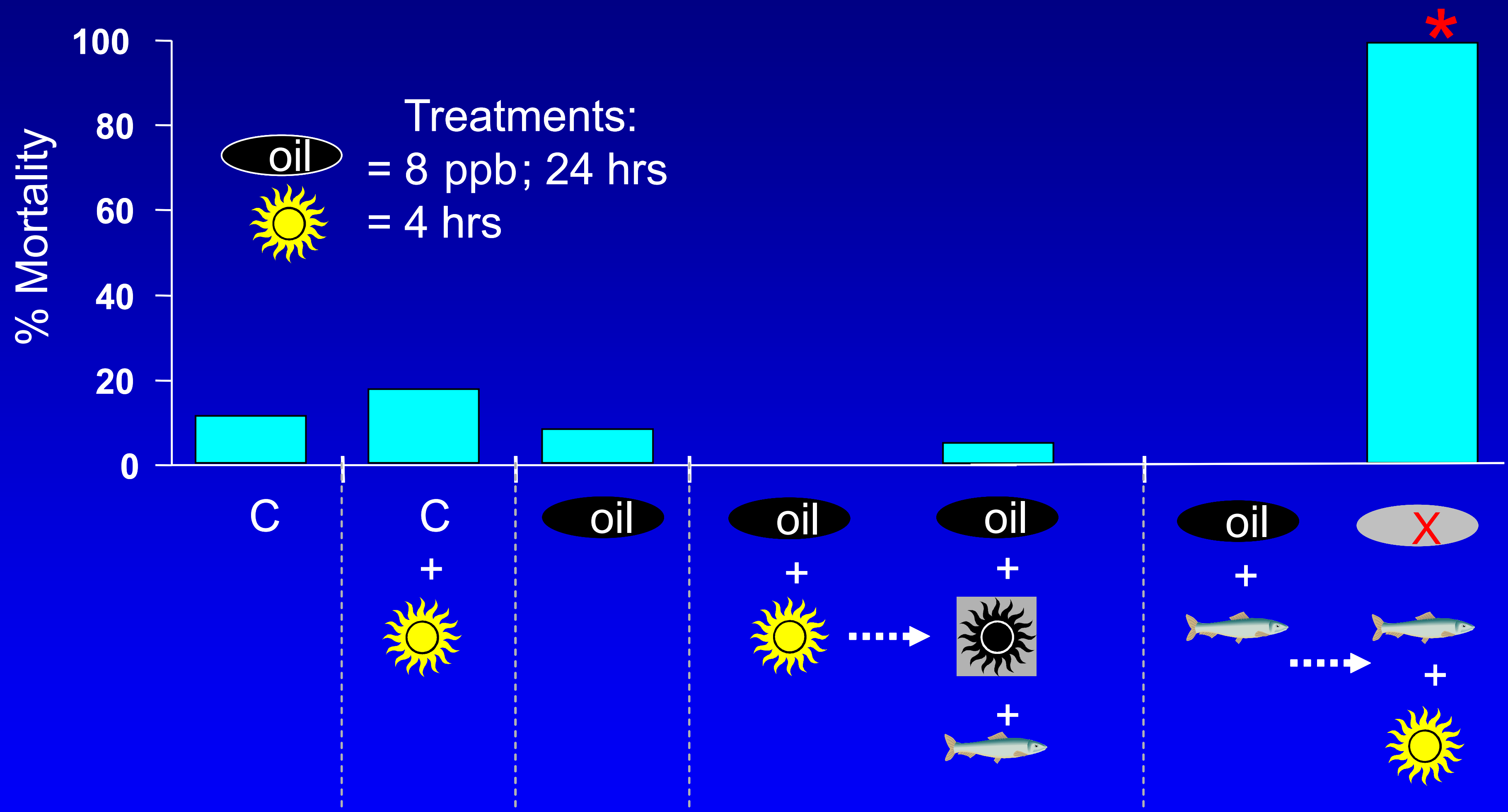


Photooxidation : photo-product toxicity



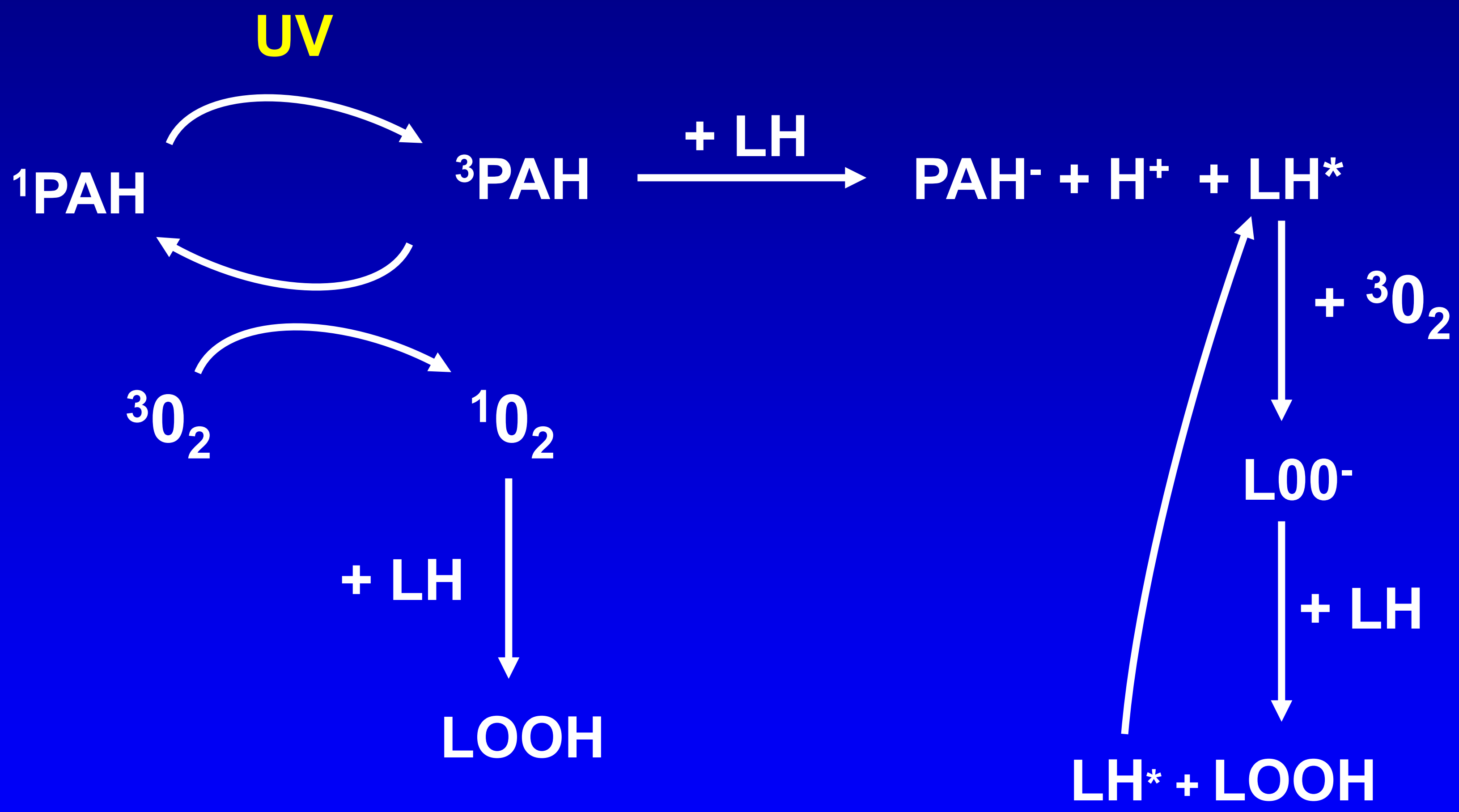
Adapted from Zhu et al. (EPA 2001) and www.researchgate.net/profile/Jorge_Alonso-Gutierrez

Photosensitization:
UV increases toxicity in herring larvae pre-exposed to oil



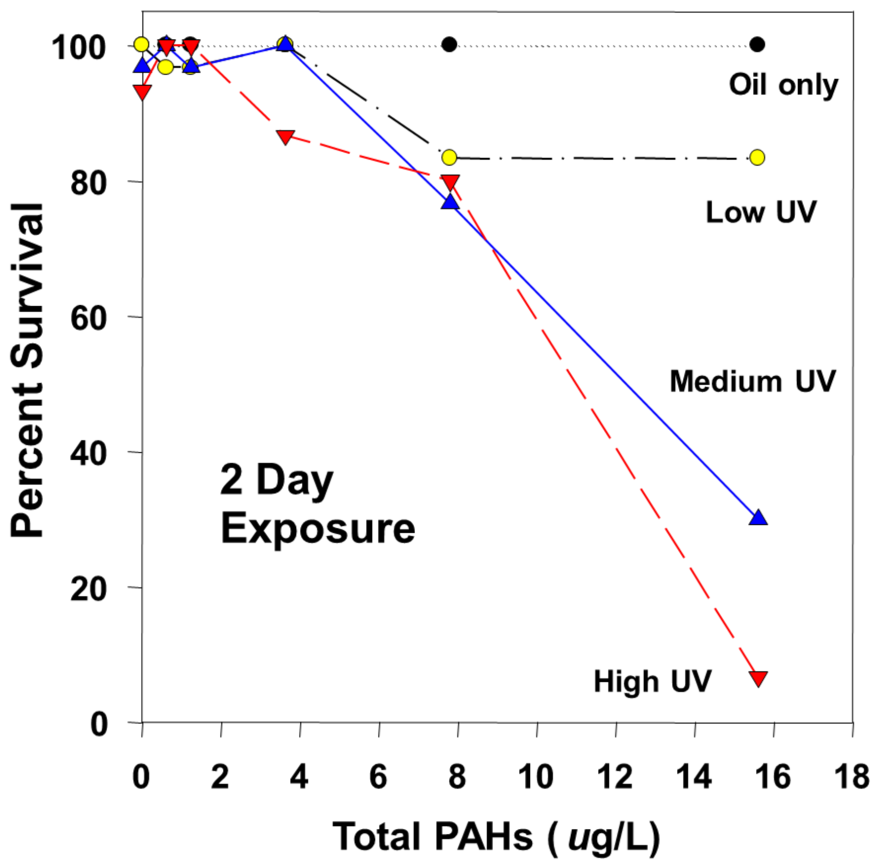
Barron et al. 2003. ETC 22:650

Photosensitization Reactions



Dose-response and Reciprocity

- oil and UV exposure exhibit dose-response
- demonstrated in > 30 species of fish and invertebrates

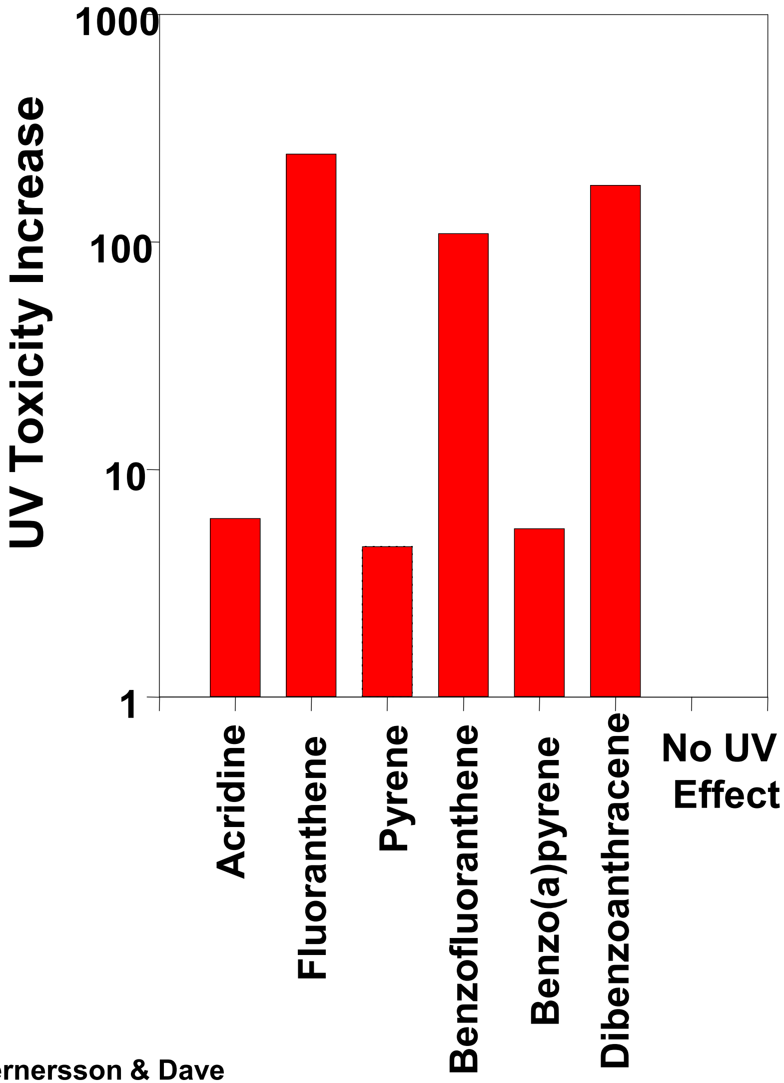


Source: Little et al. 2000. ETC 19:926

- and reciprocity

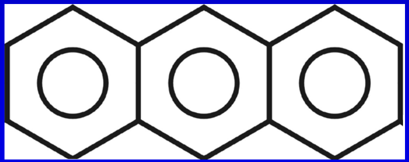
Ptox = f (UV x PAH)

PAH composition determines oil phototoxicity

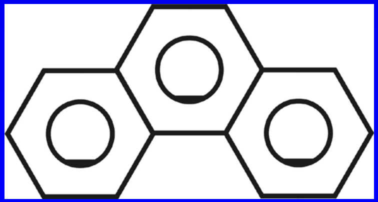


Wernersson & Dave (2003) AECT 32:268

- PAHs and heterocyclic aromatics (N,S,O substitution)
- limited effect of alkyl substitution
- specific 3-5 ring conformations



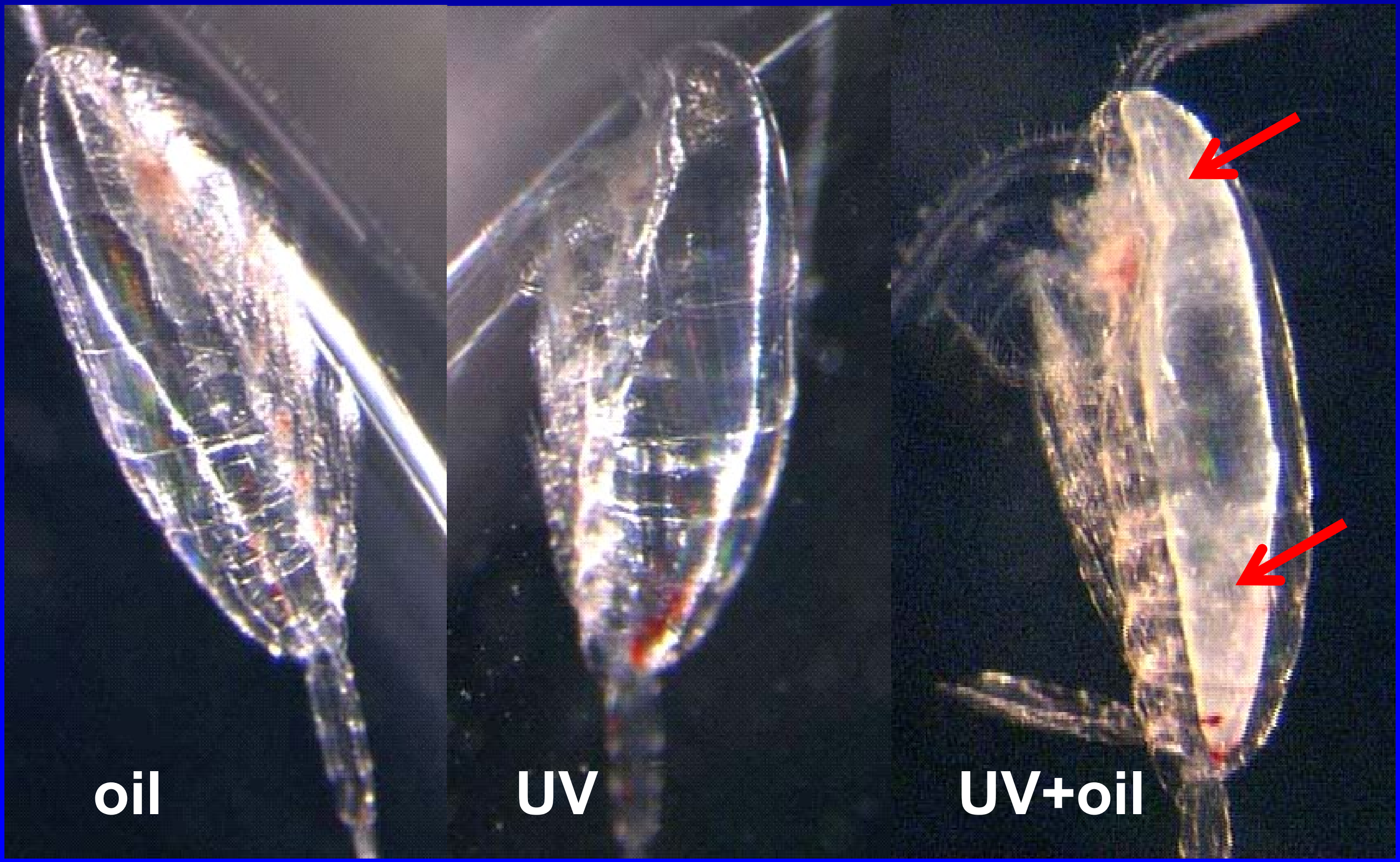
anthracene (>100x)



phenanthrene (none)

Alaska North Slope crude oil phototoxicity to marine zooplankton

- field collected calanoid copepods
- 2 ug/L total PAHs, 24 hr exposure; 4-8 hr low UV



UV+oil

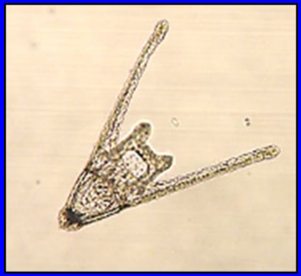
- **indications of lipid sac peroxidation**
- **death, immobility, impaired swimming**

Deusterloh et al 2002. EST 36:3953

Environmental and biological modulation of phototoxicity

- 30 years of lab studies show oil phototoxicity at ppb PAHs and UV levels in aquatic environments
  - freshwater, marine, estuarine, sediment
  - > 30 species of aquatic organisms
- Degree of phototoxicity determined by:
  - phototoxic PAC exposure
  - quantity and spectra of absorbed UV dose
- Biological modulation of oil and UV exposure
  - habitat use; life history
  - phenotypic traits (behavioral avoidance, armoring)



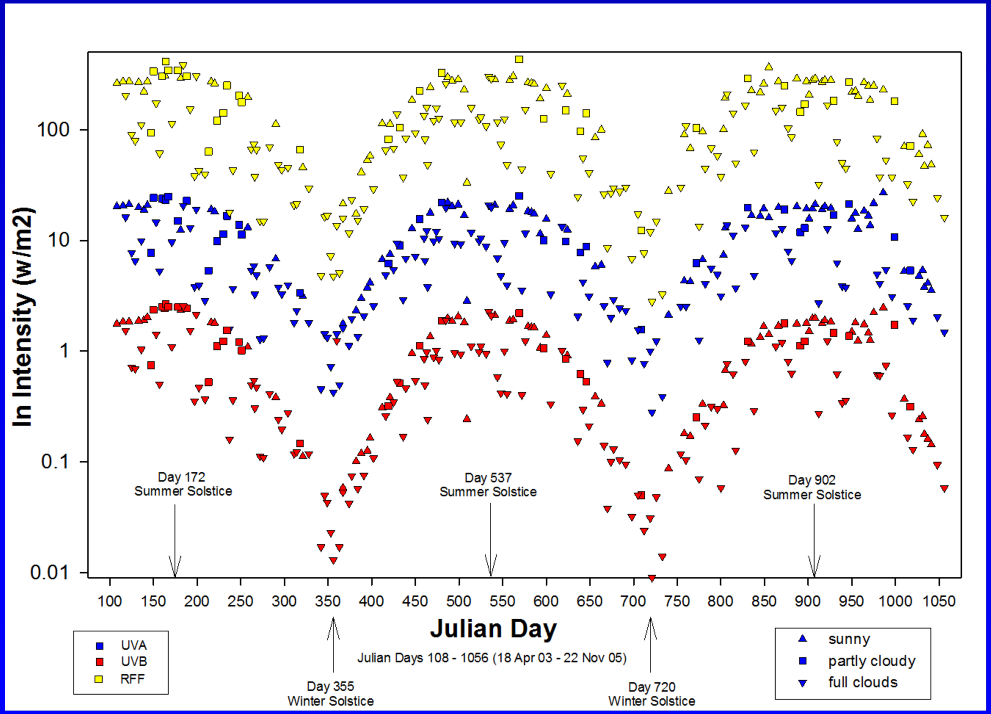
UV Exposure

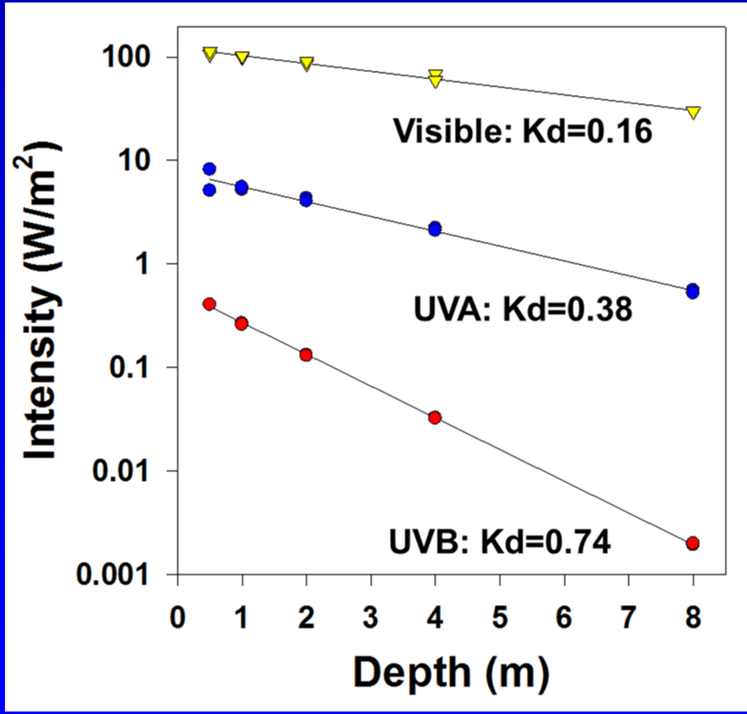
Seasonal and Environmental variation

- Surface reflectance; cloud cover; seasonal incidence

Water column attenuation

- UVB > UVA > visible
- colorous ocean water: >20 m; turbid, high DOC: < 0.5 m

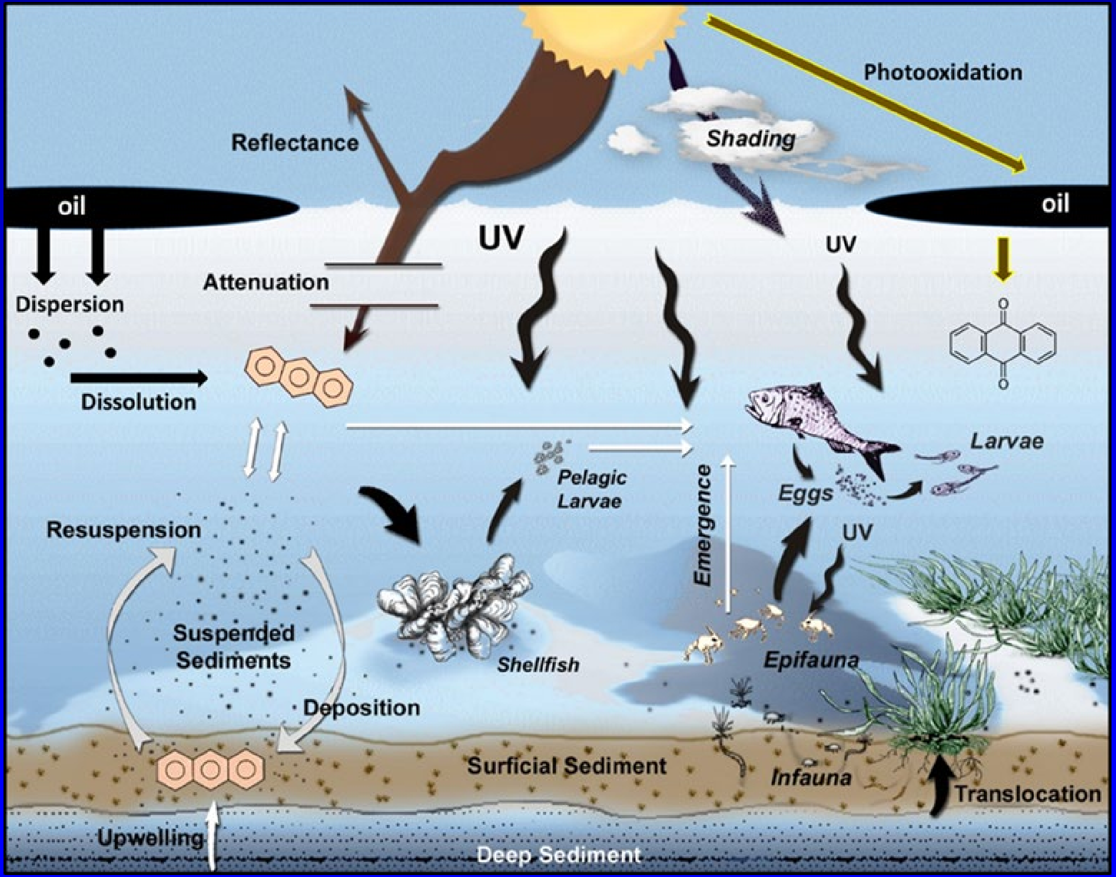




Barron et al (2008) ETC 27:727

Aquatic organisms at risk

- life stage, species-specific sensitivity; intrinsic species differences
- shallow water, intertidal habitats
- blue water: pelagic species, neuston, coral systems
- translucent eggs and larvae in photic zone



Barron (2017) AECT 73:40-46

Images: NOAA

Conclusions

- Phototoxicity demonstrated in over 20 different fresh, laboratory weathered, and field collected oil products
- Photo-oxidation important degradation; but not phototoxicity
  - may reduce dispersant effectiveness (Ward et al. 2018)
- Oils with phototoxic properties contain specific 3 ring to 5 ring phototoxic PAHs and heterocyclic aromatics
- Demonstrated in over 30 species of aquatic organisms
- Species at risk:
  - translucent early life stages in photic zone
  - minimal pigmentation, armoring, or refugia
- Environmental phototoxicity requires sufficient oil and UV exposure:
  - requires bioaccumulation of polycyclic aromatics
  - can occur at low ppb total PAHs in water column and few hours sunlight exposure

Recommendations

Assess ecological relevance

- solar radiation exposure ?
- species/life stages at risk ?
- lab versus field effects ?

Incorporate into spill planning and impact assessment

- toxicity thresholds can be substantially lower
- larger impacts? greater spatial extent; longer duration
- dispersant efficacy?

Questions?

Arch Environ Contam Toxicol (2017) 73:40–46
DOI 10.1007/s00244-016-0360-y

SPECIAL ISSUE: OCEAN SPILLS AND ACCIDENTS

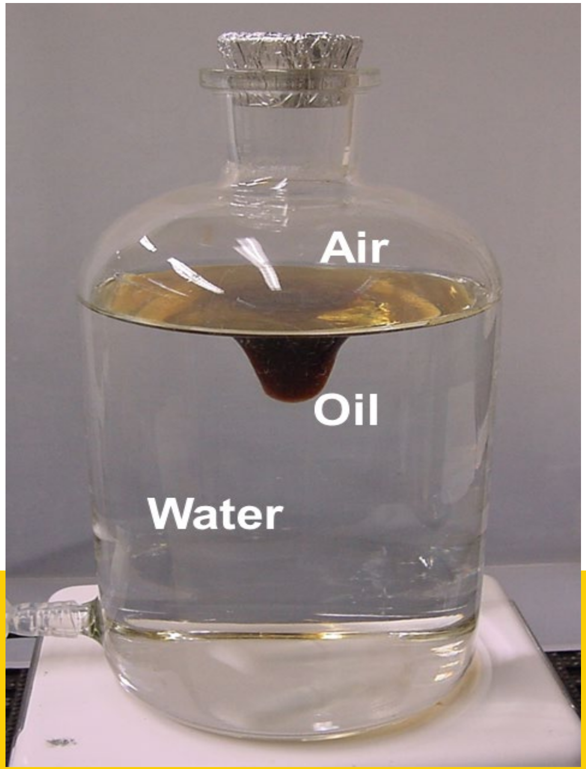
Photoenhanced Toxicity of Petroleum to Aquatic Invertebrates and Fish

Mace G. Barron[1]

Please refuel and be back by 1 pm ET!

Modeling Approaches for Toxicity Determination:

Challenges and Opportunities



Adriana C. Bejarano*

Senior Ecotoxicologist
Shell Health – Americas

* The content of is research reflects personal contributions to NASEM--Oil in the Sea IV: Inputs, Fates, and Effects

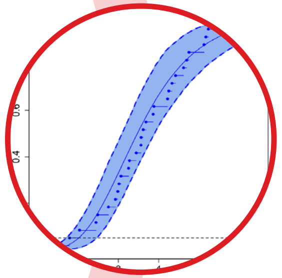
February 2021

The Challenges of Toxicity Testing: Complexity

Laboratory to Field Extrapolations

The real world

- Environmental complexity (physical & biological)
- Reproducibility under laboratory conditions



Tools

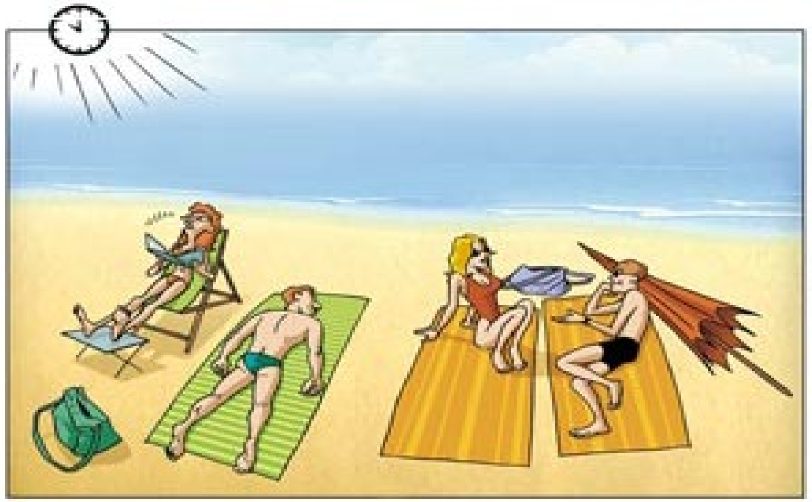
- Synthesis of relevant toxicity data
- Development/validation of predictive models

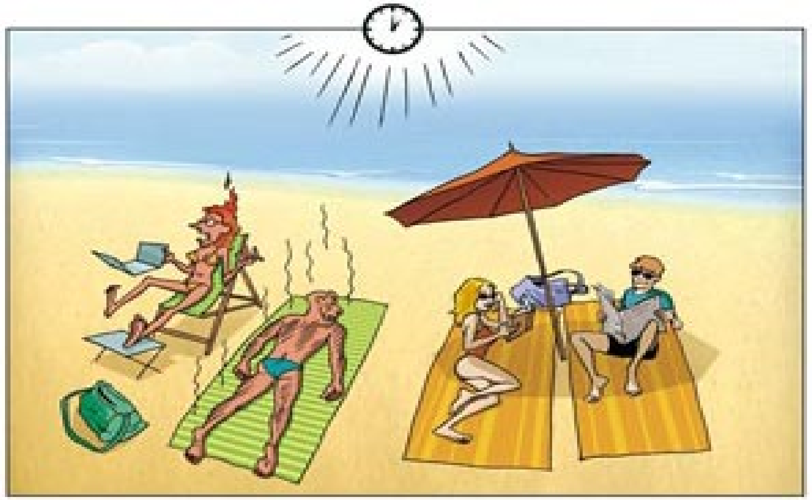
The lab world

- Oversimplified, but controlled
- Species-relative sensitivities

Utility of Aquatic Toxicity Testing

Risk= f {Hazard , Exposure}





Toxicity tests quantify **Hazard**

- Compare hazard of a substance for a particular species/ endpoint
- Assess relative sensitivity of different species/ endpoints
- Calibrate/ validate predictive models

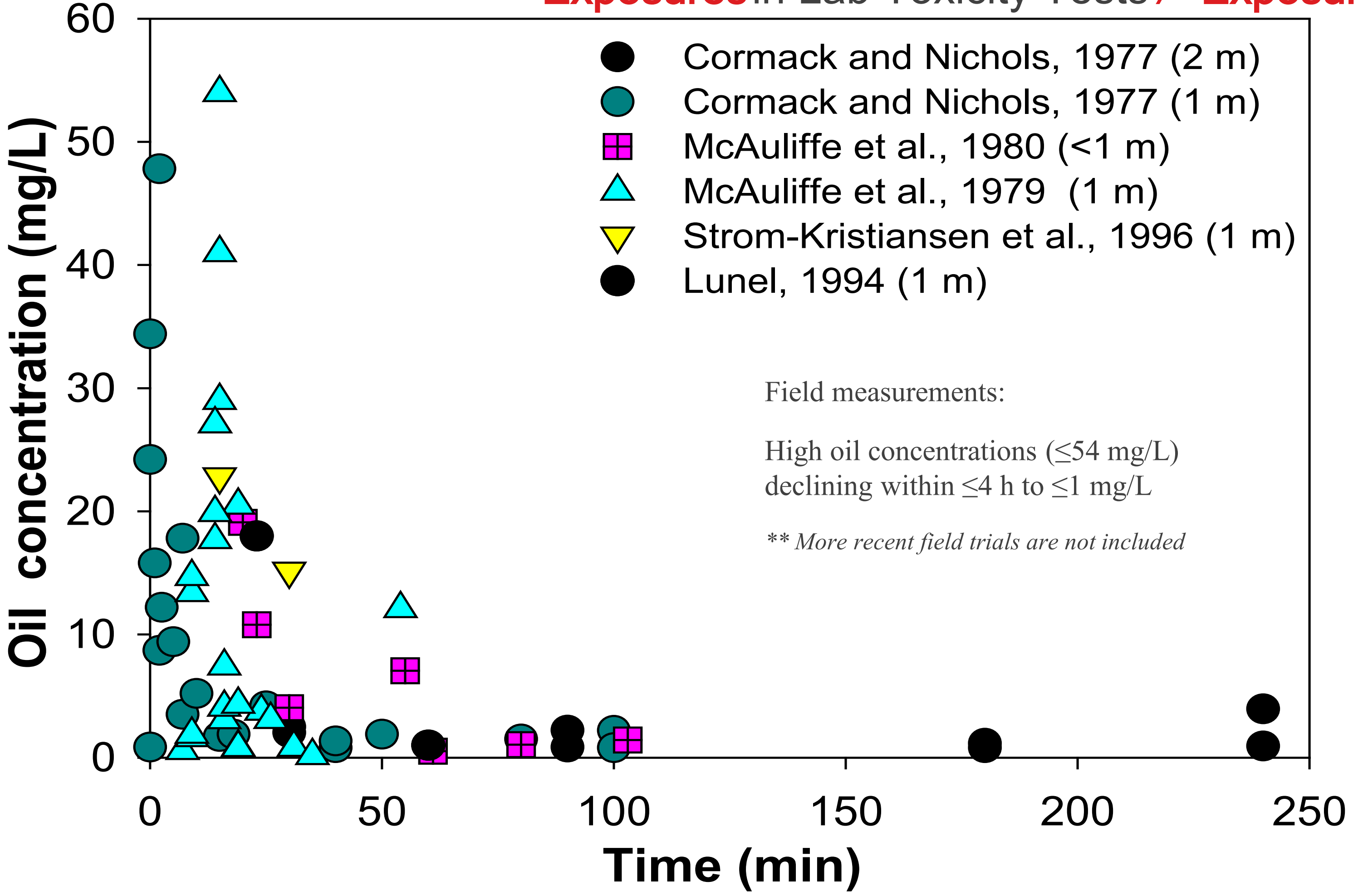
Limitations:

- Do not represent field conditions (concentration, duration)
- Unknown sensitivity of untested species

Utility of Aquatic Toxicity Testing

Risk= f {Hazard , Exposure}

Exposures in Lab Toxicity Tests ≠ Exposures in Field



Source: modified from Bejarano et al. 2014 ET&C 33:732–742

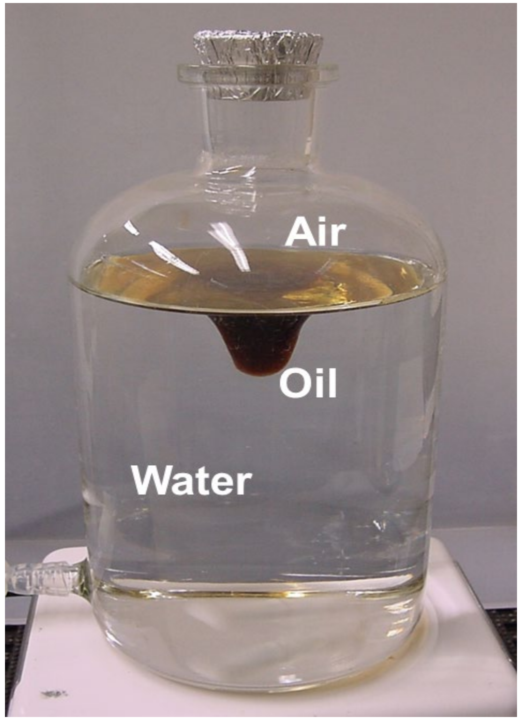
Toxicity tests alone cannot define Risk! - We cannot conclude that effects under laboratory conditions occur in the field

Key Challenge: Preparation of Exposure Media

Aqueous solubility behavior of oil constituents is influenced by the settings used to prepare the exposure media

Headspace – Volatilization reduces the amount of oil constituents in the exposure media

Water – Water characteristics (i.e., temperature, salinity) influence the solubility of oil constituents



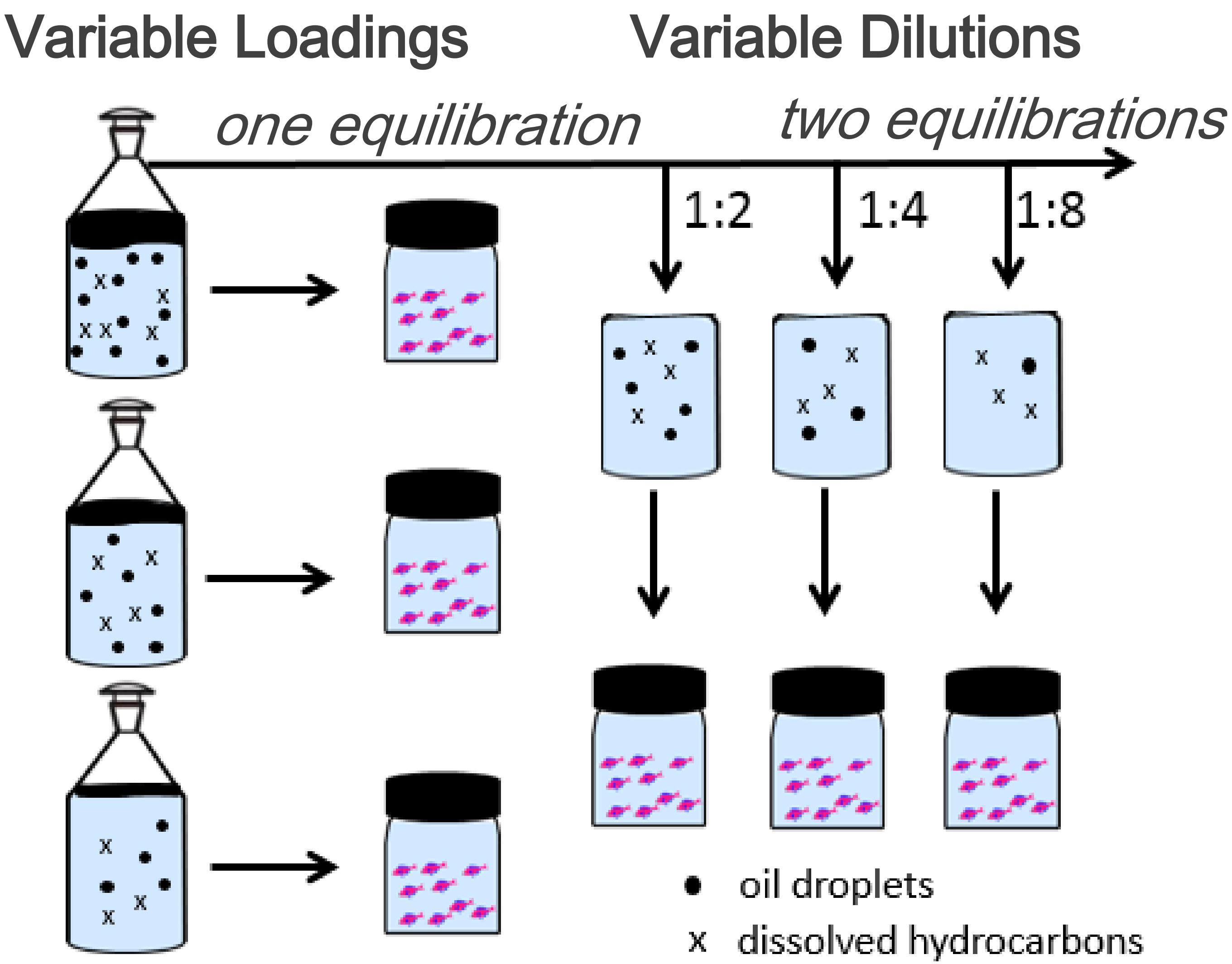
Dispersants – Increased partitioning of oil constituents is influenced by dispersant: oil ratio, entrained oil droplets

Mixing energy – Entrained oil droplets create noise in the interpretation of results (e.g., direct interaction with organisms, source of dissolved fractions)

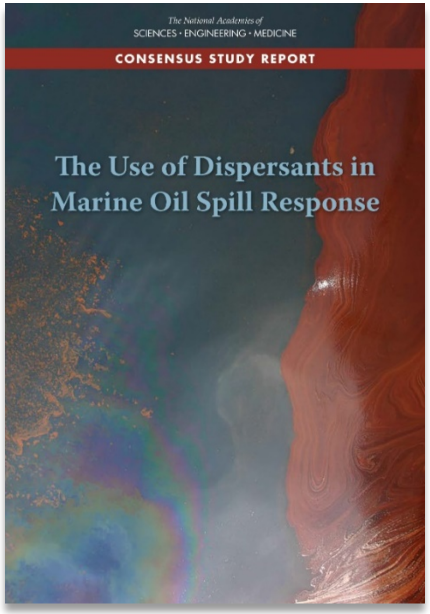
Oil – Each oil/weathering stage has a unique composition

Standardization of test protocols is important for comparisons across studies

Key Challenge: Dosing Methods



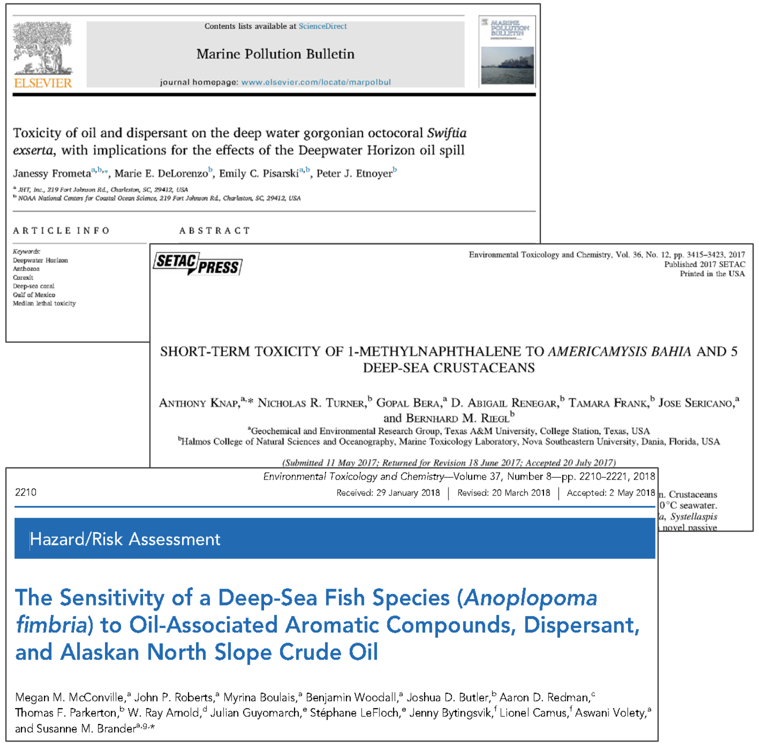
Source: Redman and Parkerton, 2015 MPB 98: 156–170



Chapter 3: Aquatic Toxicology and Biological Effects

Opportunities: Data Integration & Predictive Modeling

- Scientific knowledge that exists as discreate pieces of information hinder their use for decision making


Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Toxicity of oil and dispersant on the deep water gorgonian octocoral *Swiftia exserta*, with implications for the effects of the Deepwater Horizon oil spill

Janessy Frometa[a,b,*], Marie E. DeLorenzo[b], Emily C. Pisarski[a,b], Peter J. Etnoyer[b]

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Corexit
Deep-sea coral
Gulf of Mexico
Median lethal toxicity

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SHORT-TERM TOXICITY OF 1-METHYLNAPHTHALENE TO *AMERICAMYSIS BAHIA* AND 5 DEEP-SEA CRUSTACEANS

Anthony Knap,[a,*] Nicholas R. Turner,[b] Gopal Bera,[a] D. Abigail Renegar,[b] Tamara Frank,[b] Jose Sericano,[a] and Bernhard M. Riegl[b]

[a]Geochemical and Environmental Research Group, Texas A&M University, College Station, Texas, USA
[b]Halmos College of Natural Sciences and Oceanography, Marine Toxicology Laboratory, Nova Southeastern University, Dania, Florida, USA

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2210

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Hazard/Risk Assessment

The Sensitivity of a Deep-Sea Fish Species (*Anoplopoma fimbria*) to Oil-Associated Aromatic Compounds, Dispersant, and Alaskan North Slope Crude Oil

Megan M. McConville,[a] John P. Roberts,[a] Myrina Boulais,[a] Benjamin Woodall,[a] Joshua D. Butler,[b] Aaron D. Redman,[c] Thomas F. Parkerton,[b] W. Ray Arnold,[d] Julian Guyomarch,[e] Stéphane LeFloch,[e] Jenny Bytingsvik,[f] Lionel Camus,[f] Aswani Volety,[g] and Susanne M. Brander[a,g,*]

- Data repositories/databases facilitate access to information supporting tool/model development
  - Generating reliable test results is vital
  - Appropriate use of data & data quality are required

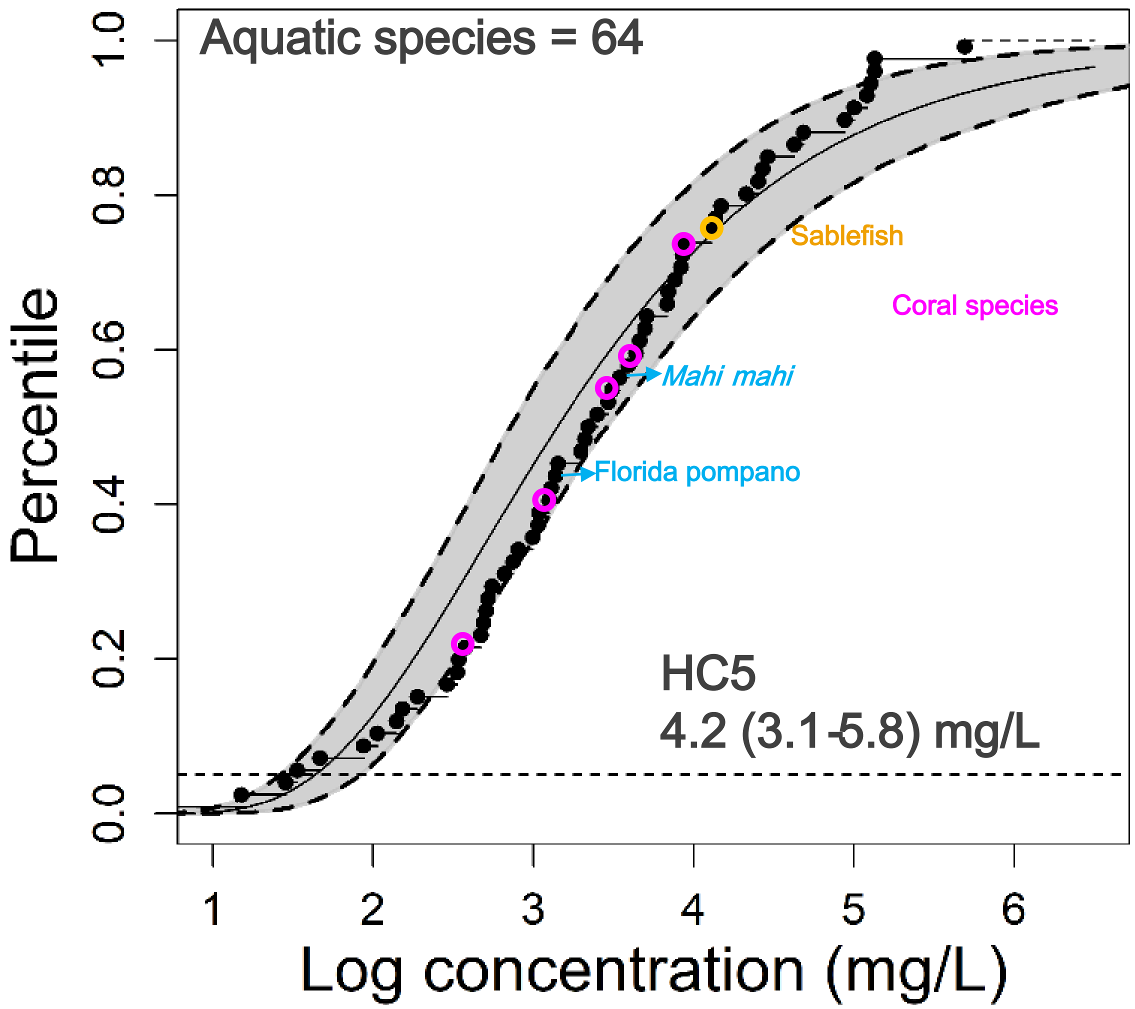
The Chemical Aquatic Fate and Effects Database

Data Integration Visualization Exploration and Reporting

GULF OF MEXICO RESEARCH INITIATIVE

- Data can be used in tools and models that capture complexity
  - **Examples:** species sensitivity distributions, effects-based predictive models, integrated models, etc.

Case Study: Data synthesis for Corexit 9500



Toxicity data from constant static/static renewal tests

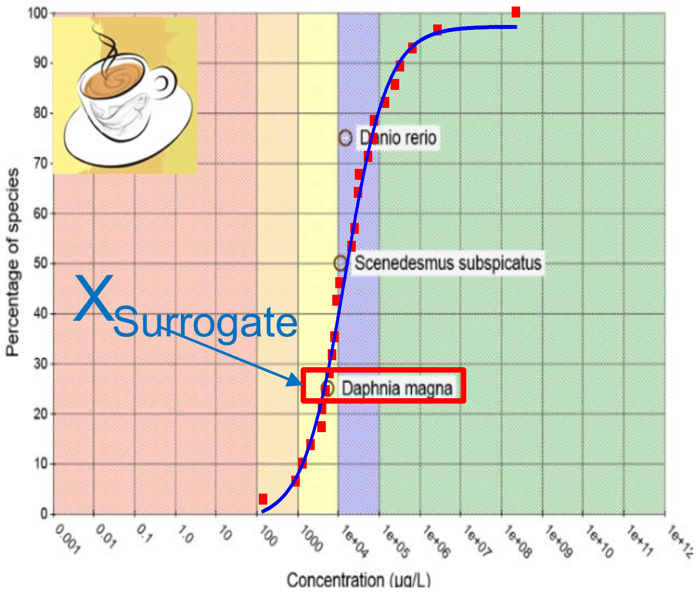
Significance:

- Data for newly-tested species fall within the previous range of sensitivities
- HC5s are protective of most species

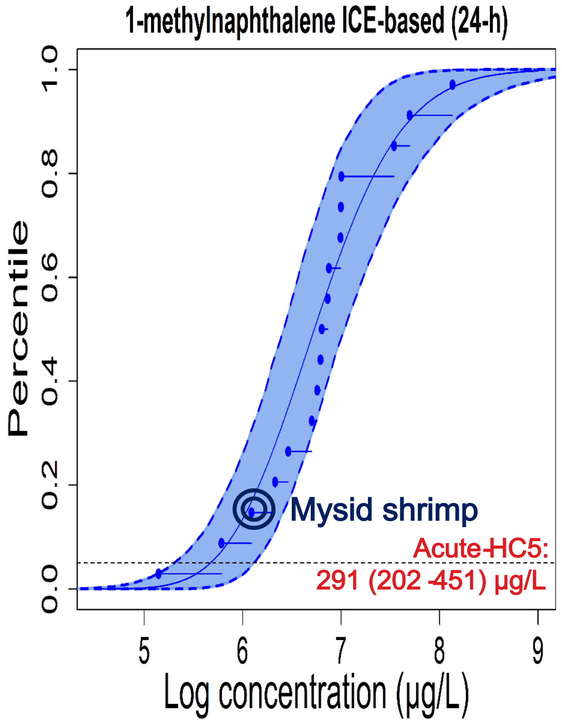
* Summarized in Bejarano, 2018 ET&C 37(12): 2989–3001

Interspecies Correlation Estimation Models for Single Hydrocarbons

- Log-linear relationships between the toxicity of two species

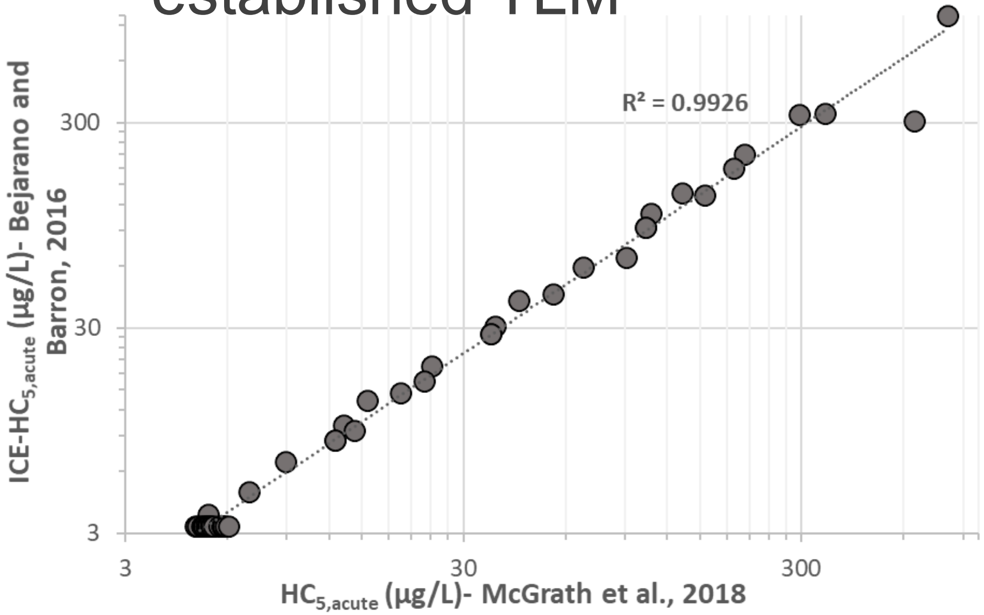


- ICE-based HC5 for 21 hydrocarbons (Bejarano and Barron, 2016)



* Modified from Barron, Chiasson, Bejarano, 2020

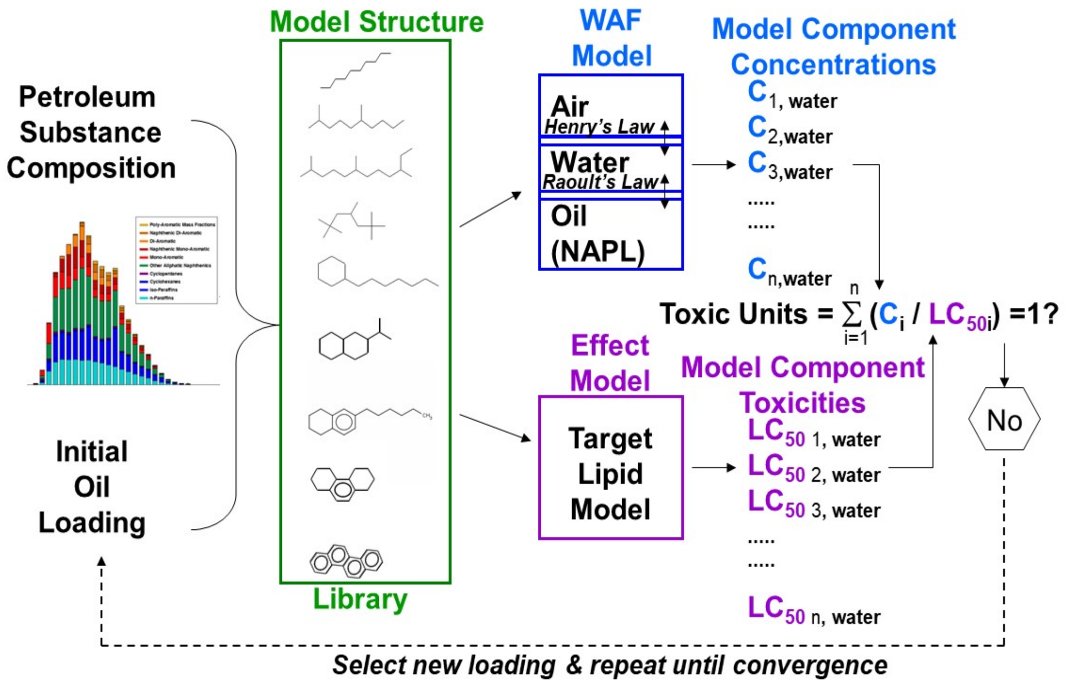
- ICE-based HC5s are comparable to the well established TLM*

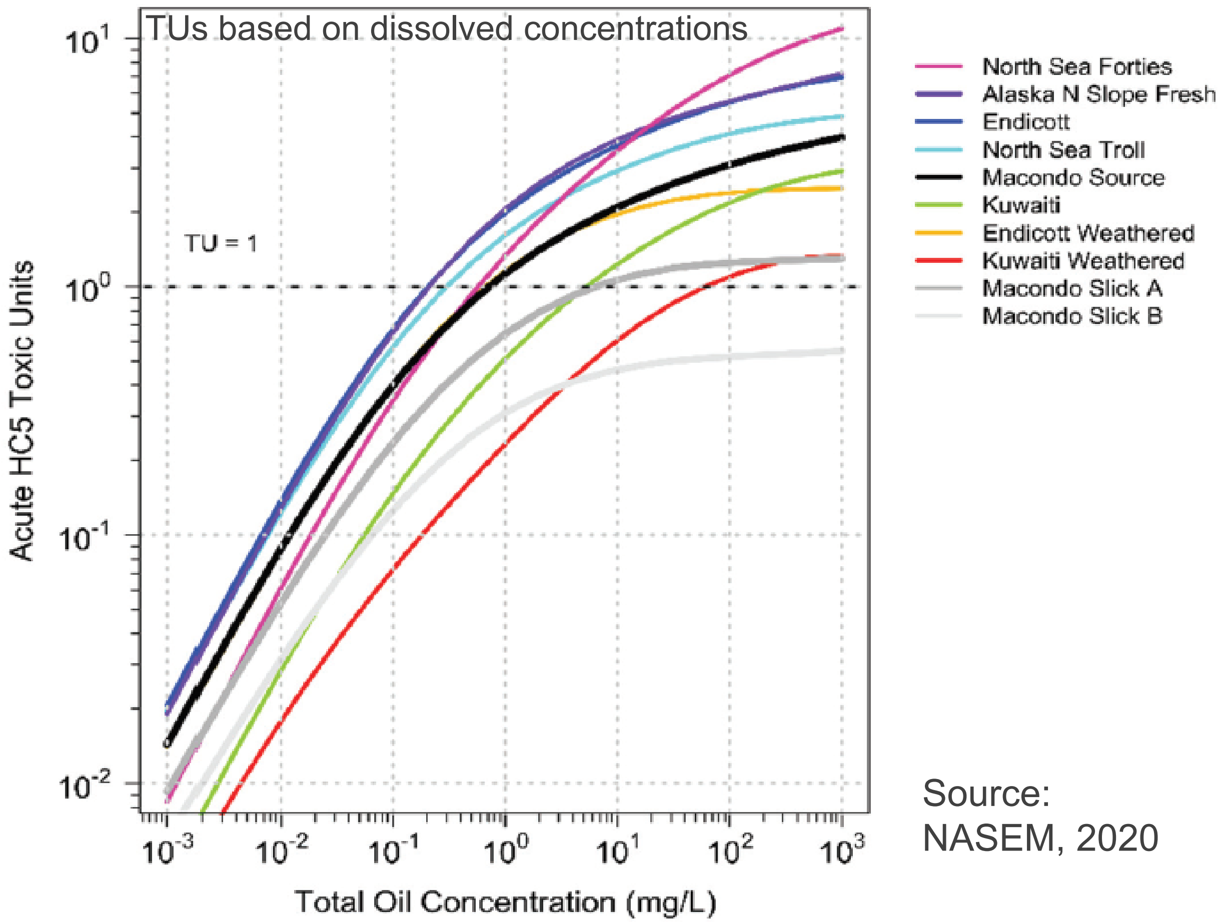


* TLM= assumes that mortality occurs when the chemical concentration in the target lipid reaches a threshold concentration

TLM & PETROTOX

- A tool for predicting aquatic toxicity from oil composition (mass fractions of hydrocarbon blocks), chemical-specific physicochemical properties (partitioning, solubility) and aquatic toxicity (species-specific CTLBB)





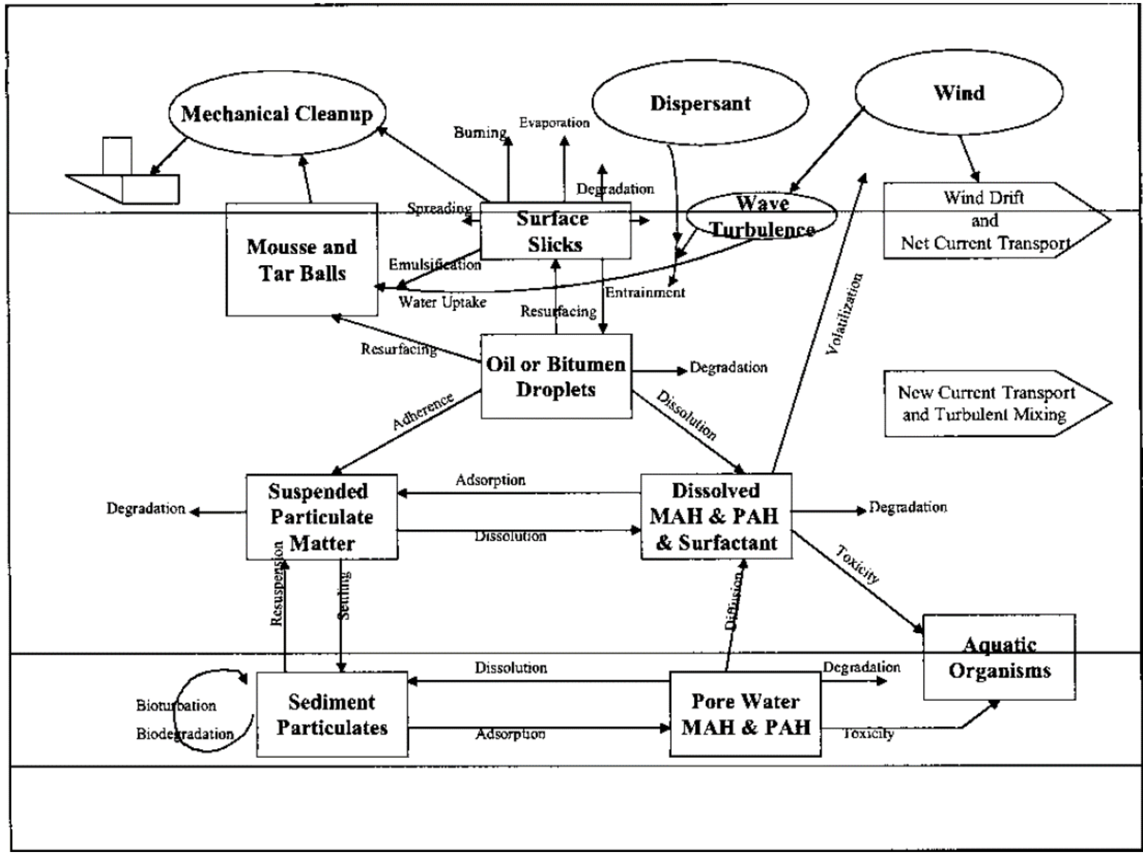
Source: NASEM, 2020

- Allows toxicity comparisons using the same metric (based on oil-specific composition)

Source:
Redman et al. 2014 ET&C 31:2498; Redman et al. 2017 ET&C 8:2245

SIMAP (Spill Impact Model Application Package)

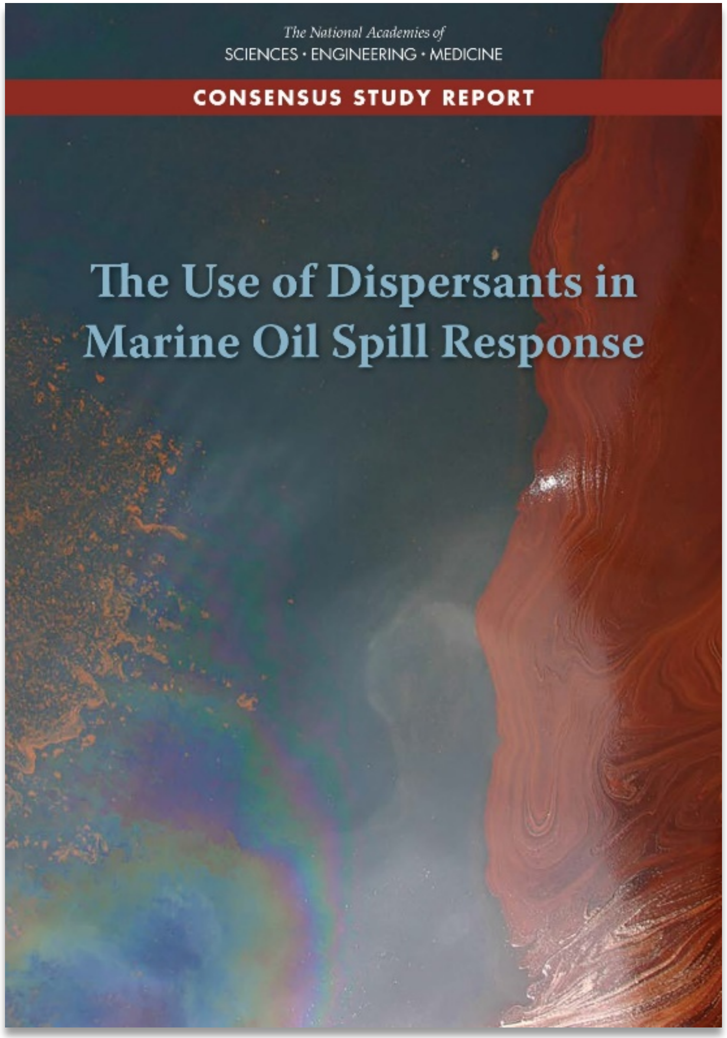
- A model that quantifies oil impacts on aquatic organisms, wildlife and habitats
- Oil toxicity model for aquatic organisms (OilToxEx):
  - Oil modeled as pseudo-components (aliphatics and aromatics [MAH; 2-ring, 3-ring, ≥4-ring PAHs])
  - Impact thresholds based on dissolved concentrations of hydrocarbons in the mixture
  - Builds on single-hydrocarbon toxicity data and assumes additive toxicity (TU approach)
  - Accounts for temperature and exposure duration
  - Addresses phototoxicity



Source:
French McCay 2002, ET&C 21(10): 2080-2094; French McCay 2004, ET&C 23(10): 2441–2456

NASEM Recommendations

- Advances in predictive toxicity models should be incorporated into user accessible tools
- Tool availability would facilitate their calibration, validation, refinement, and support decision-making
- Information from standardized toxicity testing, and oil characterization/composition could be coupled with fate and effect models



Knowledge Gaps & Future Directions:

Scientific gaps

- Standardized protocols/experimental designs, and minimum reporting quality criteria would provide more data suitable for model development and validation
- Chemical characterization of the exposure media, including quantification of dissolved and particulate phases is critical for correct data interpretation
- Data limitations for environmentally relevant hydrocarbons (e.g., heterocyclic [S-containing] hydrocarbons, oxidized byproducts, unresolved complex mixtures)
- Evaluation of modes of toxic action other than narcosis (e.g., disruption of calcium channels)

Research for Spill Response

- Toxicity data from time-variable exposures → provide endpoints for assessing effects at short exposure durations
- Single hydrocarbon toxicity tests → Important for improving/calibrating effects models
- Wave tanks/controlled trials → model calibration of effects on aquatic species under environmentally realistic exposures

Questions and Answers

Useful Resources

- Databases and tools: Chemical Aquatic Fate and Effects Database (link); PETROTOX (link)
- Scientific papers:

- Hansen, BH T Parkerton, TR Størseth, T Nordtug, A Redman (2019) Modeling the toxicity of dissolved crude oil exposures to characterize the sensitivity of cod (*Gadhus morhua*) larvae and role of individual and unresolved hydrocarbons, Marine Pollution Bulletin 138:286-294
- Bejarano, AC (2018). Critical Review and Analysis of Aquatic Toxicity Data on Oil Spill Dispersants. *Environ. Toxicol. Chem.* 33(12): 2989-3001
- Bejarano, AC, and MG Barron (2016). Aqueous and tissue residue-based interspecies correlation estimation models provide conservative hazard estimates for aromatic compounds. *Environ. Toxicol. Chem.* 35: 56-64.
- Bejarano, AC, Clark, JR, Coelho, GM, (2014). Issues and challenges with oil toxicity data and implications for their use in decision making: a quantitative review. *Environ. Toxicol. Chem.* 33, 732–742
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- French-McCay, D. P. 2002. Development and application of an oil toxicity and exposure model, OilToxEx. *Environ. Toxicol. Chem.* 21(10):2080-2094
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- Hodson PV, Adams J, Brown RS (2019). Oil toxicity test methods must be improved. *Environ. Toxicol. Chem.* 38(2):302-11
- Letinski, DJ, TF Parkerton, AD Redman, RG. Manning, G. Bragin, EJ. Febbo, D. Palandro, T. Nedwed (2014) Use of Passive Samplers For Improving Oil Toxicity and Spill Effects Assessment, *Marine Pollution Bulletin* 86: 274–282.
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- Paquin, P, J McGrath, C Fanelli, D Di Toro (2018) The Aquatic Hazard of Hydrocarbon Gases and the Modulating Role of Pressure on Dissolved Gas and Oil Toxicity, *Marine Pollution Bulletin*. https://doi.org10.1016/j.marpolbul.2018.04.051
- Redman AD, Butler JD, Letinski DJ, Di Toro DM, Leon Paumen, M, Parkerton, TF (2018). Technical Basis for Using Passive Sampling as a Biomimetic Extraction Procedure to Assess Bioavailability and Predict Toxicity of Petroleum Substances, Chemosphere 199:585-594.
- Redman AD, Parkerton TF, Leon Paumen M, Butler JD, Letinski DJ, Den Haan K (2017). Re-evaluation of PETROTOX for predicting acute and chronic toxicity of petroleum substances. *Environ. Toxicol. Chem.* 36:2245-2252.
- Redman, AD, TF Parkerton (2015). Guidance for improving comparability and relevance of oil toxicity tests, *Marine Pollution Bulletin* 98:156-170

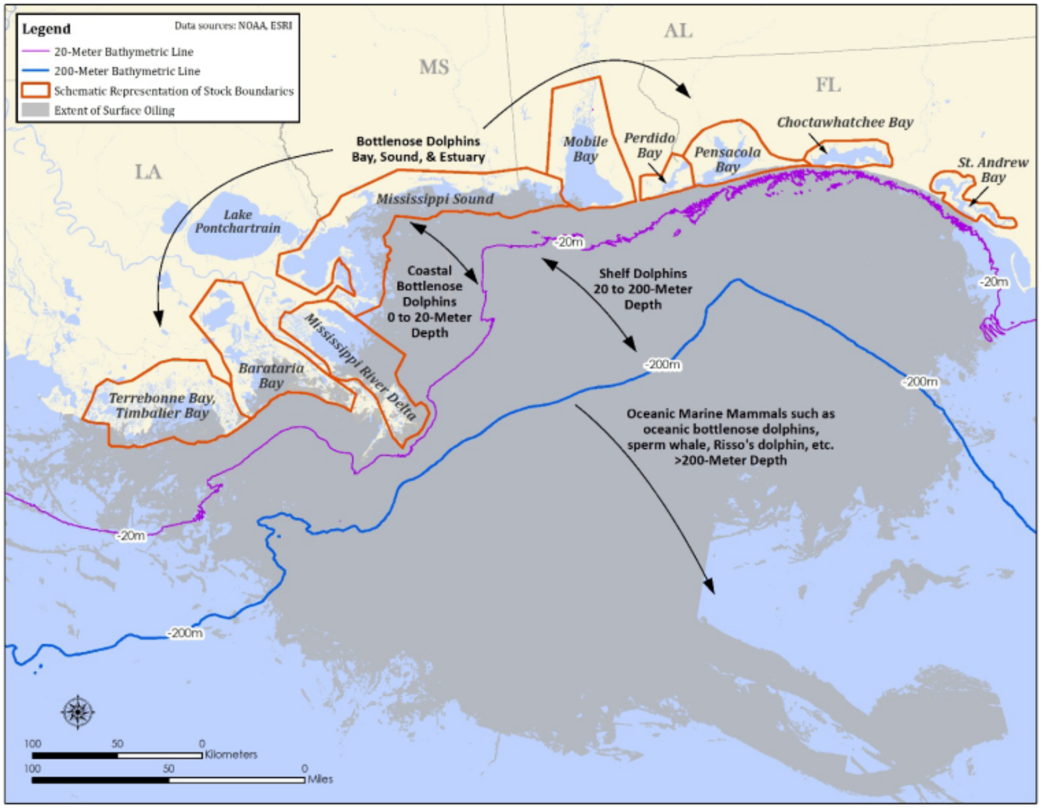
Population impacts associated with the *Deepwater Horizon* oil spill: a dolphin case study

Lori Schwacke, National Marine Mammal Foundation

Presentation for NASEM Committee on Oil in the Sea IV: Inputs, Fates, and Effects

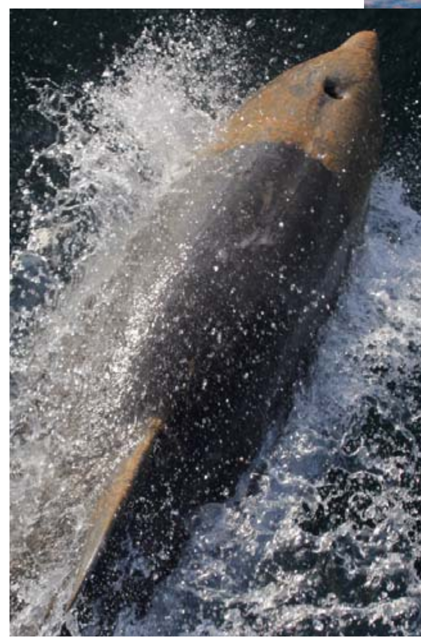
NATIONAL MARINE MAMMAL FOUNDATION

Gulf of Mexico cetacean species



From: DWH Programmatic Damage Assessment and Restoration Plan
http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan
Also see: Takeshita et al. 2017, *ESR*

Tursiops truncatus

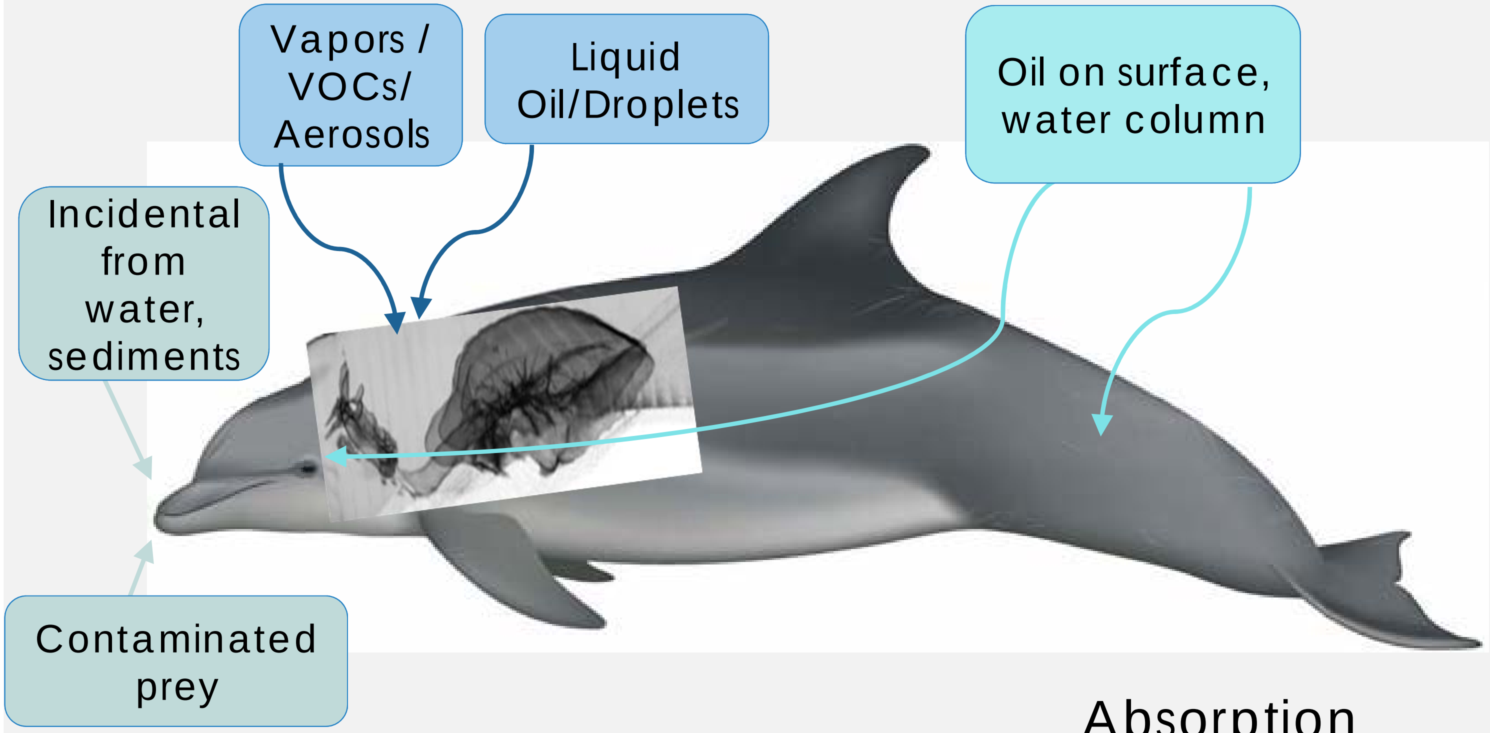


Stenella coeruleoalba

Photo credits: NOAA

Physeter macrocephalus

Routes of exposure



- Inhalation
- Direct aspiration

- Ingestion → Absorption, Aspiration

- Dermal, ocular contact

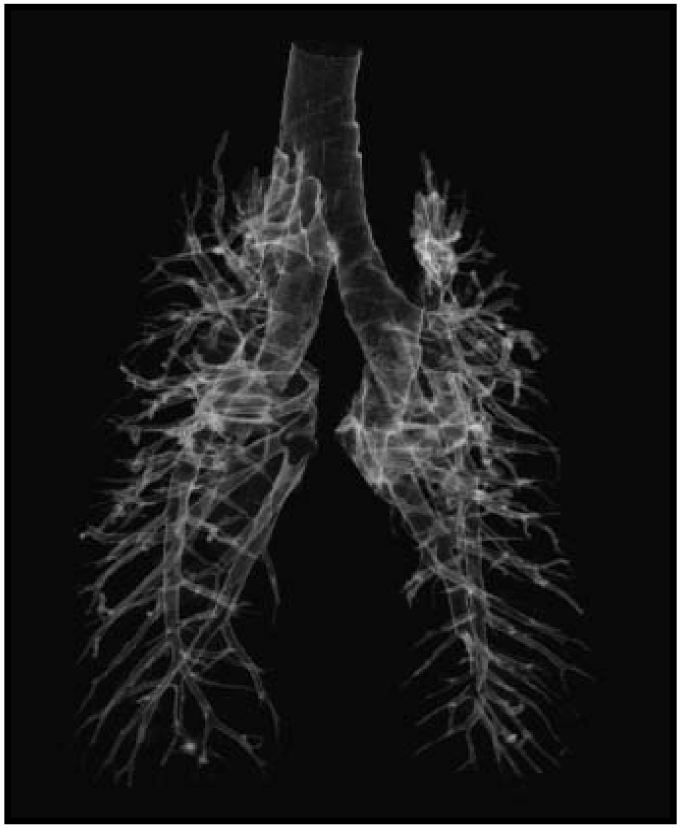
Susceptibility of the dolphin respiratory system to inhaled chemical contaminants

NATIONAL MARINE MAMMAL FOUNDATION

Straight, rapid intake of surrounding > 10L air directly to lungs without protective nasal turbinates with cilia

80-90% exchange of deep lung air with every breath & extended breath hold

Double layer capillary beds to enable efficient movement of airborne compounds into blood



Study approaches

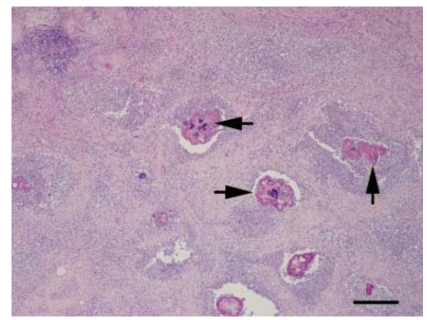
Live Dolphin Health Assessments

- Physical exams
- Blood panels
- Ultrasound
- Pregnancy assessment
- Fecal and blowhole
- Weight & length
- Tooth aging
- Infectious diagnostics

Observational Studies & Remote Biopsy Sampling

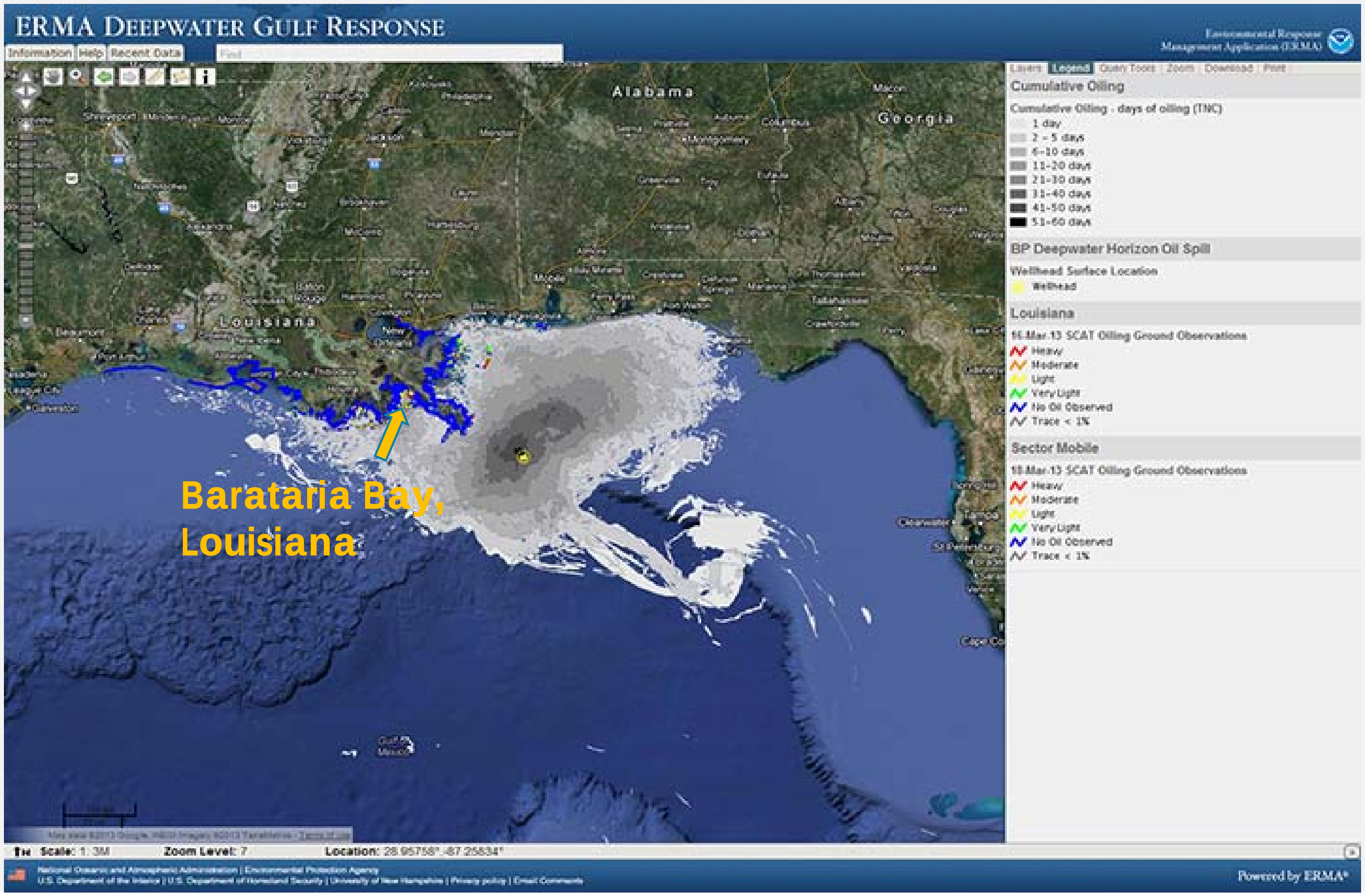
- Survival rates
- Reproductive outcomes
- Genetics
- Hormones(pregnancy)
- Persistent contaminants (POPs)

Stranded Dolphins & Dead Dolphin Tissue Evaluations



- Demographics
- Weight & length
- Gross observations
- Full histology set (tissues)
- Infectious & biotoxin diagnostics

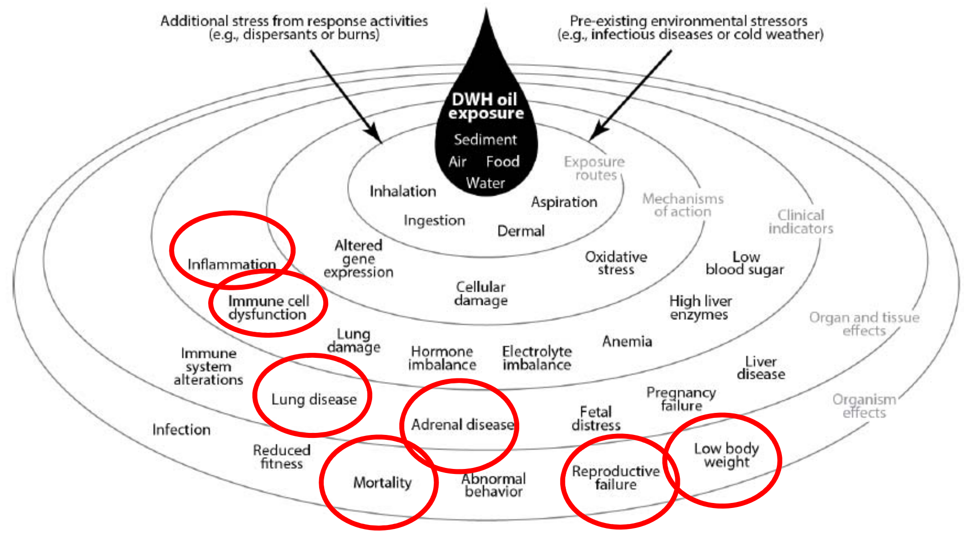
Focus on Barataria Bay – NRDA (2010-2014), GoMRI (2016-2019)



Observed health effects following DWH

Photo: LDWF

Photo: LDWF



From: DWH Programmatic Damage Assessment and Restoration Plan (PDARP) 2016, Chapter 4 Injury to Natural Resources

Schwacke et al. 2014, *ES&T*; Lane et al. 2015, *Proc Roy Soc*; Smith et al. 2017, *ESR*; De Guise et al. 2017, *ESR*; Takeshita et al. 2017, *ESR*

Veterinary prognosis for comparing health of populations over time

Prognosis categories

- Good
- Fair
- Guarded
- Poor
- Grave

Evaluated based on:

- Physical exam
- Mass:length ratio
- Complete blood count (CBC), serum chemistry
- Stress, thyroid & reproductive
- Diagnostic ultrasounds
- Serology
- Comparison with established reference intervals

Schwacke et al. 2014, *ES&T*; Smith et al. 2017, *ESR*

Defining pre- and post-spill cohorts

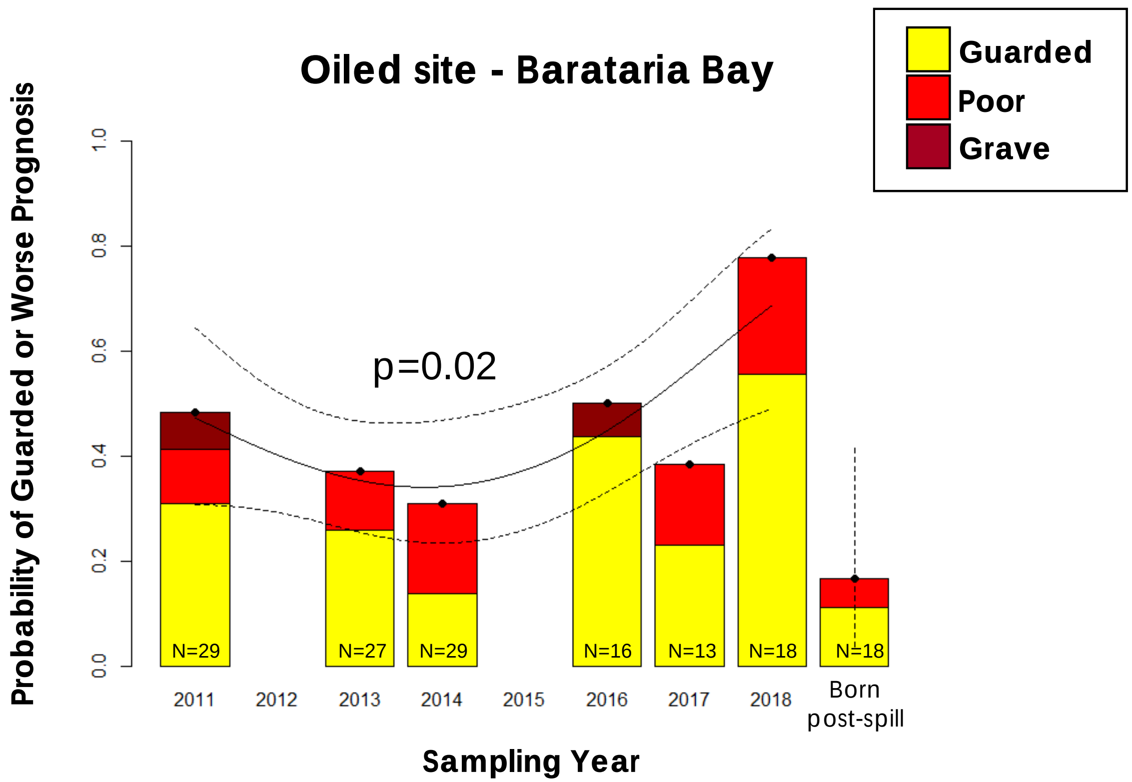
Using photo-ID histories, identified 2 cohorts:

- dolphins that were alive during the spill, and thus presumably exposed to oil in Barataria Bay
- dolphins born after the spill (2010)

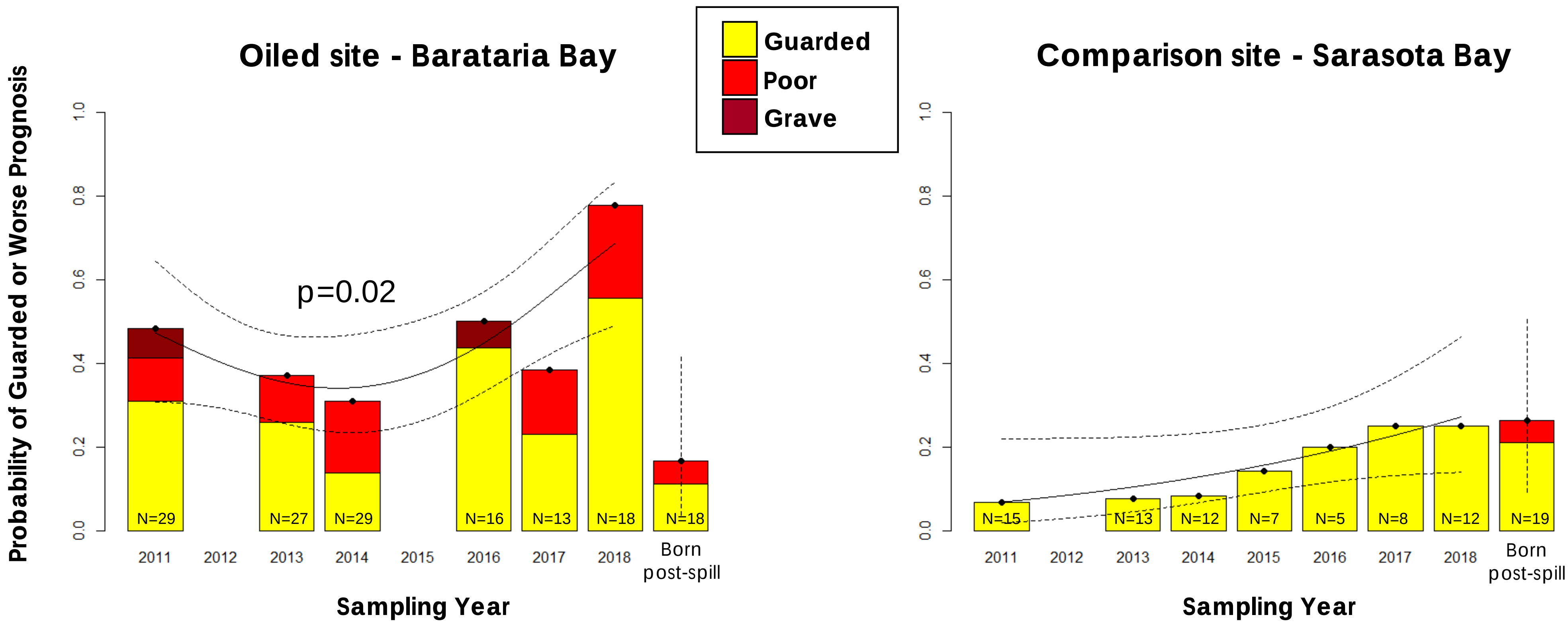
Conducted same photo-ID analyses for unoiled site, Sarasota Bay for comparison

Applied Generalized Additive Model (GAM) to examine effect of time (year), and site (oiled vs. unoiled) for both cohorts

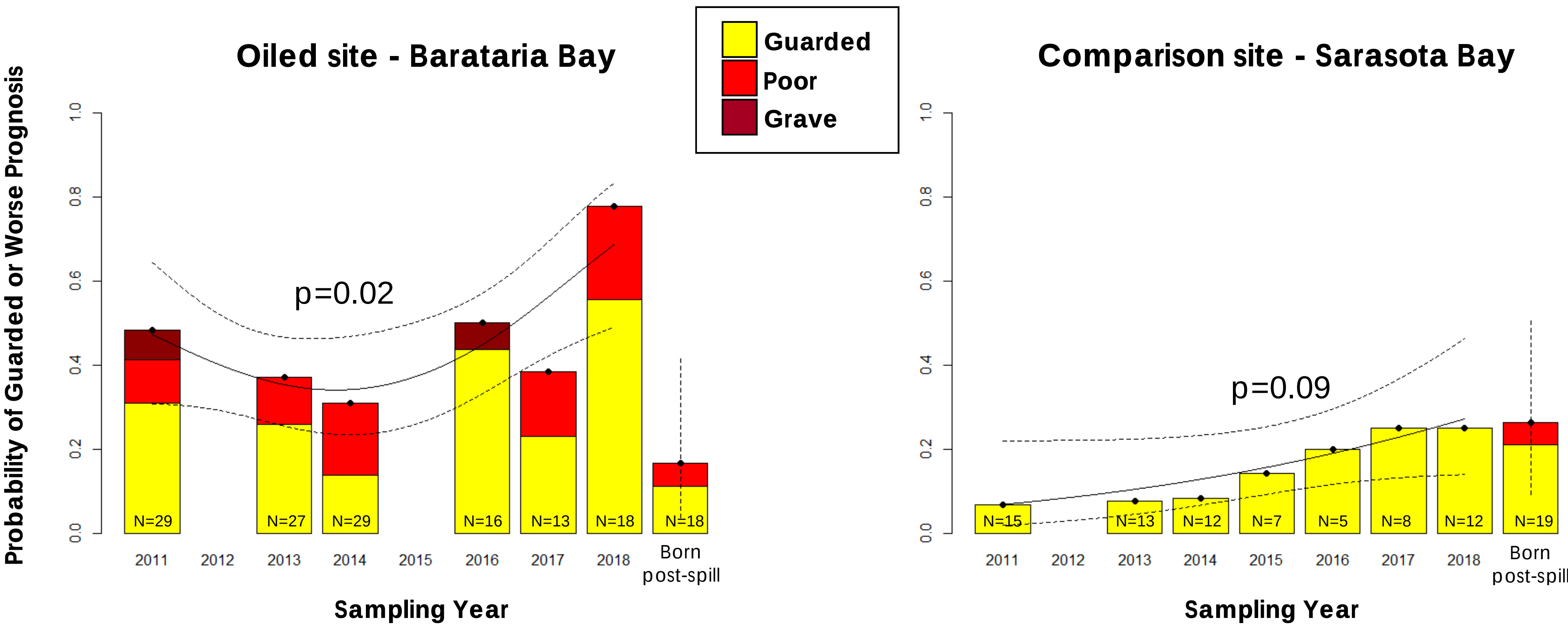
Prognosis scores over time



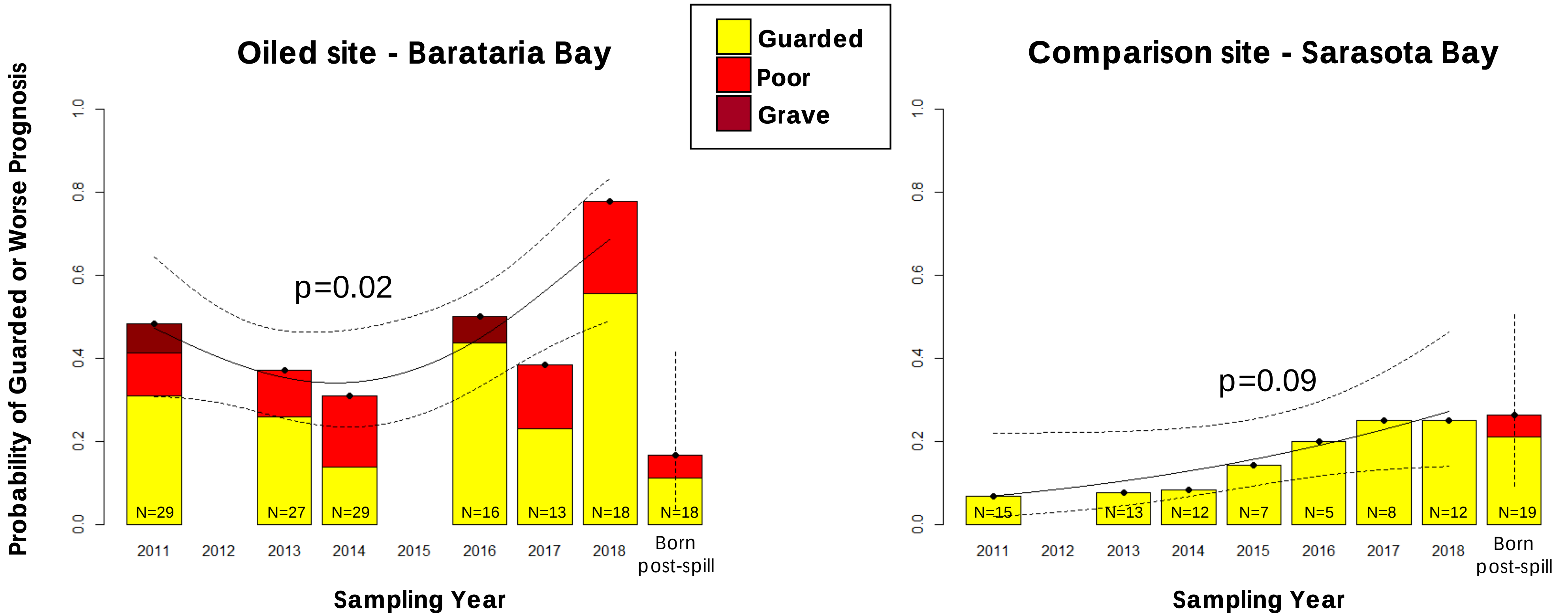
Prognosis scores over time



Prognosis scores over time



Prognosis scores over time



Dolphins alive at time of DWH spill Barataria vs. Sarasota Bay: p<0.0001
Dolphins born after 2010 Barataria vs. Sarasota Bay: p=0.19

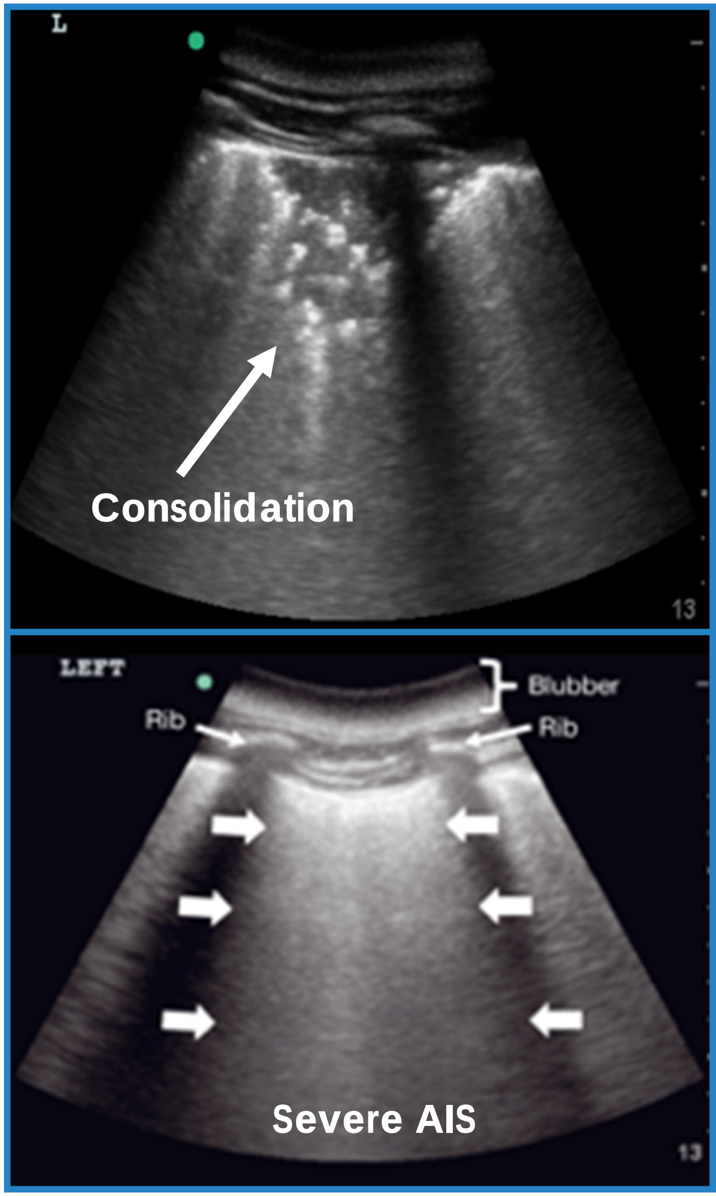
Primary health concerns for pre-spill cohort in later years

Lung disease as diagnosed via ultrasound, specifically:

- Pulmonary nodules - round to ovoid focus of non-aerated lung
- Consolidation – fluid and/or infiltrate in the alveolar spaces
- Alveolar-interstitial syndrome (AIS) – increased fluid or cellular infiltrate in the interstitium of the lung and reduced air in alveolar spaces
- In later years, AIS worsening dorsal to ventral

Continued evidence of **impaired stress response**

Continued high prevalence for markers of chronic disease - **inflammation** (primarily neutrophilia), and **anemia**



Barataria Bay population health trends over time

Health of pre-spill dolphin cohort in Barataria Bay has not improved, and likely has worsened, in the decade after the spill. This could be related to:

- Aging cohort
- Progression of chronic disease
- Increased susceptibility to other stressors (e.g., infectious pathogens)

Health parameters for **post-spill cohort appear to be within normal range** (with exception of immune*)

- Short monitoring period and small sample sizes

*See: De Guise et al. In press, ET&C

Quantifying the impact to populations

- Cetaceans are long-lived, slow to mature (~ 8 yrs)
- Difficult for populations to recover from loss of reproductive adults
- Just counting dead individuals does not fully describe impact to stock

Injuries were quantified using a population model that allowed for consideration of **long-term impacts to population** resulting from individual losses, and allowed incorporation of reproductive effects that **slow population recovery**

Modeling population impacts

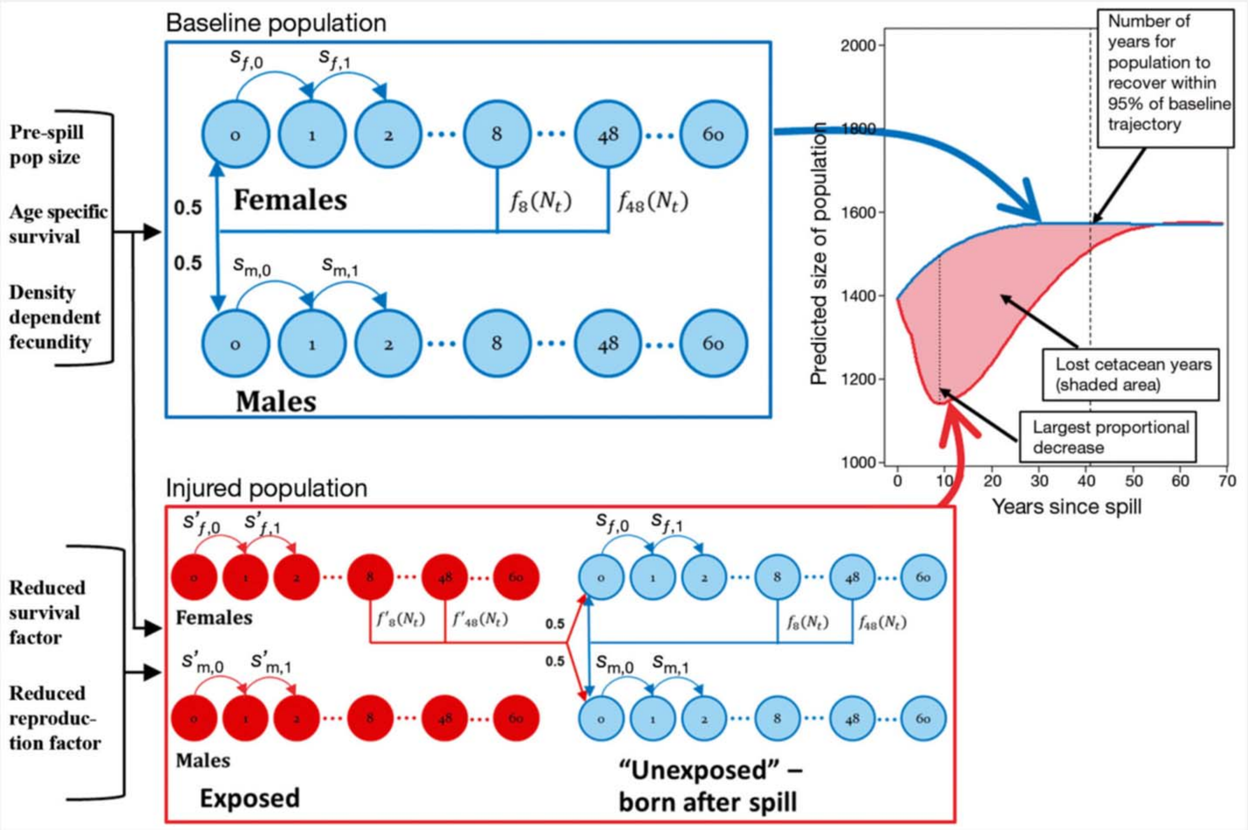
Age-, sex-, and class- structured population model

Synthesized estimates of reduced survival and reproduction from empirical studies conducted after the spill

Used veterinary prognoses to predict how long compromised health for exposed cohort would continue into the future

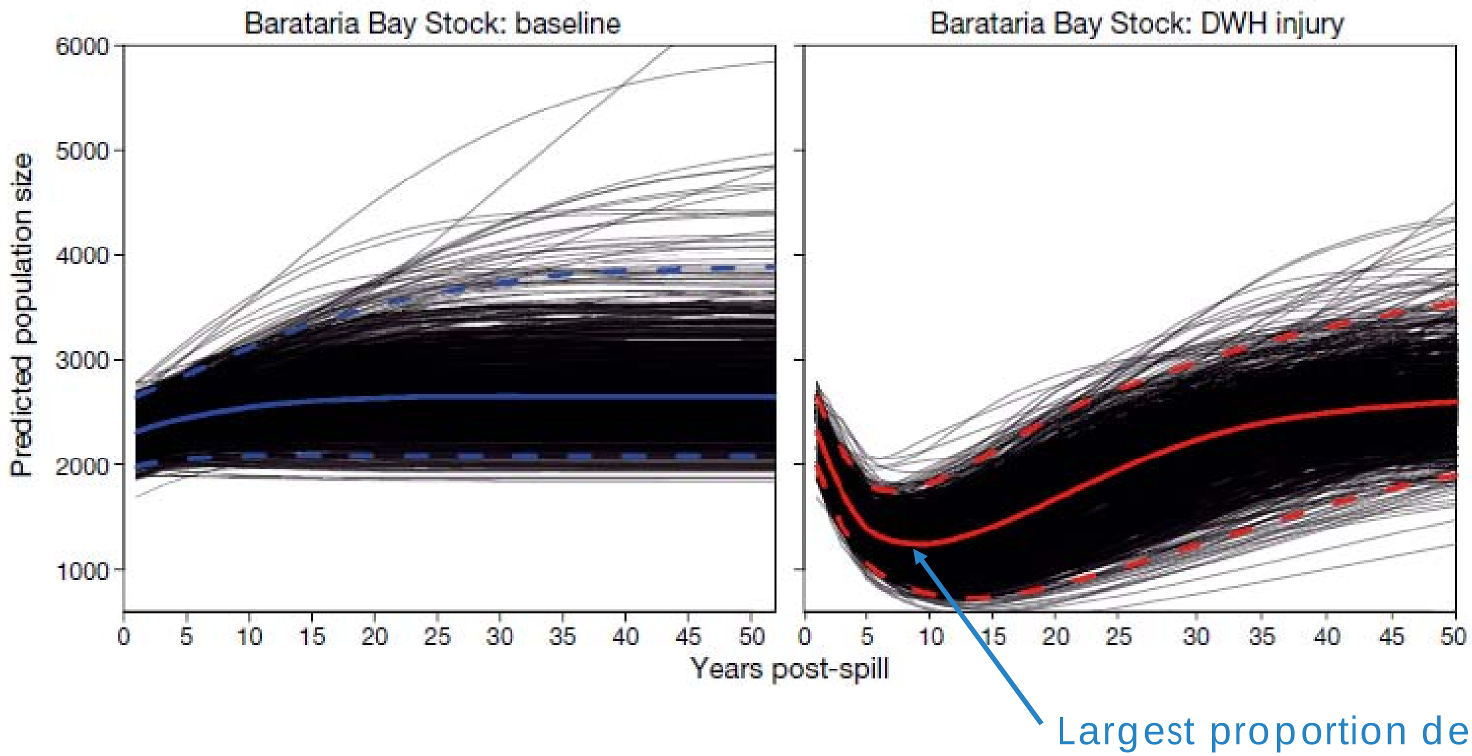
<u>Important assumptions:</u>

- Density dependent fecundity
- Dolphins born after spill have baseline rates (no progeny effects)
- Exposed class recovers over some period



From: Schwacke et al. 2017, *Endangered Species Research*

Population model results



From: Schwacke et al. 2017, *Endangered Species Research*

What we've learned

Response & short-term impacts

- DWH greatly enhanced our understanding or exposure pathways, health effects, and likely chronicity of effects in cetaceans – **inhalation/aspiration exposure pathway is important!**
- Still, much is still not understood related to differences in oil type, dose, thickness of oil on surface, etc., and how response activities may alter risk to cetaceans. This is a knowledge gap that we need to address to improve our ability to effectively respond to future spills.

What we've learned

Response & short-term impacts

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- Still, much is still not understood related to differences in oil type, dose, thickness of oil on surface, etc., and how response activities may alter risk to cetaceans. This is a knowledge gap that we need to address to improve our ability to effectively respond to future spills.

Long-term population effects

- There continues to be a significant impact from DWH oil spill on cetaceans in the Gulf of Mexico with **chronic poor health continuing to impact survival and reproductive success.**
- While the NRDA focused on direct toxic effects, **indirect impacts through prey loss, habitat loss, and/or disturbance cannot be ruled out, and may have been more significant for offshore cetaceans.**
- Restoration efforts are critical to assist in recovery of multiple cetacean stocks.
- **Recovery of many stocks will be slow and vulnerability of these stocks must be considered when planning development and/or restoration activities.**

Thank you!

Fieldwork was conducted under NMFS research permit no. 18786.

Thank you to our CARMMHA partners and the many collaborators who supported our field efforts. Special thanks to co-PIs Teri Rowles and Cynthia Smith.

Portions of this research were conducted as part of the DWH Natural Resource Damage Assessment led by NOAA and other Trustees; portions were made possible by a grant from The Gulf of Mexico Research Initiative.

CARMMHA | NATIONAL MARINE MAMMAL FOUNDATION | CREEM | NOAA | Dauphin Island Sea Lab Alabama | ILLINOIS University of Illinois at Urbana-Champaign | UCONN University of Connecticut | Chicago Zoological Society Inspiring Conservation Leadership | Gulf of Mexico Research Initiative

Population Effects: Field Measurements

Perspectives from 10 years of research post-*Deepwater Horizon*

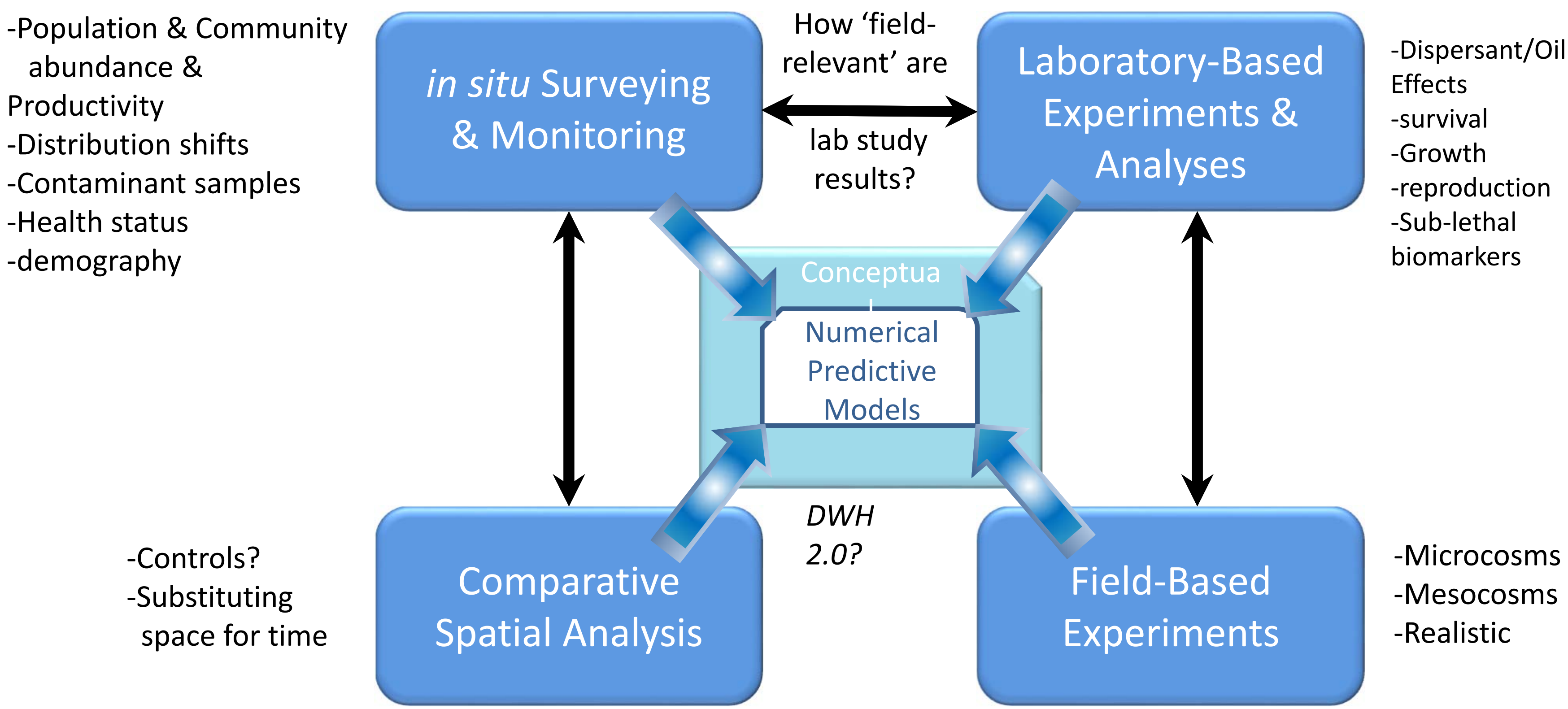
Steve Murawski
smurawski@usf.edu

Oil in the Sea IV
February 11, 2021

Issues covered

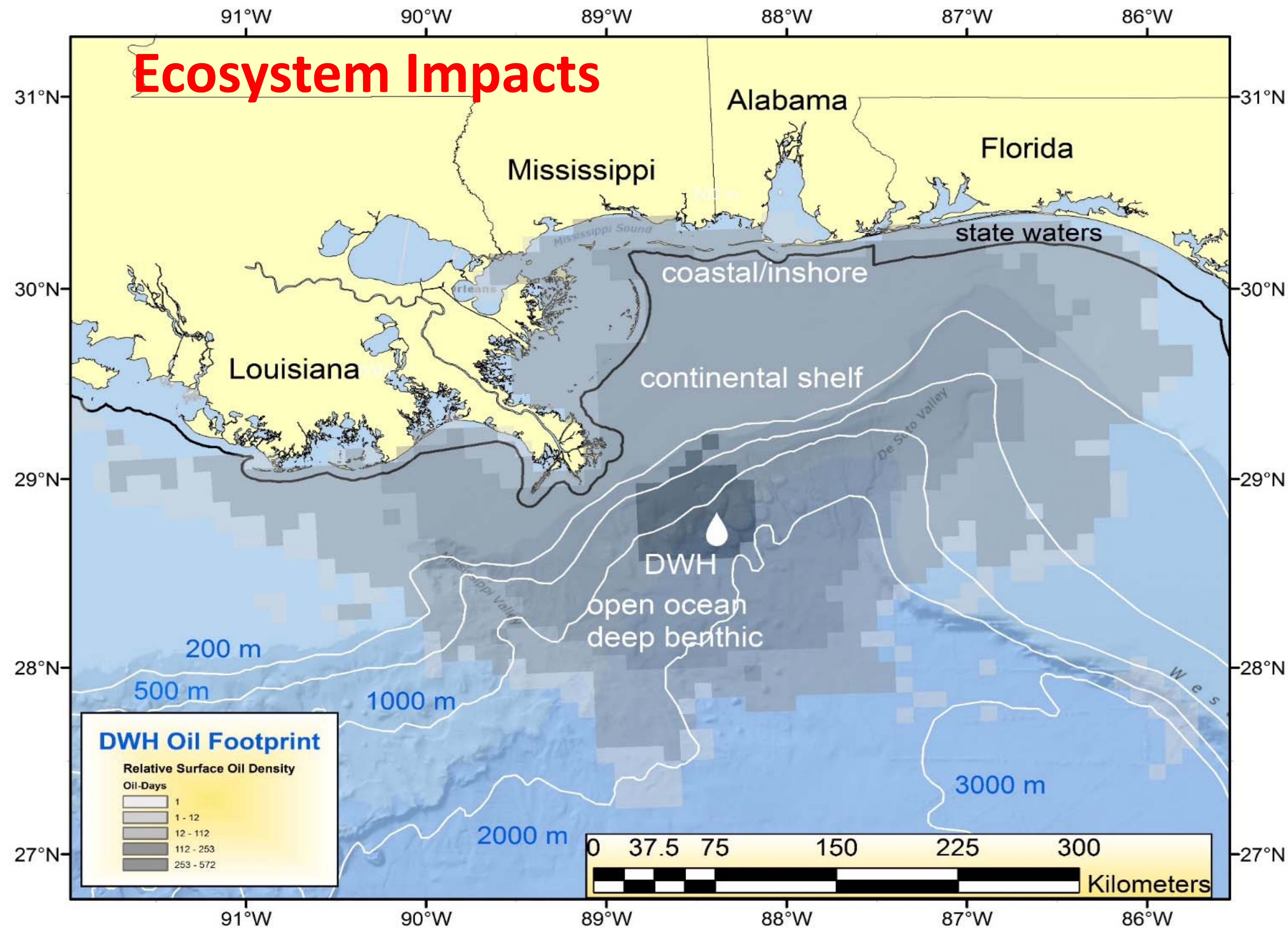
- ✓ Changes in resource abundance and demography associated with DWH,
- ✓ Vulnerability and Resilience of ecosystem components,
- ✓ Contaminant concentrations (before, after, control, impact),
- ✓ Habitat effects (temporary, permanent),
- ✓ Impacts of oil spill counter-measures,
- ✓ What do DWH Impacts portend for “restored” ecosystems?
- ✓ Significance of chronic pollution from the oil industry – Produced Waters.

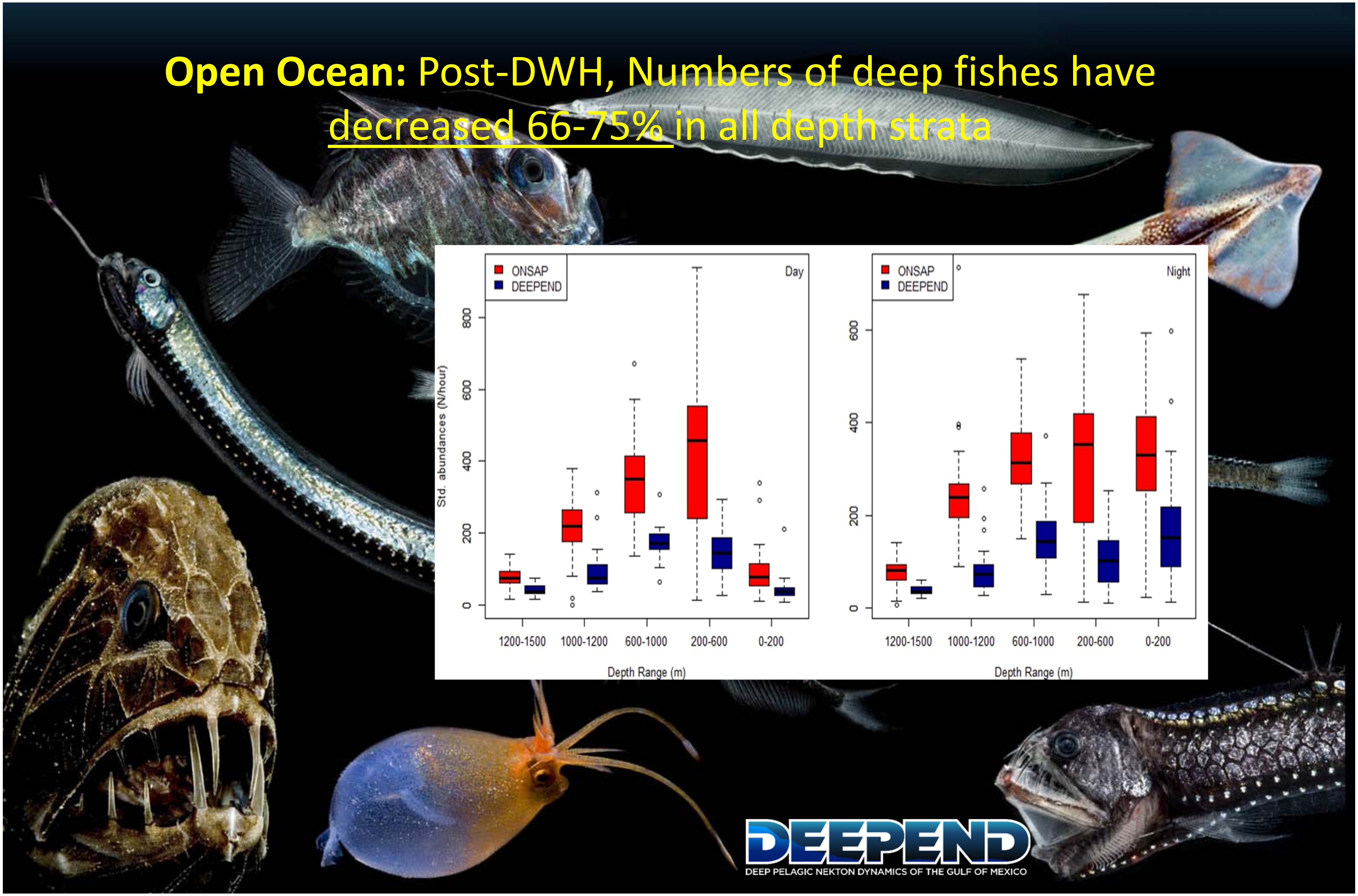
Epistemology of Oil Spill Ecological Studies: When Coupled, Represent a Powerful Learning Environment



How do we infer cause and effect?

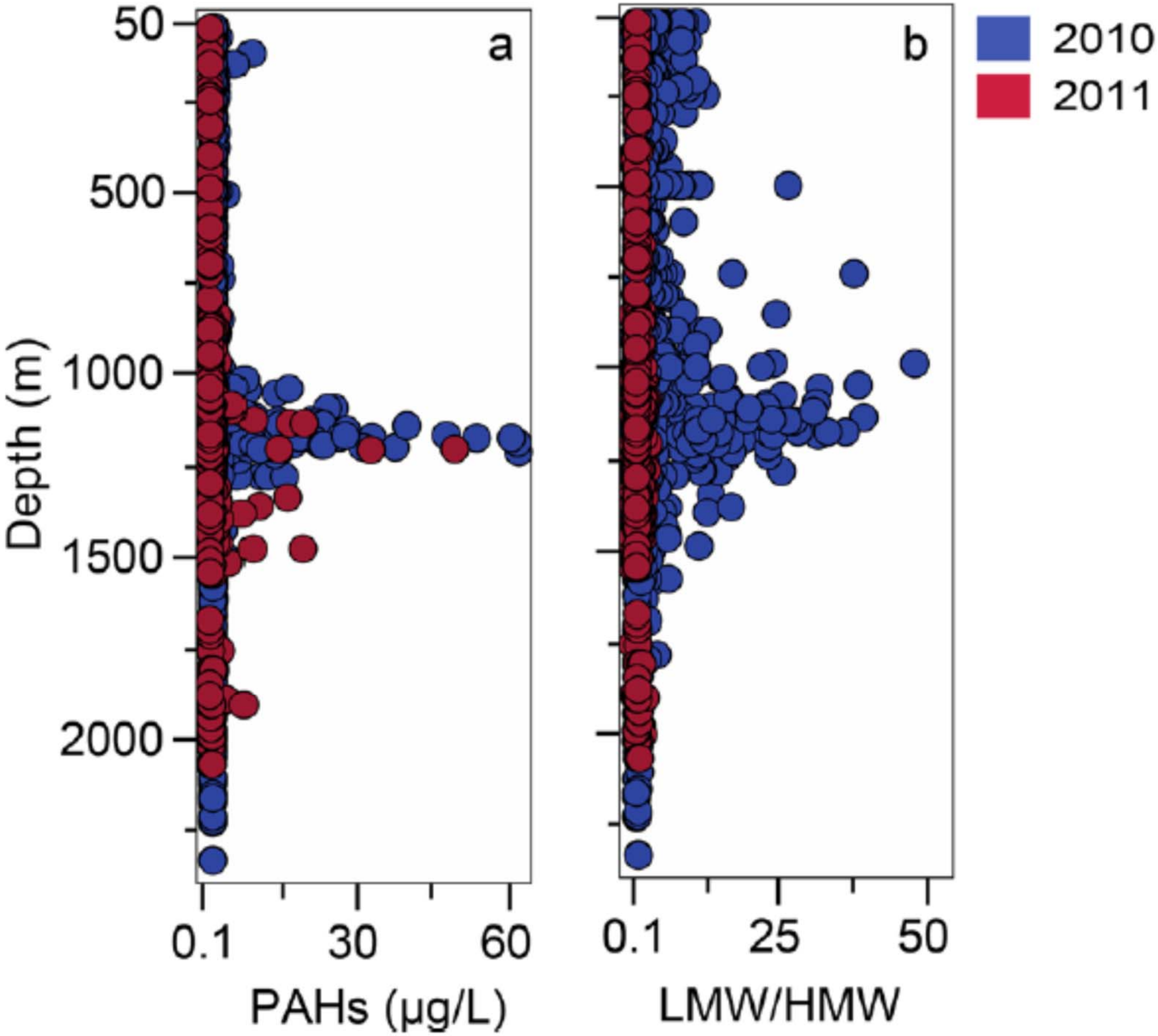
- Parsing the *synthesis* into 4 inter-connected "Ecotypes"
- Recognizing the interconnectedness among them



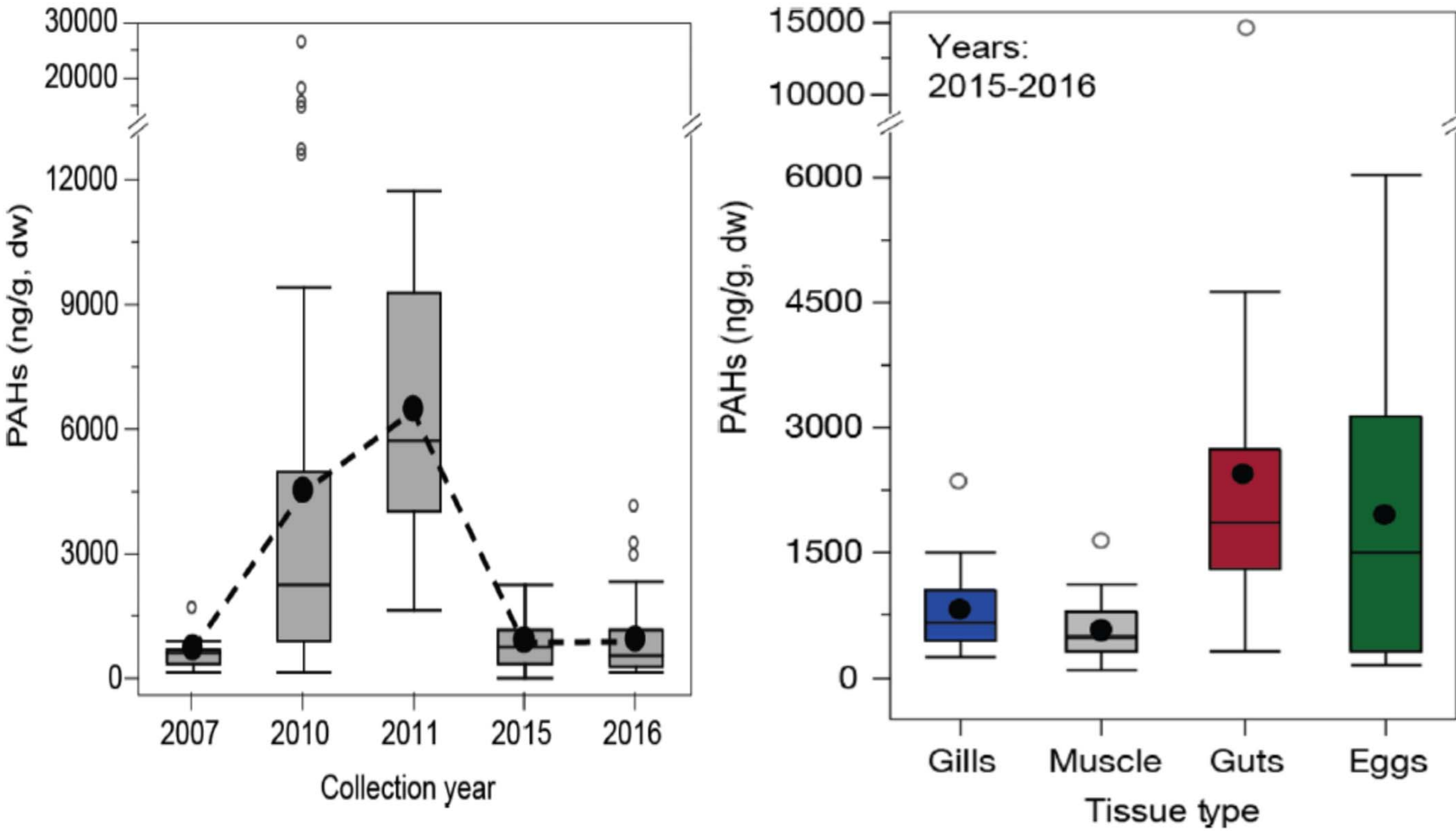


Murawski, S.A., M. Grosell, C. Smith, T. Sutton, K. Halanych, R. Shaw and C.A. Wilson 2021. Ecotoxicology: Impacts of Petroleum, Petroleum Components and Dispersants on Organisms and Populations. Oceanography (in press).

Sutton, T.T., T. Frank, H. Judkins., and I.C. Romero. 2020. As gulf oil extraction goes deeper, who is at risk? community structure, distribution, and connectivity of the deep-pelagic fauna. *In*: Murawski, S.A., et al. (Eds.) *Scenarios and Responses to Future Deep Oil Spills*. Springer (Cham).



Romero,I.C., T. Sutton, B. Carr, E. Quintana-Rizzo, S.W. Ross, D.J. Hollander, and J.J. Torres. 2018. Decadal Assessment of Polycyclic Aromatic Hydrocarbons in Mesopelagic Fishes from the Gulf of Mexico Reveals Exposure to Oil-Derived Sources. Environmental Science &Technology 52: 10985-10996.



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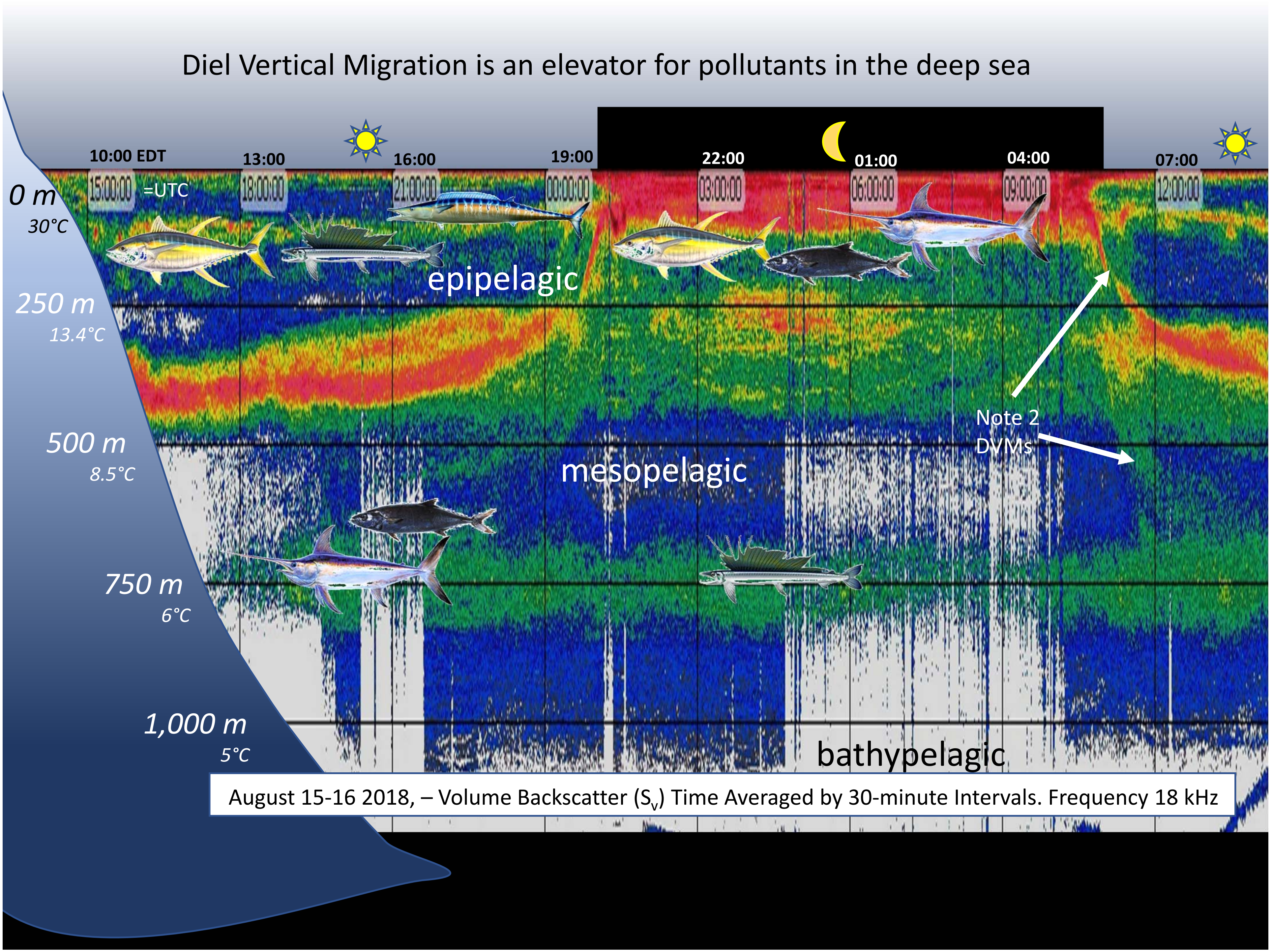

Diel Vertical Migration is an elevator for pollutants in the deep sea
10:00 EDT
13:00
16:00
19:00
22:00
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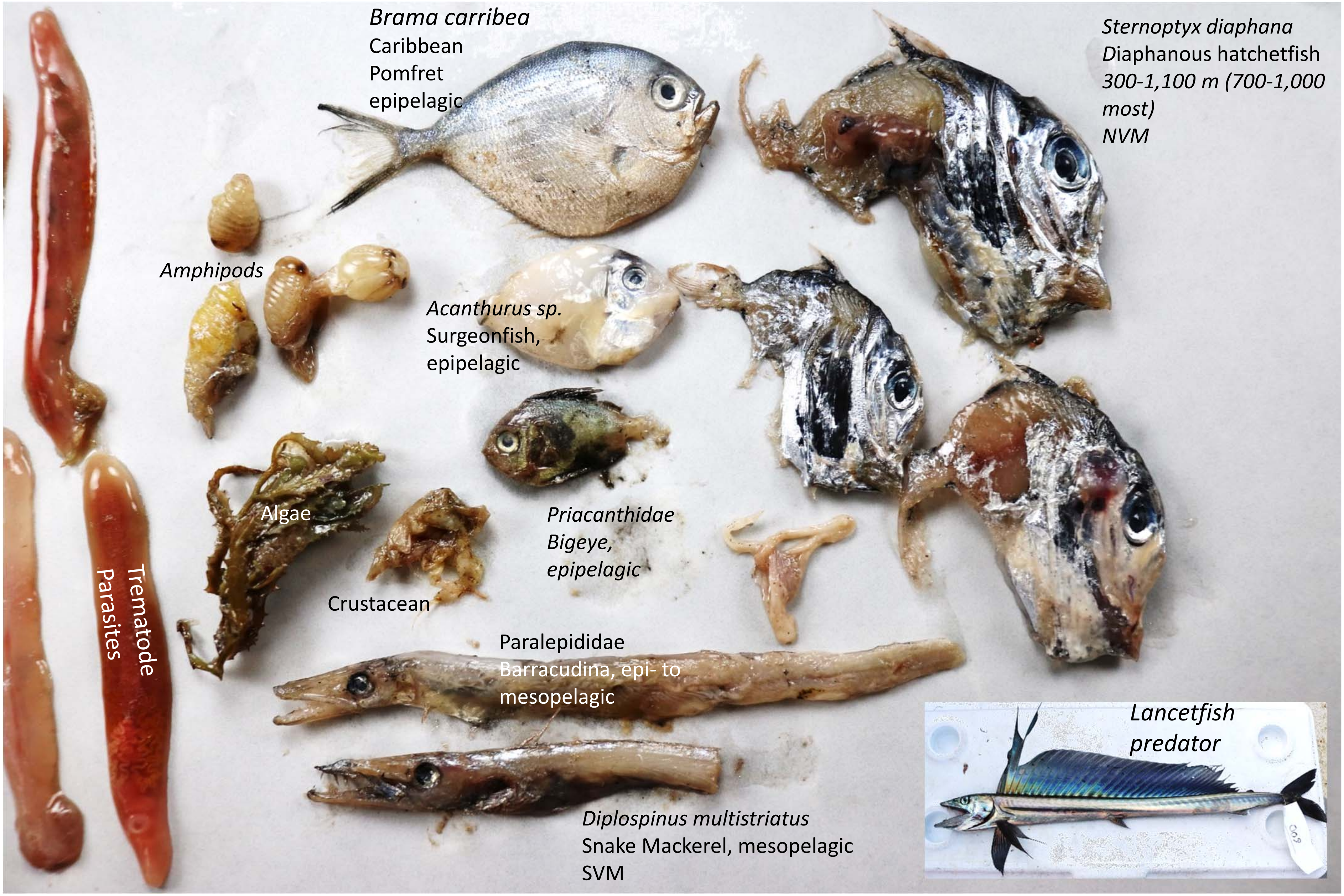
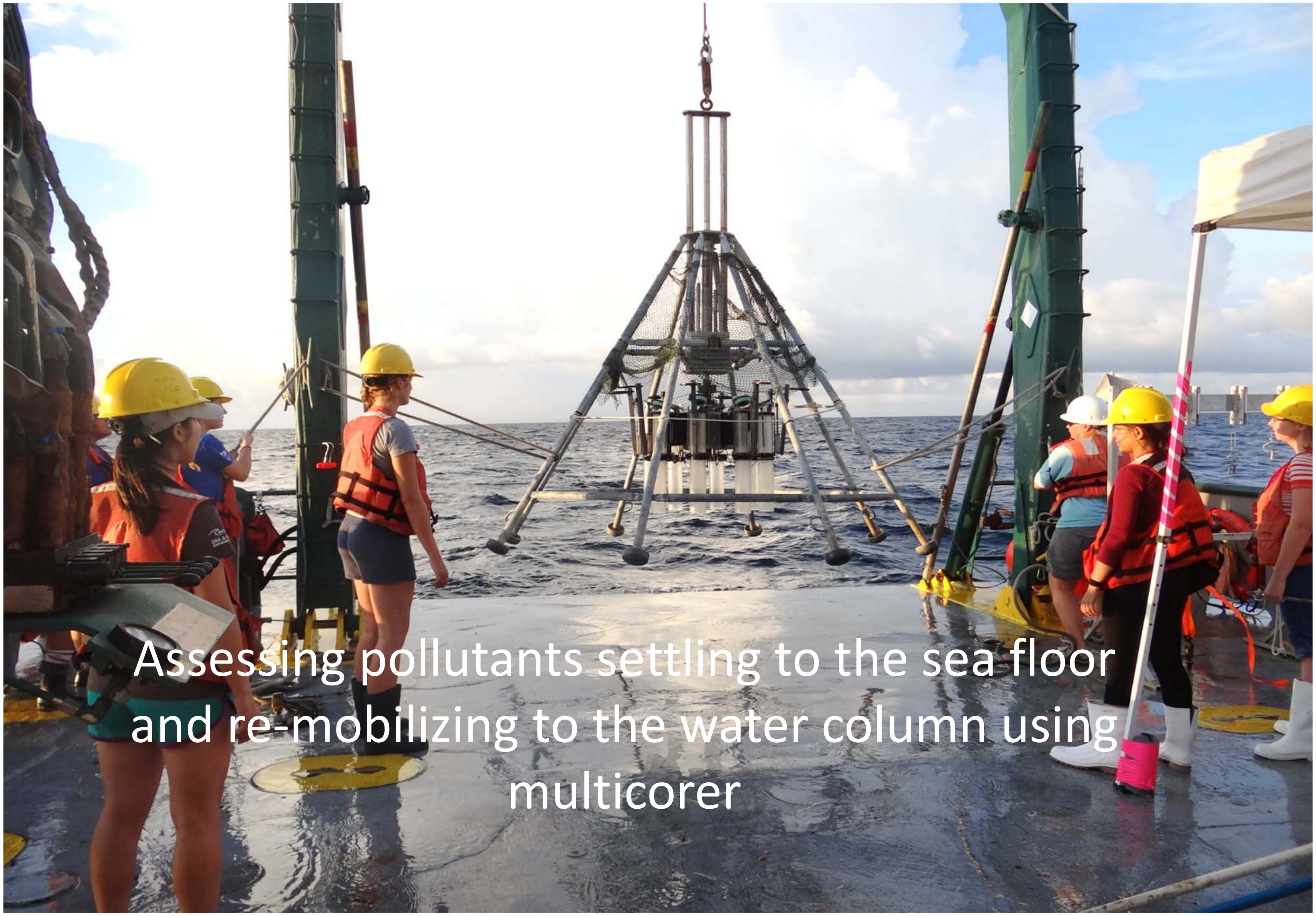
18:00:00
21:00:00
00:00:00
03:00:00
06:00:00
09:00:00
12:00:00
0 m
30°C
250 m
13.4°C
500 m
8.5°C
750 m
6°C
1,000 m
5°C
epipelagic
mesopelagic
bathypelagic
Note 2
DVMs
August 15-16 2018, – Volume Backscatter (S_v) Time Averaged by 30-minute Intervals. Frequency 18 kHz

Food Habits Reveal Interconnected Epi- and Mesopelagic Realms GoM



Deep Benthic Species & Habitats

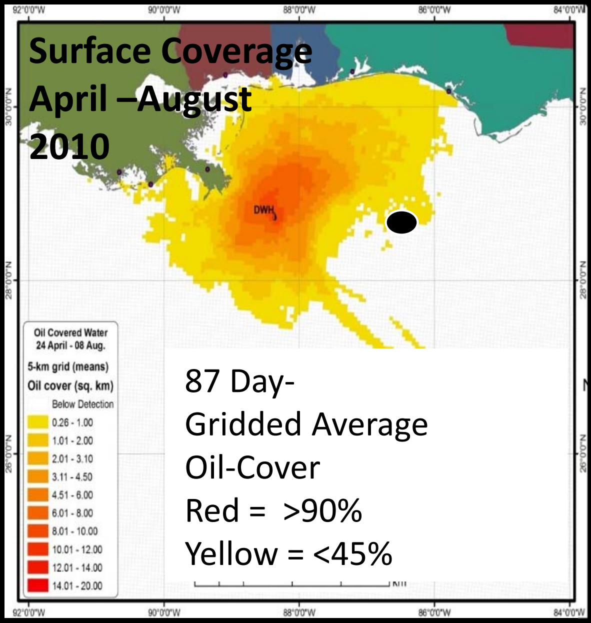


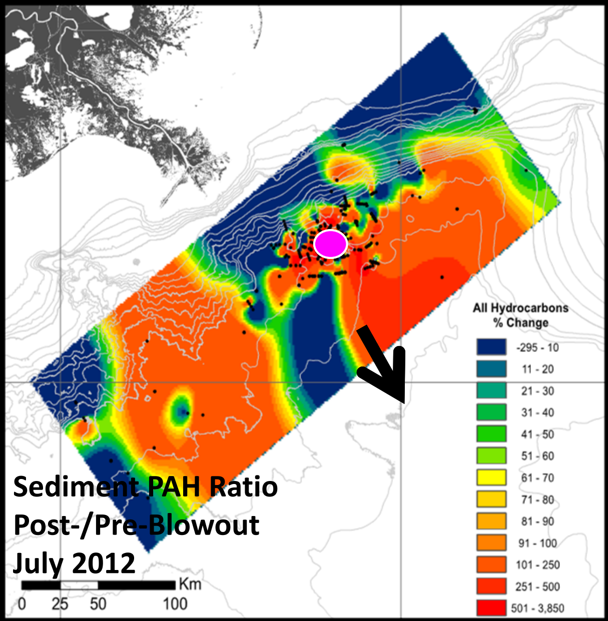
Assessing pollutants settling to the sea floor and re-mobilizing to the water column using multicorer

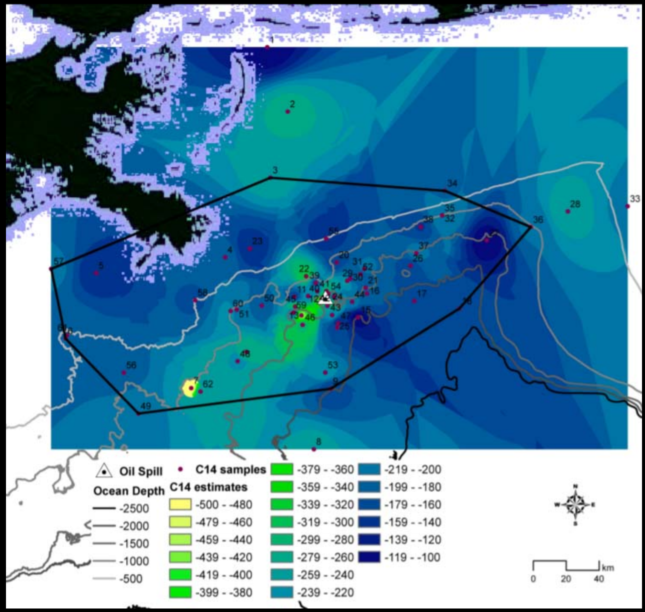
Major Sediment Discoveries Post-DWH

- Significant quantities of oil remain trapped in deep-sea sediments (4-10% of the total oil released to the ocean)

- Spatial & temporal offset between surface oil coverage & "foot-print" of sedimentary oil deposition



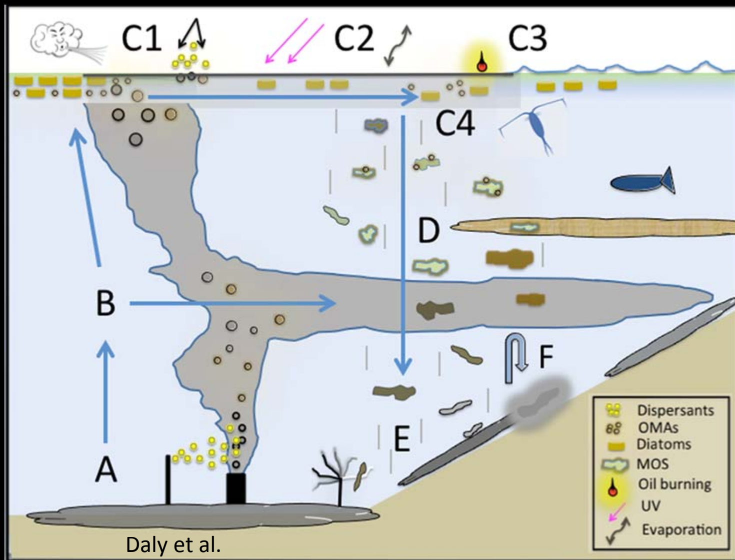




Romero, I. C., G. Toro-Farmer, G., Diercks A-R., Schwing, P., Muller-Karger, F., Murawski, S., *et al.* (2017). Large-scale deposition of weathered oil in the Gulf of Mexico following a deep-water oil spill. *Env. Poll.* 228, 179-189. doi:/10.1016/j.envpol.2017.05.019 0269-749.

Chanton, J.; Zhao, T.; Rosenheim, B.; Joye, S.; Bosman, S.; Brunner, C.; Yeager, K.; Diercks, A.; Hollander, D., Using natural abundance radiocarbon to trace the flux of petrocarbon to the seafloor following the Deepwater Horizon Oil Spill, Environmental Science And Technology, 2015, 49, 847-854.

How did benthic resources get polluted with DWH oil?



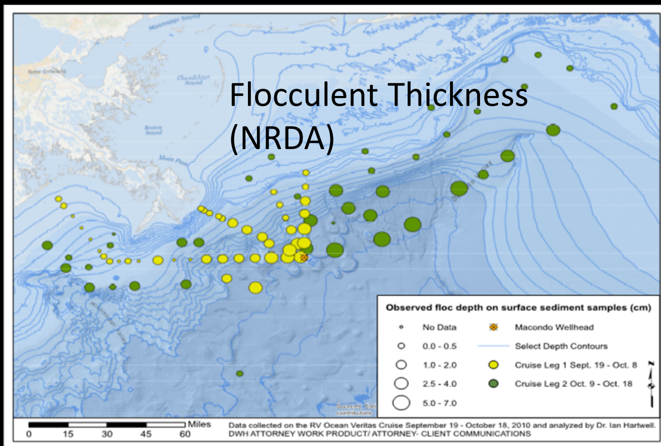
MOSSFA
MARINE OIL SNOW SEDIMENTATION
& FLOCCULENT ACCUMULATION

MOSSFA (D): Enhanced flocculation and sinking of particles containing petrogenic, pyrogenic lithogenic and biologic (organic and inorganic, marine and terrestrial) sources.

Intrusions (B): Direct impingement of hydrocarbons on continental shelf and slope.

Changing sedimentary conditions

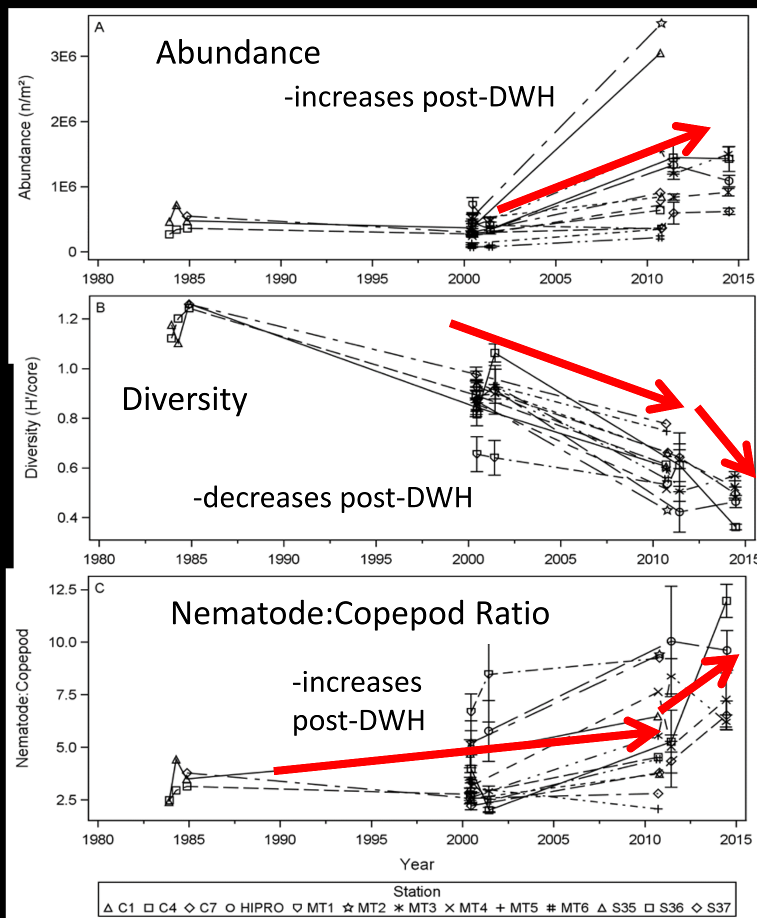
- 4-fold increase in sediment accumulation rates (Brooks et al., 2015)
- Intensification of reducing conditions (less O_2) for three years following DWH (Hastings et al., 2015)
- 2-3 fold increase in polycyclic aromatic hydrocarbon (PAH) concentrations (Romero et al., 2015)
- Resuspension of sedimented particles and oil



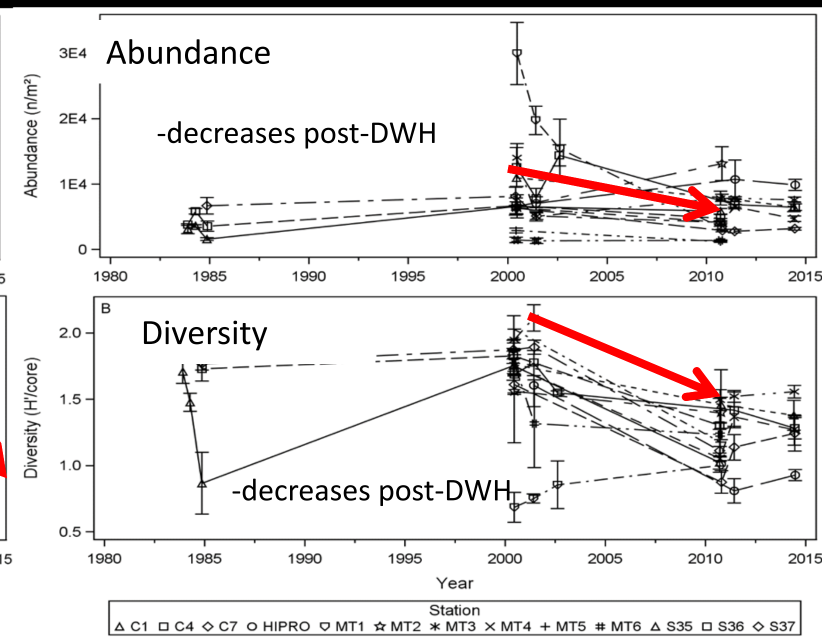
Another "black swan"

Meio- & Macro-fauna: Temporal Trends

Meiofauna



Macrofauna

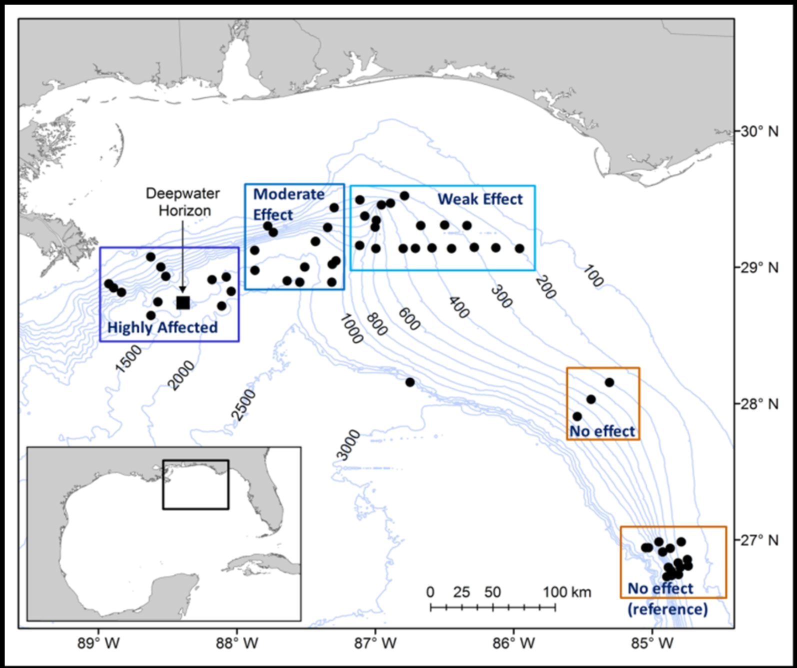


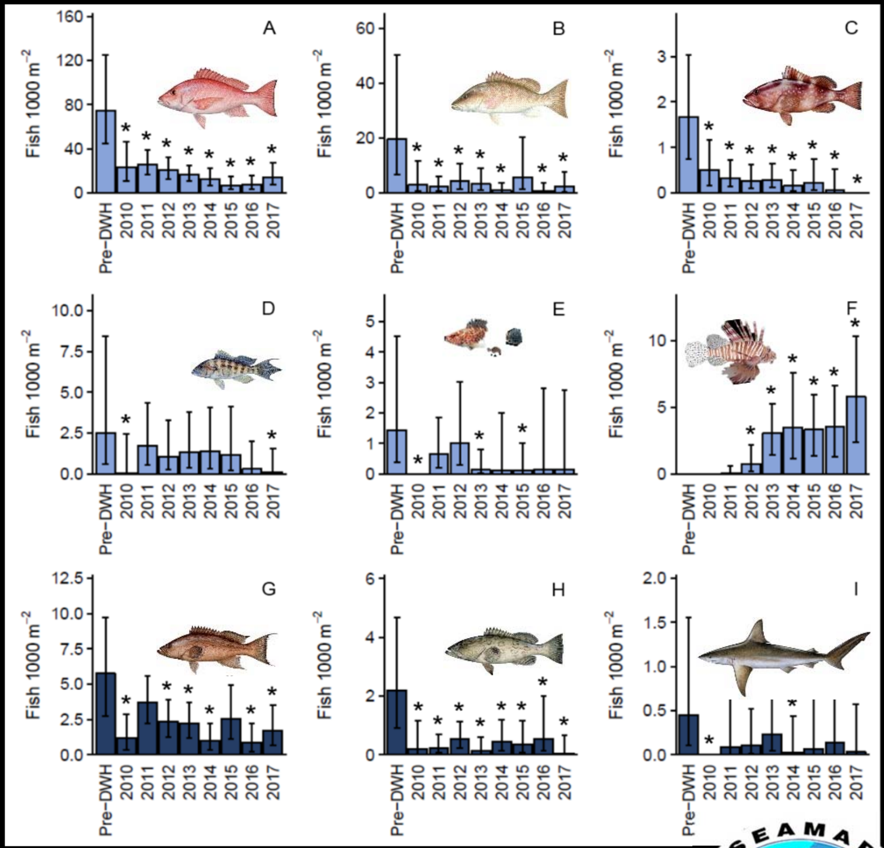
- Meiofauna/Macrofauna: indicative of more disturbed environment post-DWH - CORALS
- FORAMS Rebound in 5-7 years, slower SGoM
- May take 50-100 years to bury the DWH layer below bioturbation depth, achieving full recovery (Montagna et al. 2017).

Schwing PT, Montagna PA, Joye SB, Paris CB, Cordes EE, McClain CR, Kilborn JP and Murawski SA (2020) A Synthesis of Deep Benthic Faunal Impacts and Resilience Following the Deepwater Horizon Oil Spill. Front. Mar. Sci. 7:560012. doi: 10.3389/fmars.2020.560012

Impacts on Continental Shelf Communities

- **Clear evidence of acute exposure**
- **Longer-term exposure evident in some taxa**
- **Some reef community analysis**

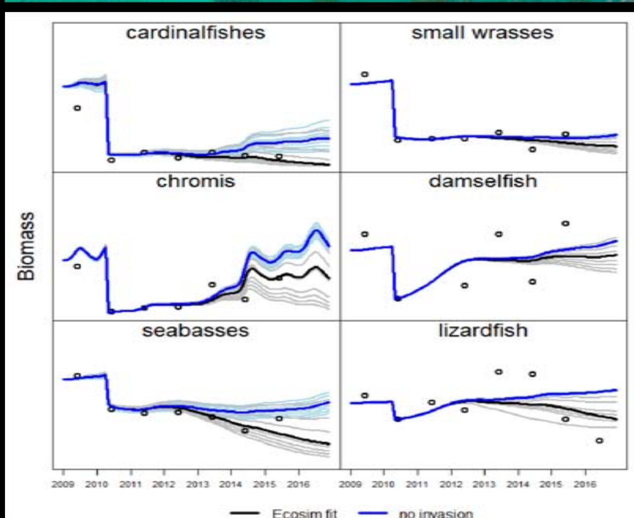


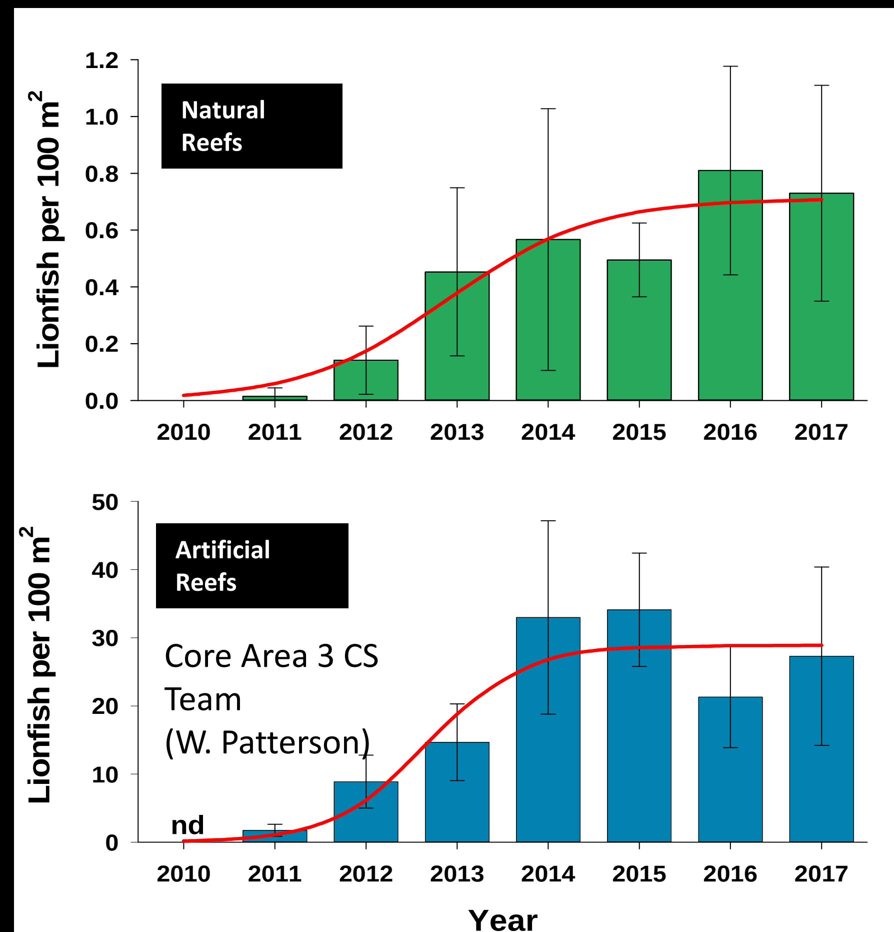


J. Lewis et al. 2020. Changes in Reef Fish Community Structure Following the Deepwater Horizon Oil Spill. Sci. Repts.

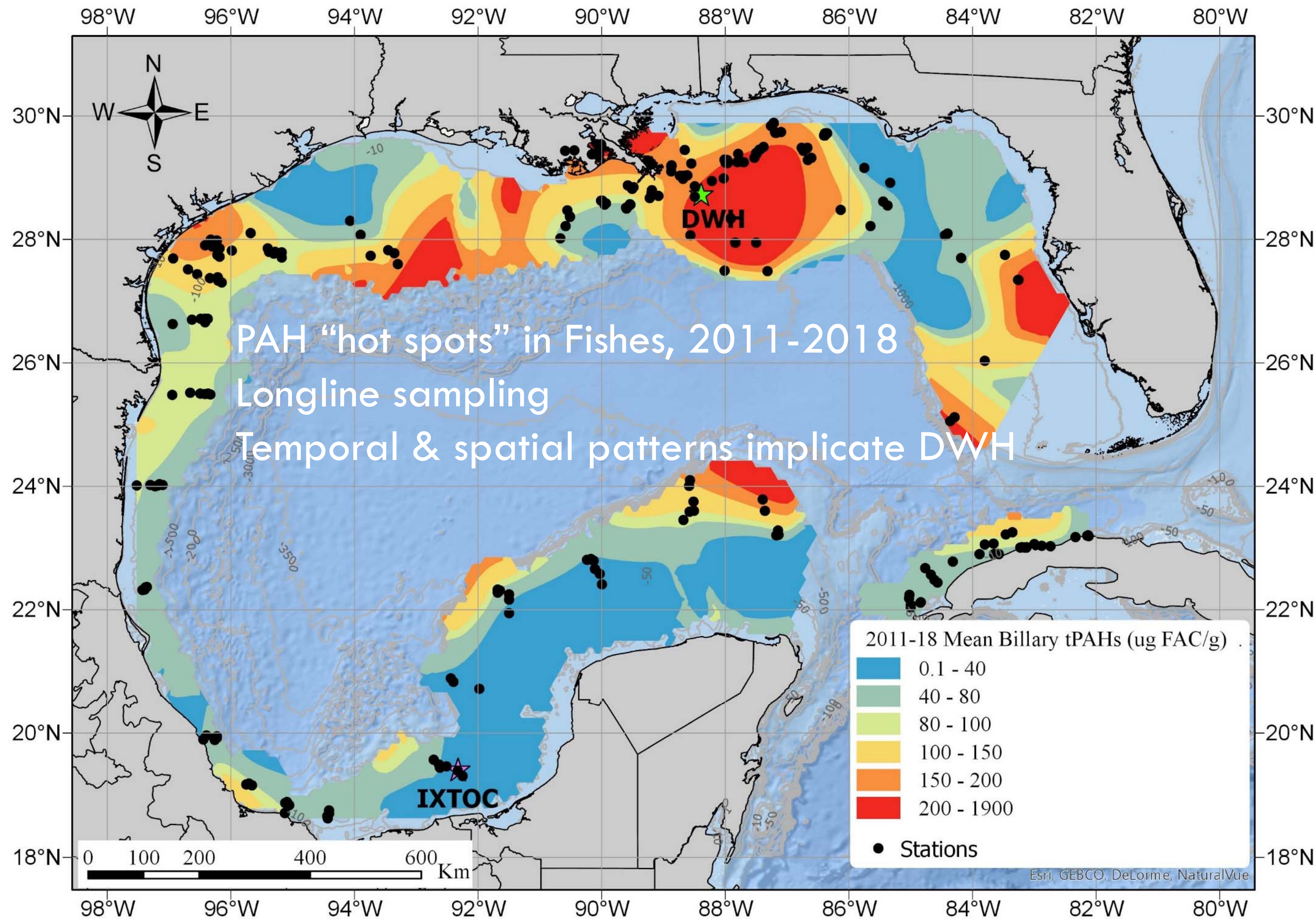
W. Patterson III

Confounding Effects: Lionfish Example

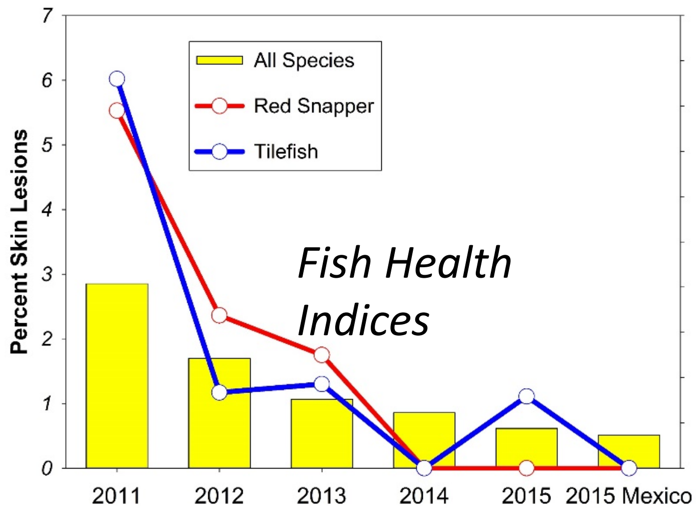


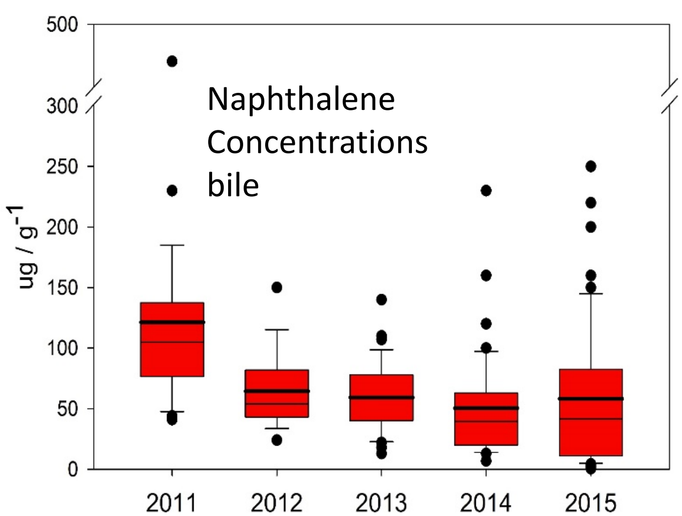


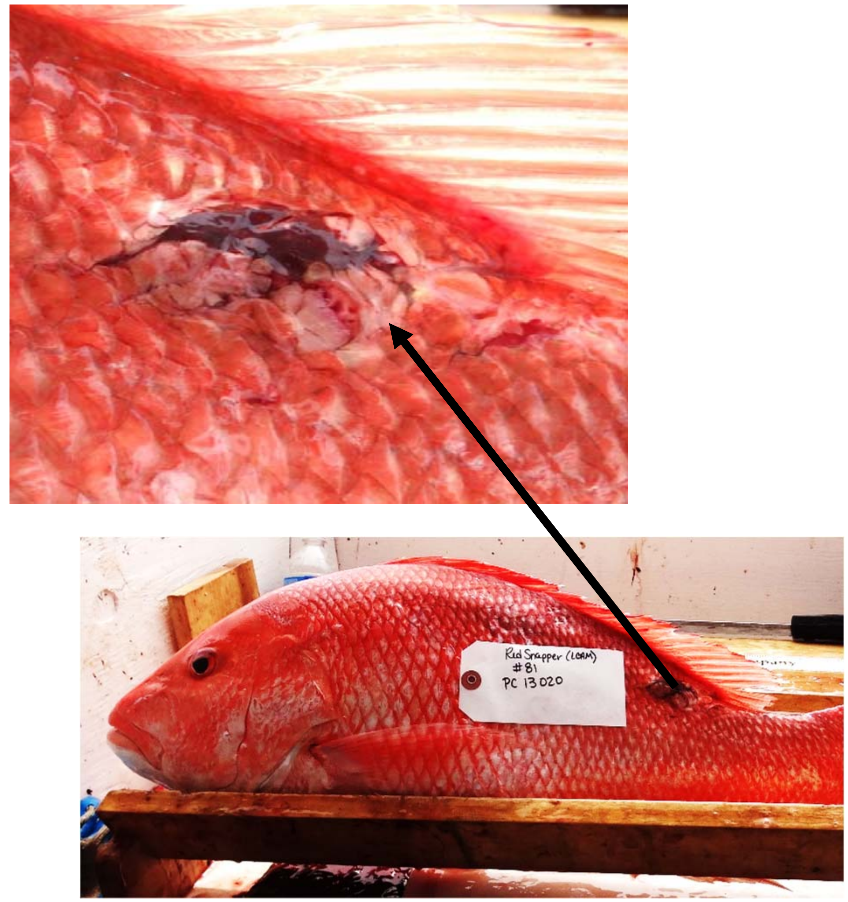
Chagaris, D., S Binion-Rock, A Bogdanoff, K Dahl, J Granneman, H Harris, et al. 2017 An ecosystem-based approach to evaluating impacts and management of invasive lionfish. Fisheries 42 (8), 421-431


PAH “hot spots” in Fishes, 2011-2018
Longline sampling
Temporal & spatial patterns implicate DWH
DWH
IXTOC
N
S
W
E
2011-18 Mean Billary tPAHs (ug FAC/g)
0.1 - 40
40 - 80
80 - 100
100 - 150
150 - 200
200 - 1900
Stations
0 100 200 400 600 Km
98°W
96°W
94°W
92°W
90°W
88°W
86°W
84°W
82°W
80°W
30°N
28°N
26°N
24°N
22°N
20°N
18°N
Esri, GEBCO, DeLorme, NaturalVue

Presence of skin lesions correlated with PAH concentrations in fishes







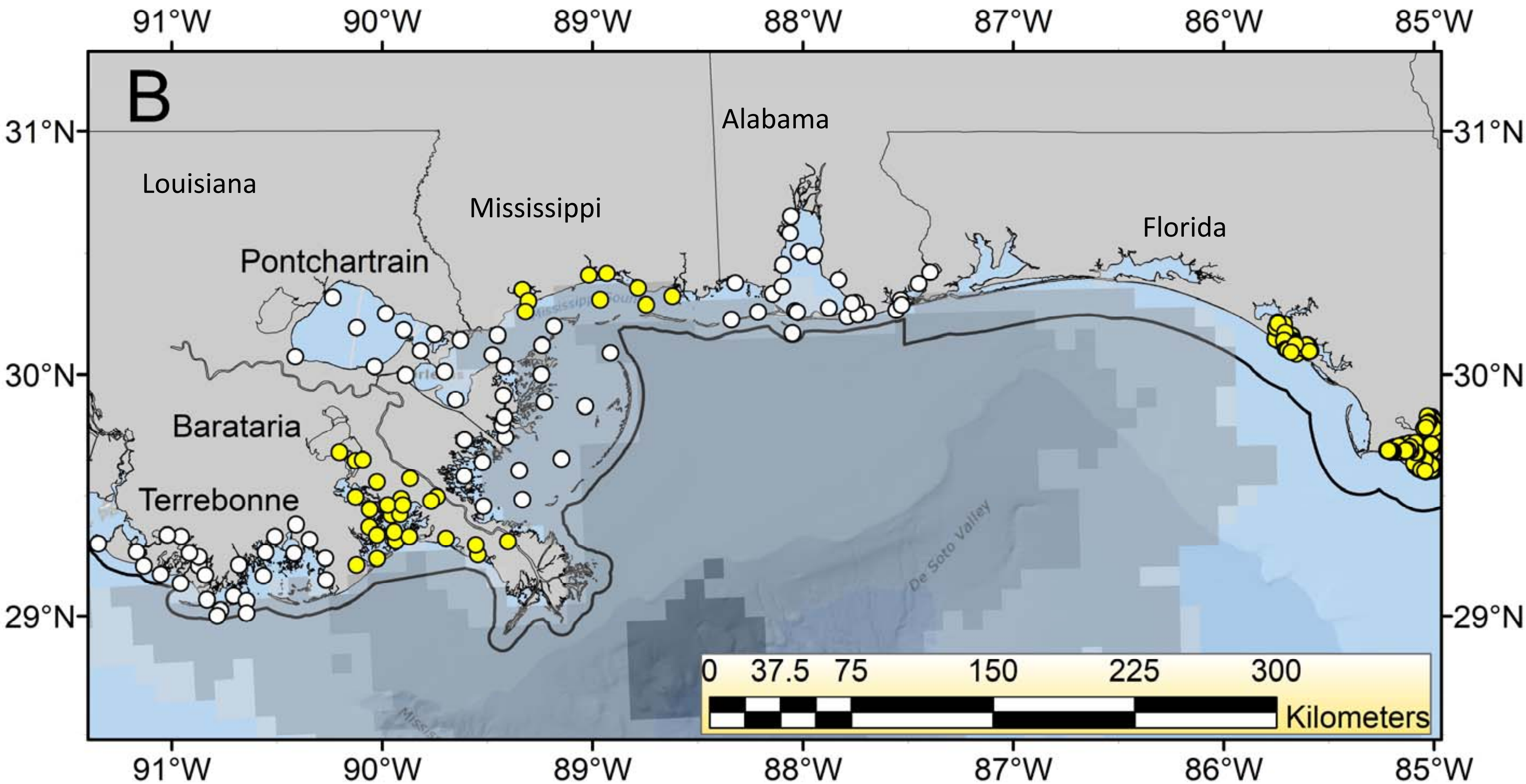
- Importance of “citizen science”
- Mechanism (bacterial immunity) validated in the lab
- Collaboration: GoMRI Centers and Small Investigators

An abundance of long-term & baseline data sources supporting coastal/nearshore assessments

- State-by-state fishery landings, 1950-2019
- Fishery-independent surveys, 1980s to present
  trawl, seine, gill net, oyster diver surveys
- Marine turtle nesting surveys (longest in Florida)
- Marine mammal stranding data (network)
- Marine mammal areal and small boat surveys
- Some bird surveys of mortalities
- NRDA-supported post-DWH surveys & science (P-DARP)
- Institution-specific surveys & analyses (some baselines)

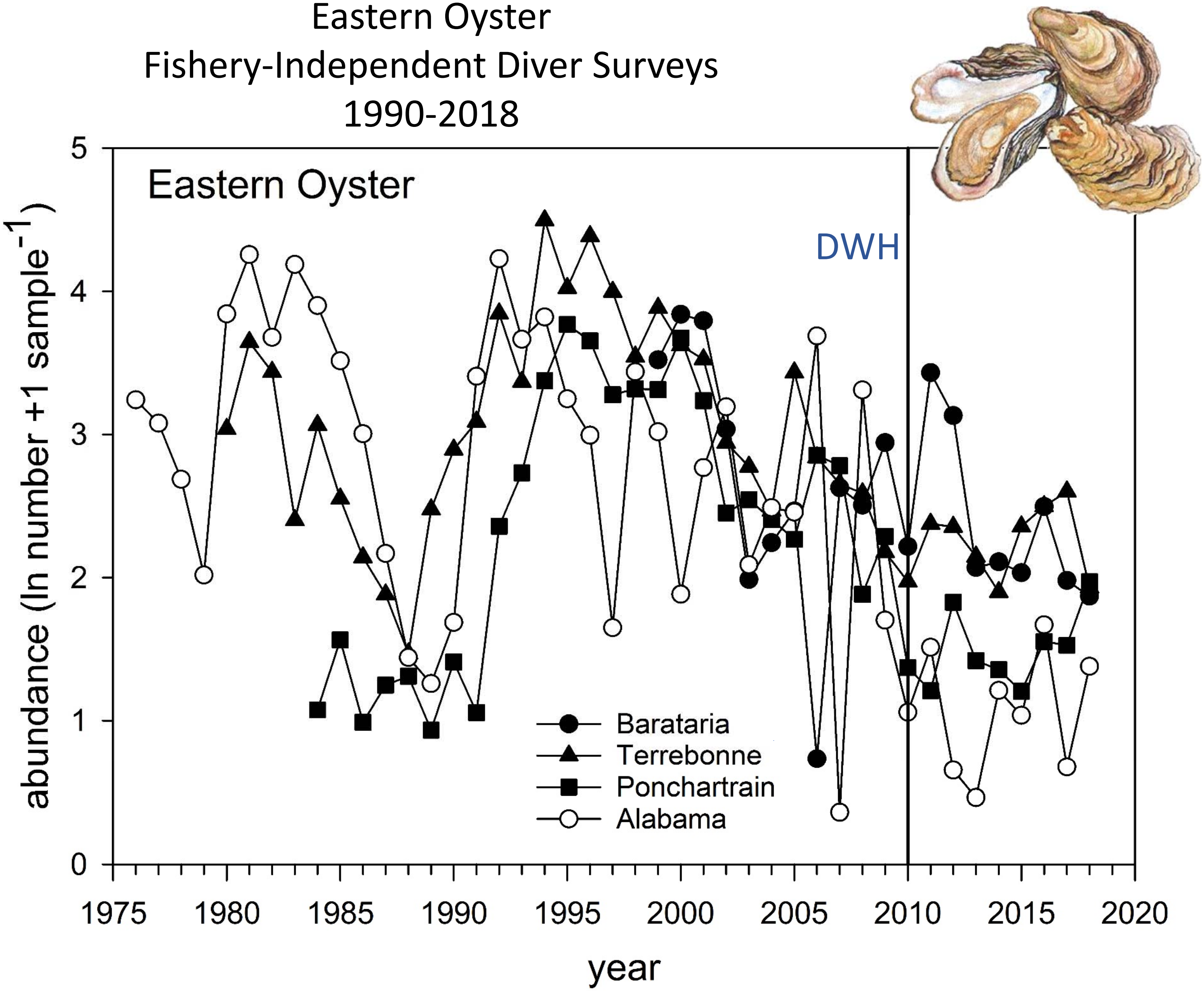
N.B.: Special Edition of MEPS (2017): *Response of nearshore ecosystems to the* Deepwater Horizon *oil spill*, Editors: C.H. Peterson, S.P. Powers, J. Cebrian, K.L. Heck Jr.

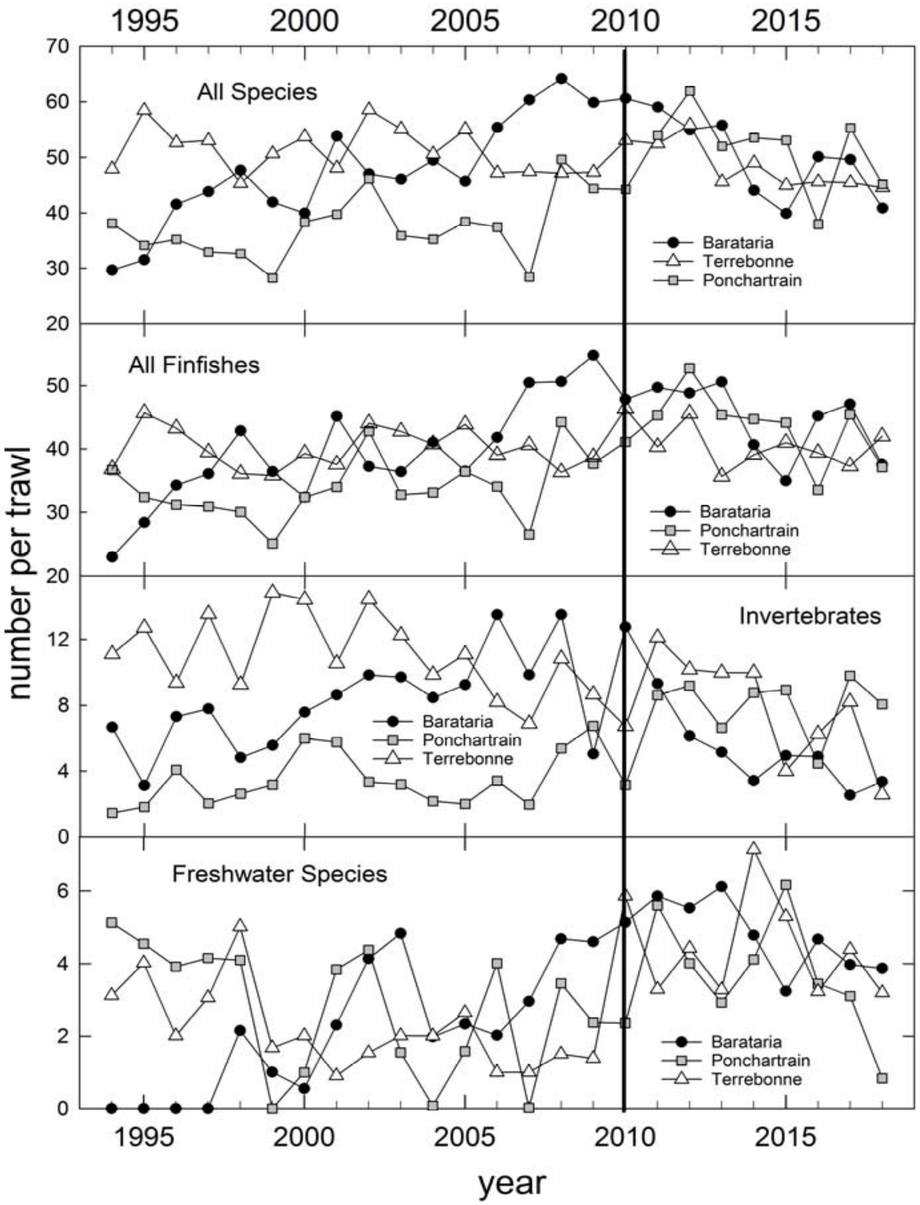
Trawl Survey Time Series by the States: Decades before & After DWH

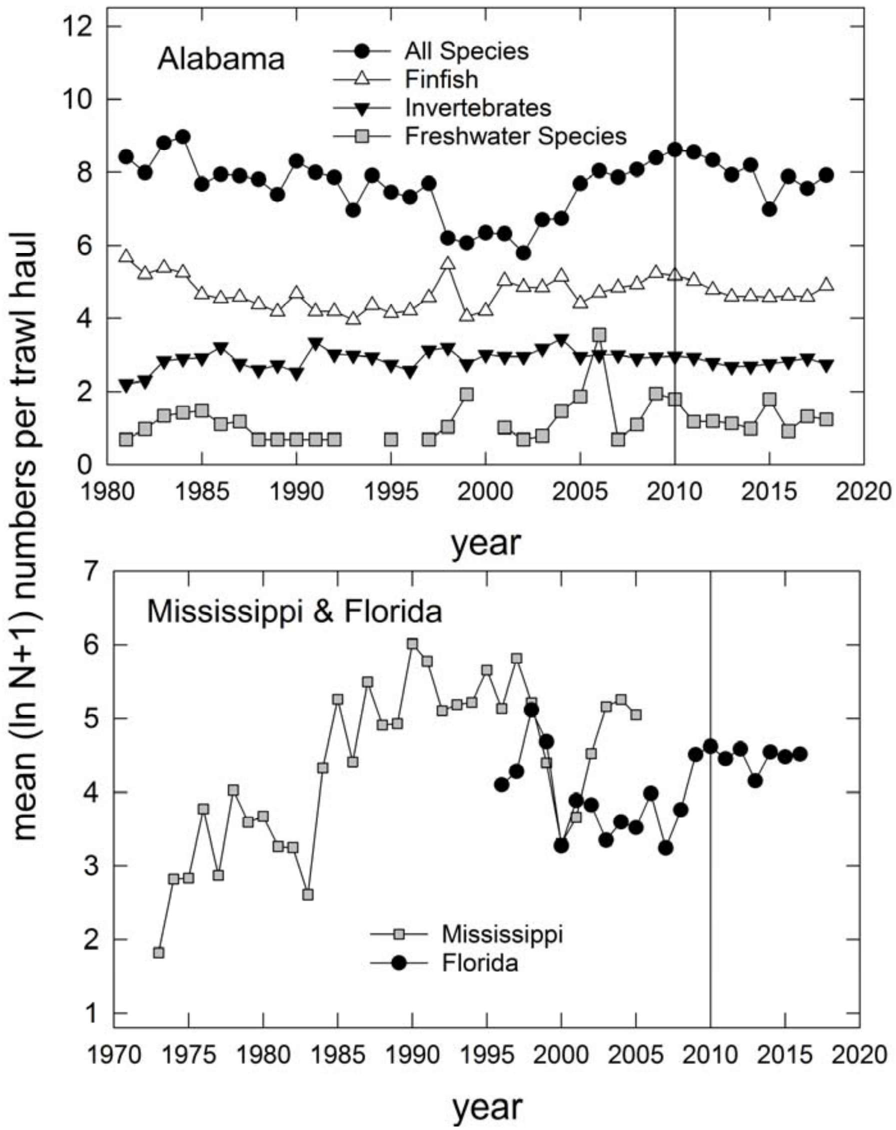


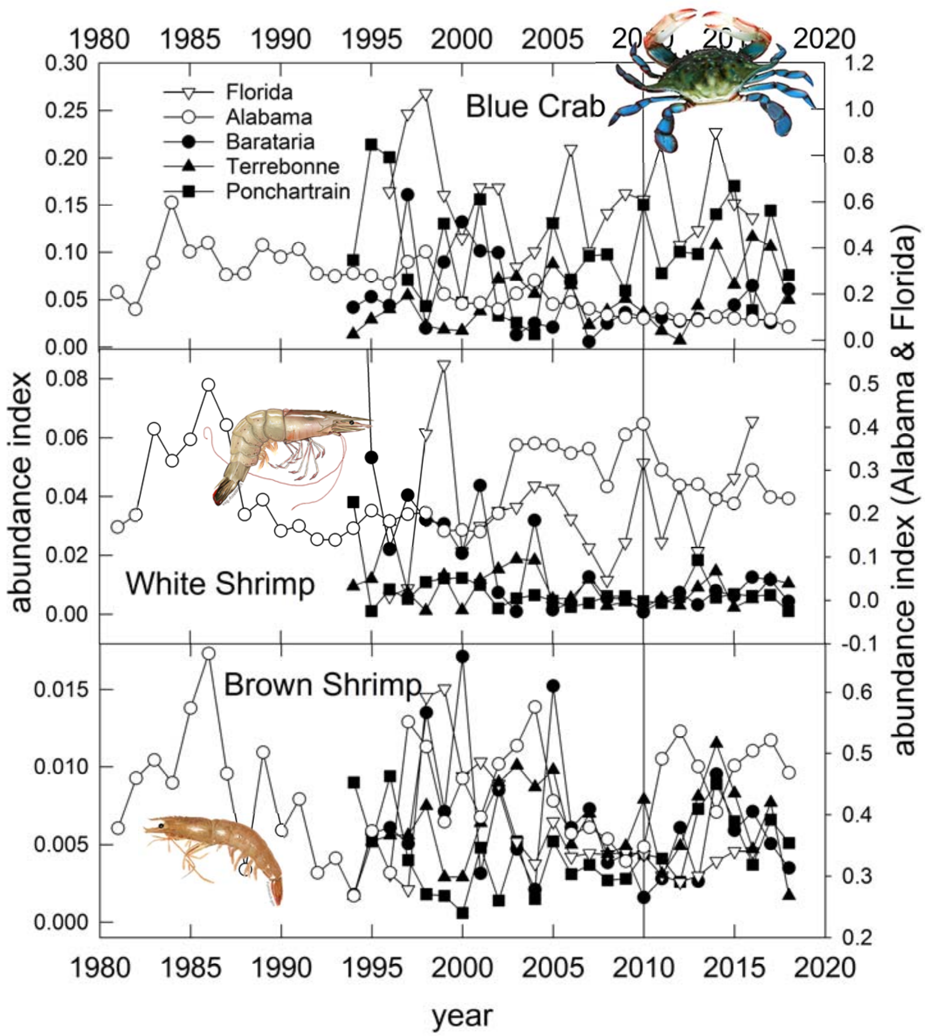
Murawski SA, Kilborn JP, Bejarano AC, Chagaris D, Donaldson D, Hernandez FJ Jr, MacDonald TC, Newton C, Peebles E and Robinson KL (2021) A Synthesis of Deepwater Horizon Impacts on Coastal and Nearshore Living Marine Resources. Front. Mar. Sci. 7:594862. doi: 10.3389/fmars.2020.594862

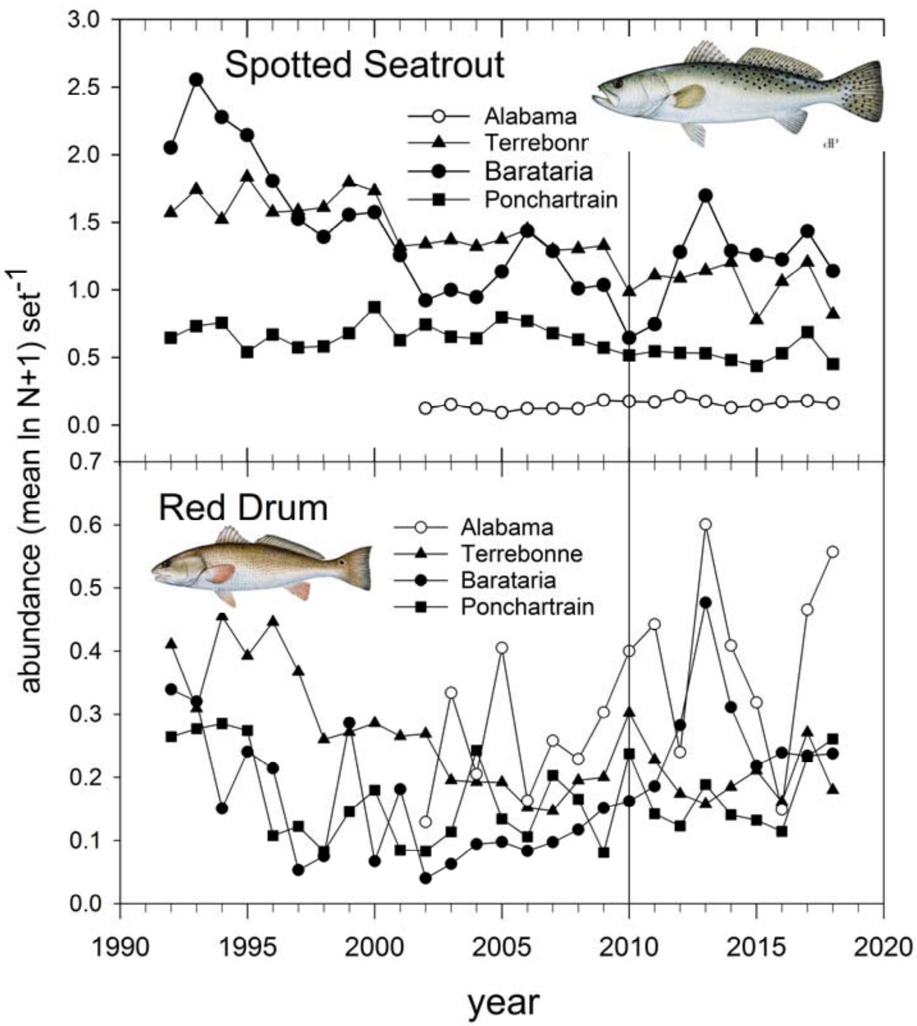
Eastern Oyster
Fishery-Independent Diver Surveys
1990-2018



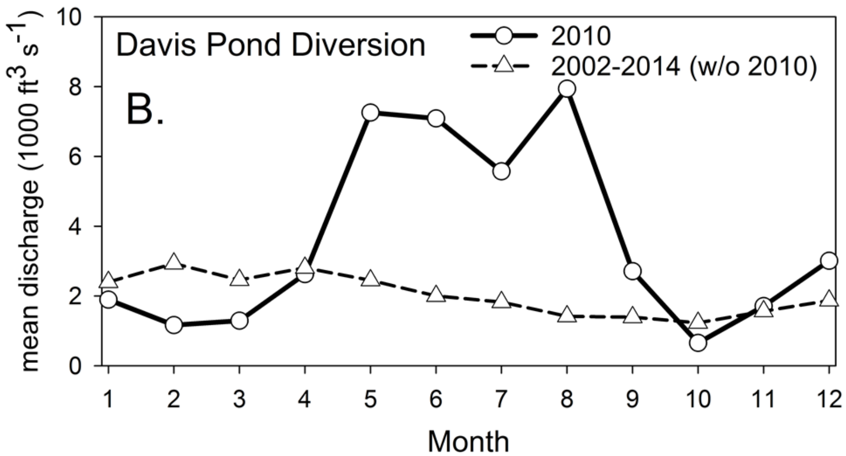

All Species
Barataria
Terrebonne
Ponchartrain
All Finfishes
Invertebrates
Freshwater Species
number per trawl
year

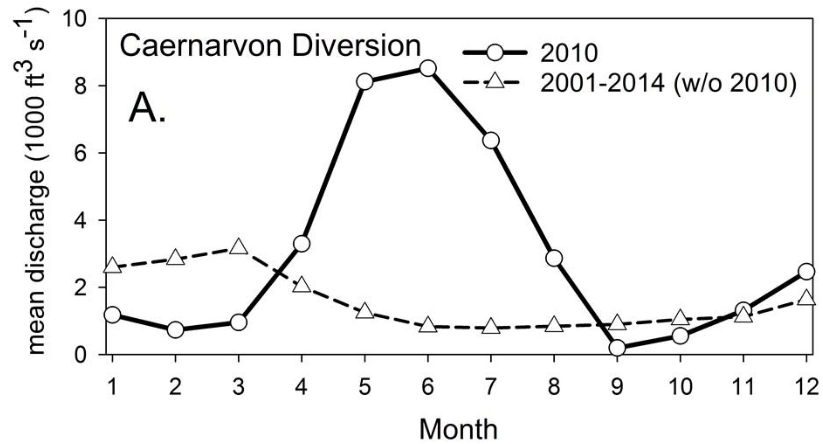

Alabama
All Species
Finfish
Invertebrates
Freshwater Species
Mississippi & Florida
Mississippi
Florida
mean (ln N+1) numbers per trawl haul
year

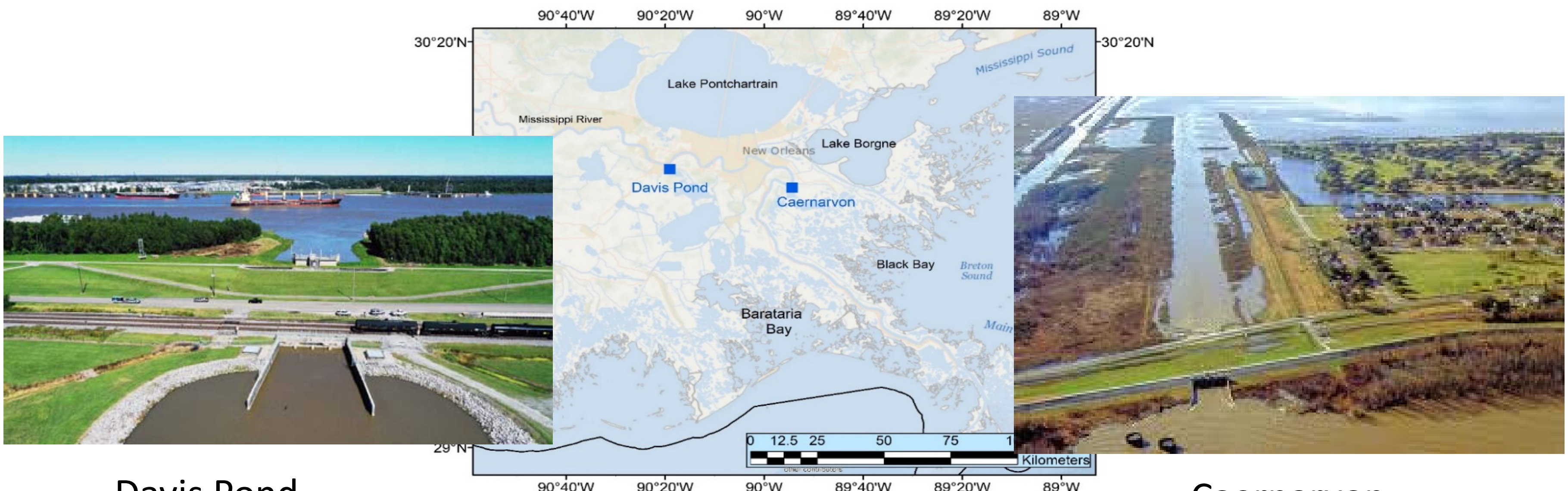

Blue Crab
White Shrimp
Brown Shrimp
Florida
Alabama
Barataria
Terrebonne
Ponchartrain
abundance index
abundance index (Alabama & Florida)
year


Spotted Seatrout
Red Drum
Alabama
Terrebonr
Terrebonne
Barataria
Ponchartrain
abundance (mean ln N+1) set-1
year

Were water diversions successful in preventing oil transiting into estuaries?







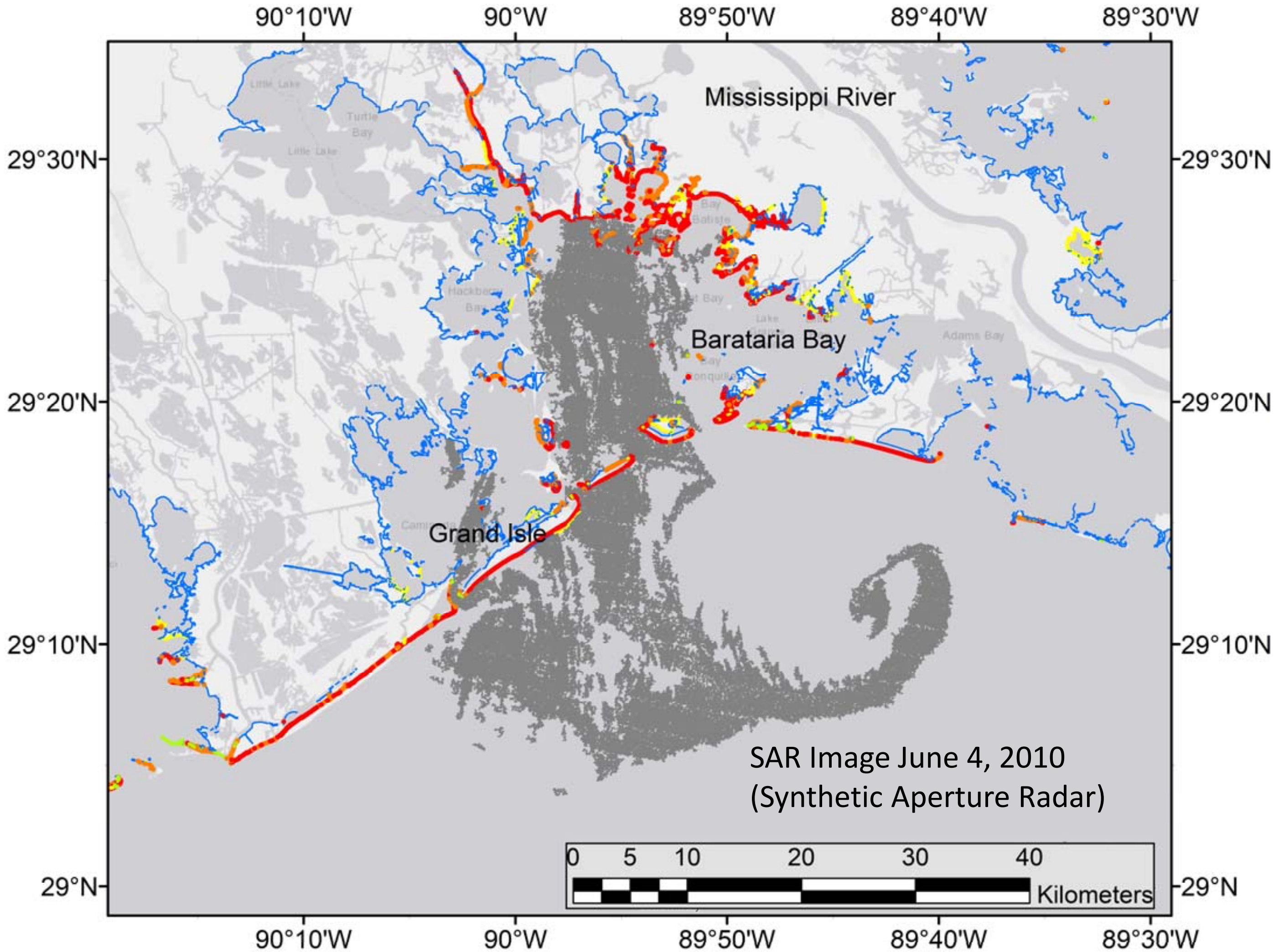
Davis Pond

Caernarvon

NO!

Color codings:
blue= no oiling,
yellow = light,
orange = medium,
red = heavy oiling.

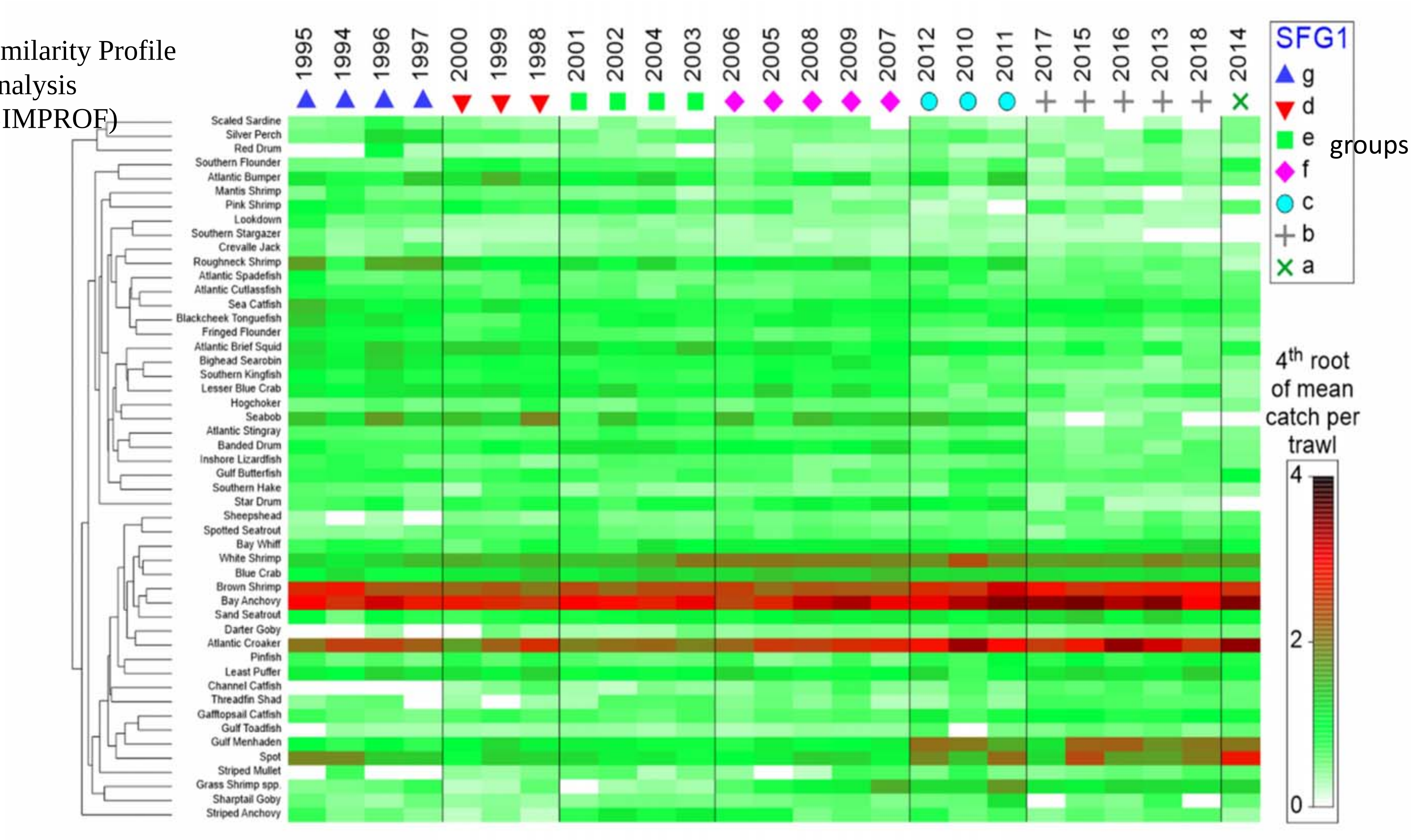
SCAT Sampling

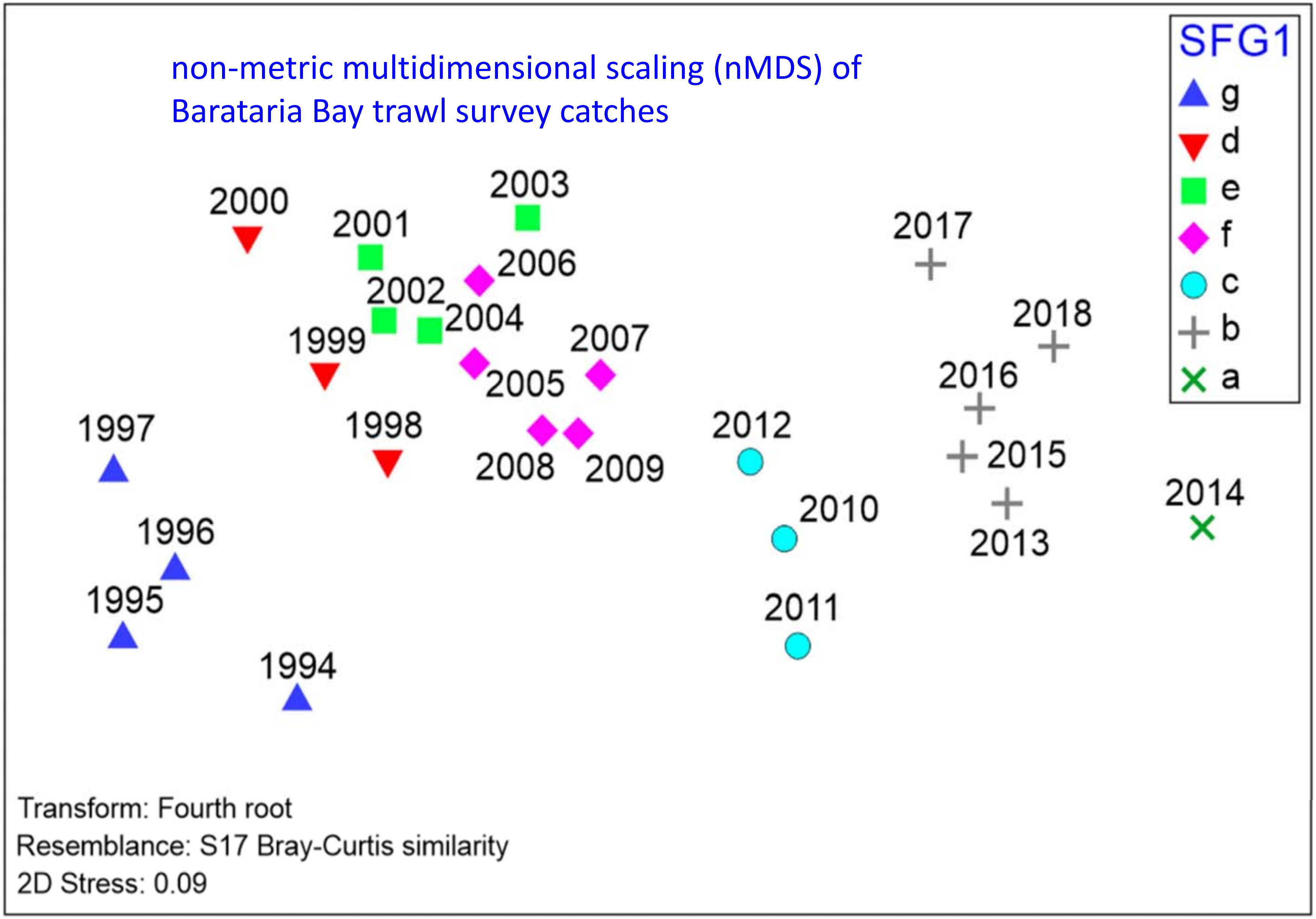


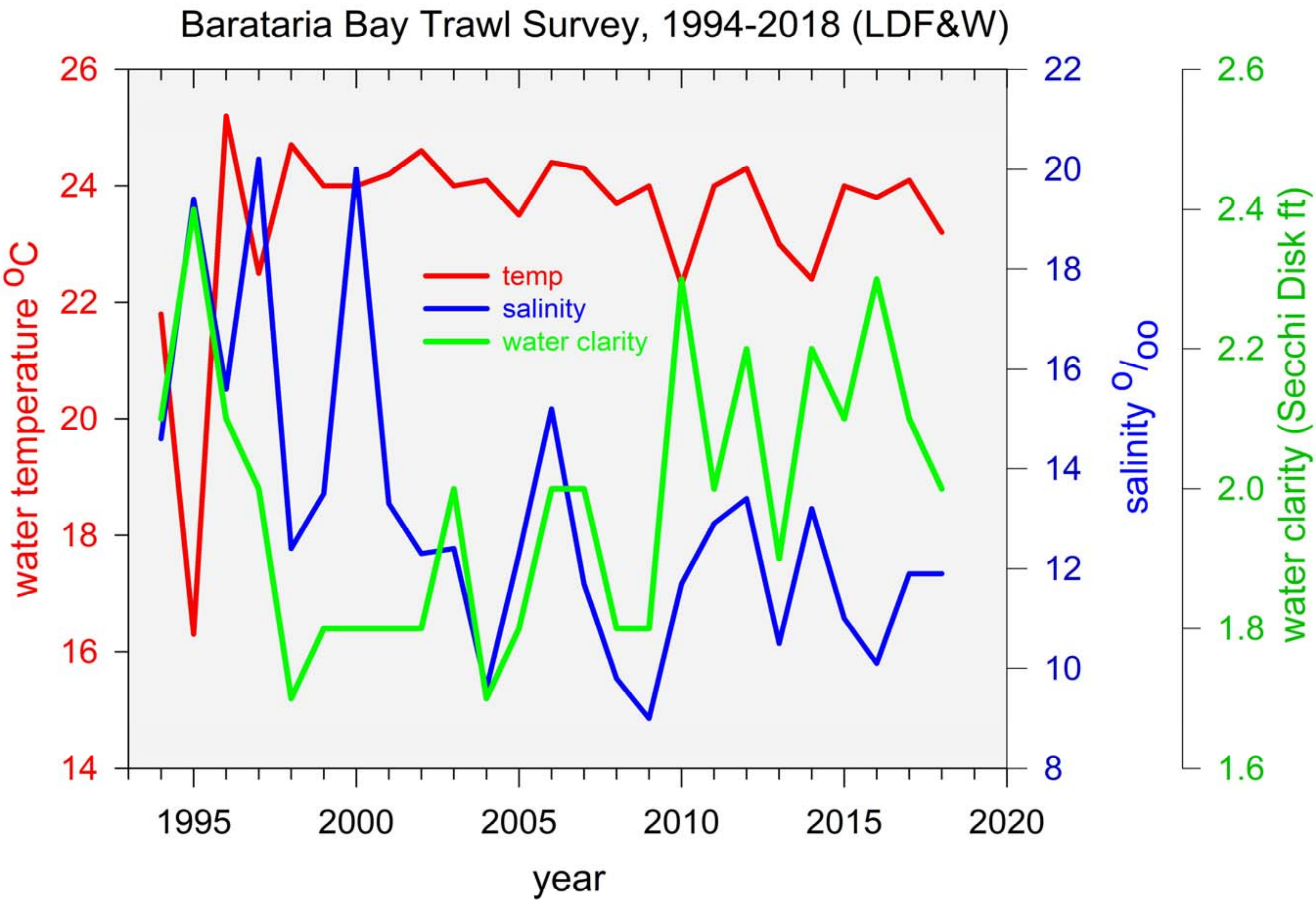
Community-level Responses Post-DWH

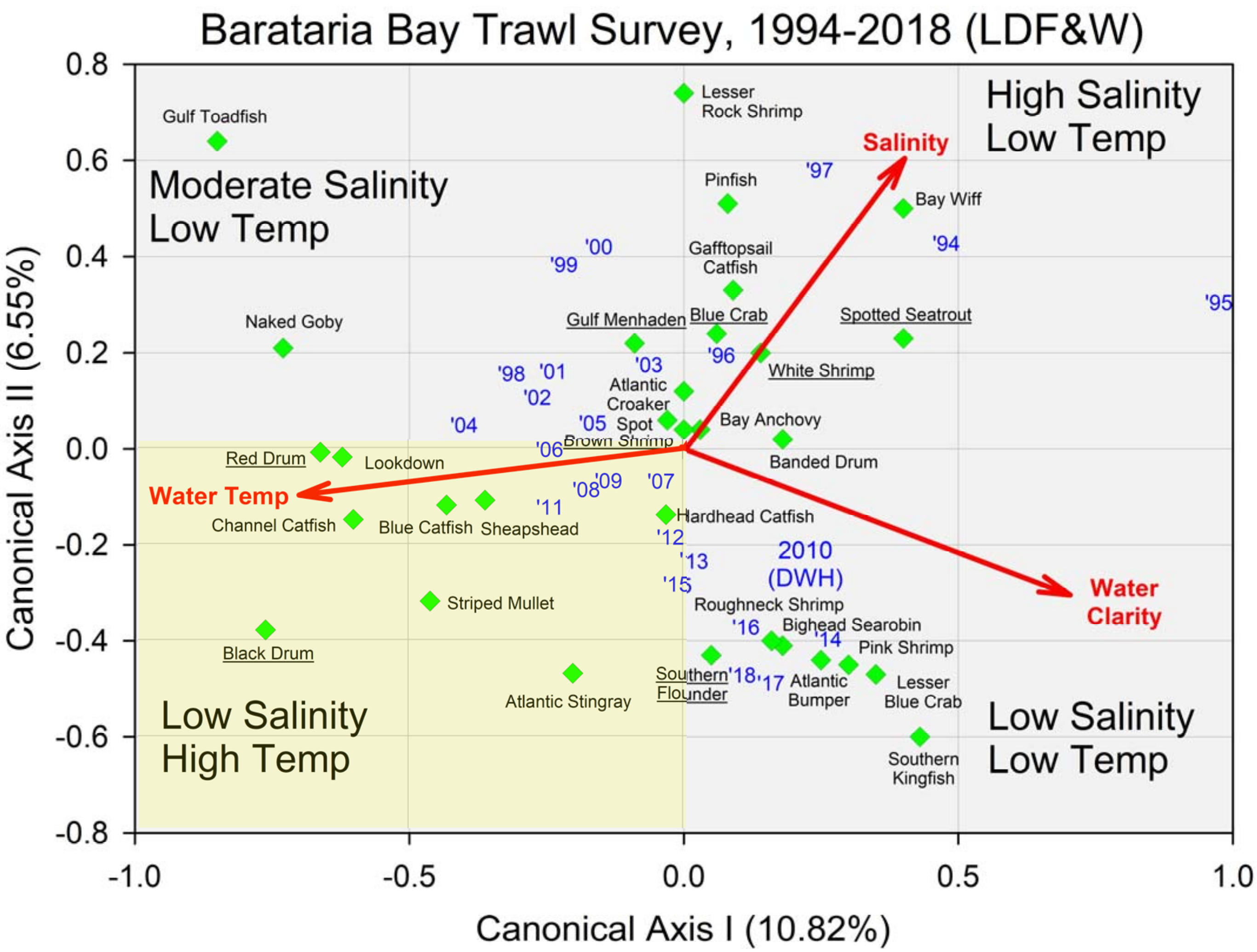
Regime Shift in Barataria Bay Fish and Invertebrate Communities Since DWH

Similarity Profile Analysis (SIMPROF)




non-metric multidimensional scaling (nMDS) of
Barataria Bay trawl survey catches
SFG1
g
d
e
f
c
b
a
2000
2001
2003
2006
2002
2004
1999
2007
2005
1997
1998
2008
2009
2012
2017
2018
2016
2015
2014
2013
2010
1996
1995
2011
1994
Transform: Fourth root
Resemblance: S17 Bray-Curtis similarity
2D Stress: 0.09

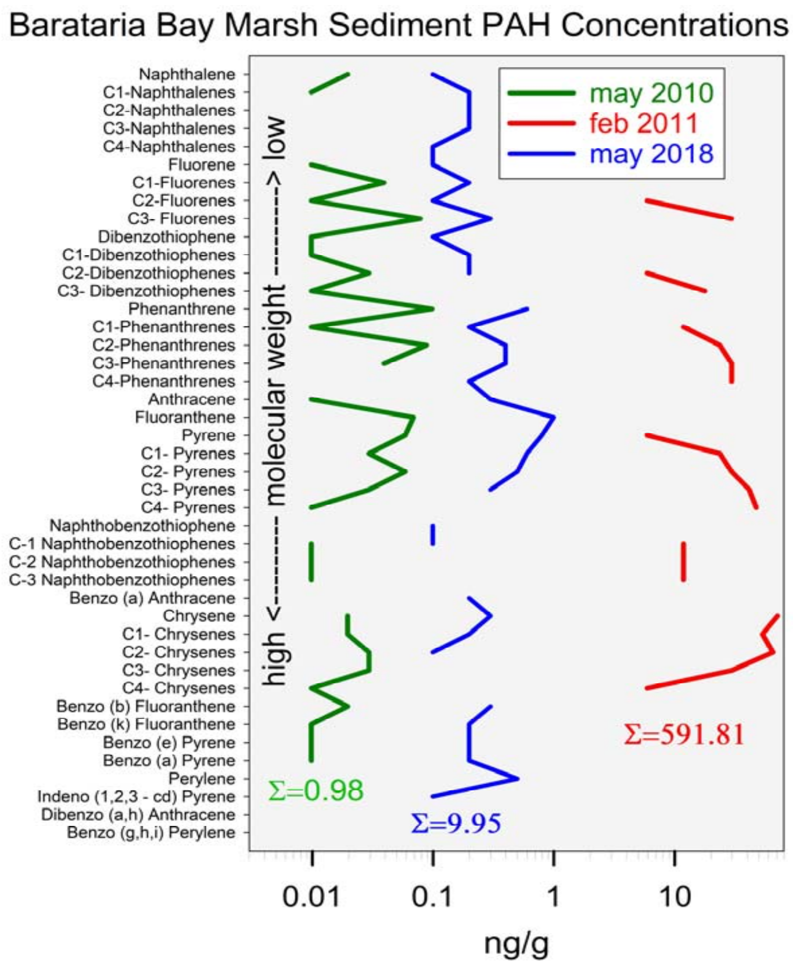

Barataria Bay Trawl Survey, 1994-2018 (LDF&W)
water temperature oC
26
24
22
20
18
16
14
salinity o/oo
22
20
18
16
14
12
10
8
water clarity (Secchi Disk ft)
2.6
2.4
2.2
2.0
1.8
1.6
temp
salinity
water clarity
1995
2000
2005
2010
2015
2020
year



Redundancy Analysis (RDA)

Relates environmental drivers to response variables

How Rapidly is Oil Weathering in Coastal Areas?



What we assumed then	What we know now
Oil disappears rapidly	**Aerobic Weathering of Aromatics occurs rapidly ½ life < 1 wk** **Oil persists at certain locations with only modest weathering for at least 8 years** **Once anaerobic, little to no degradation**
Single oiling event	**multiple, and continuous oiling**

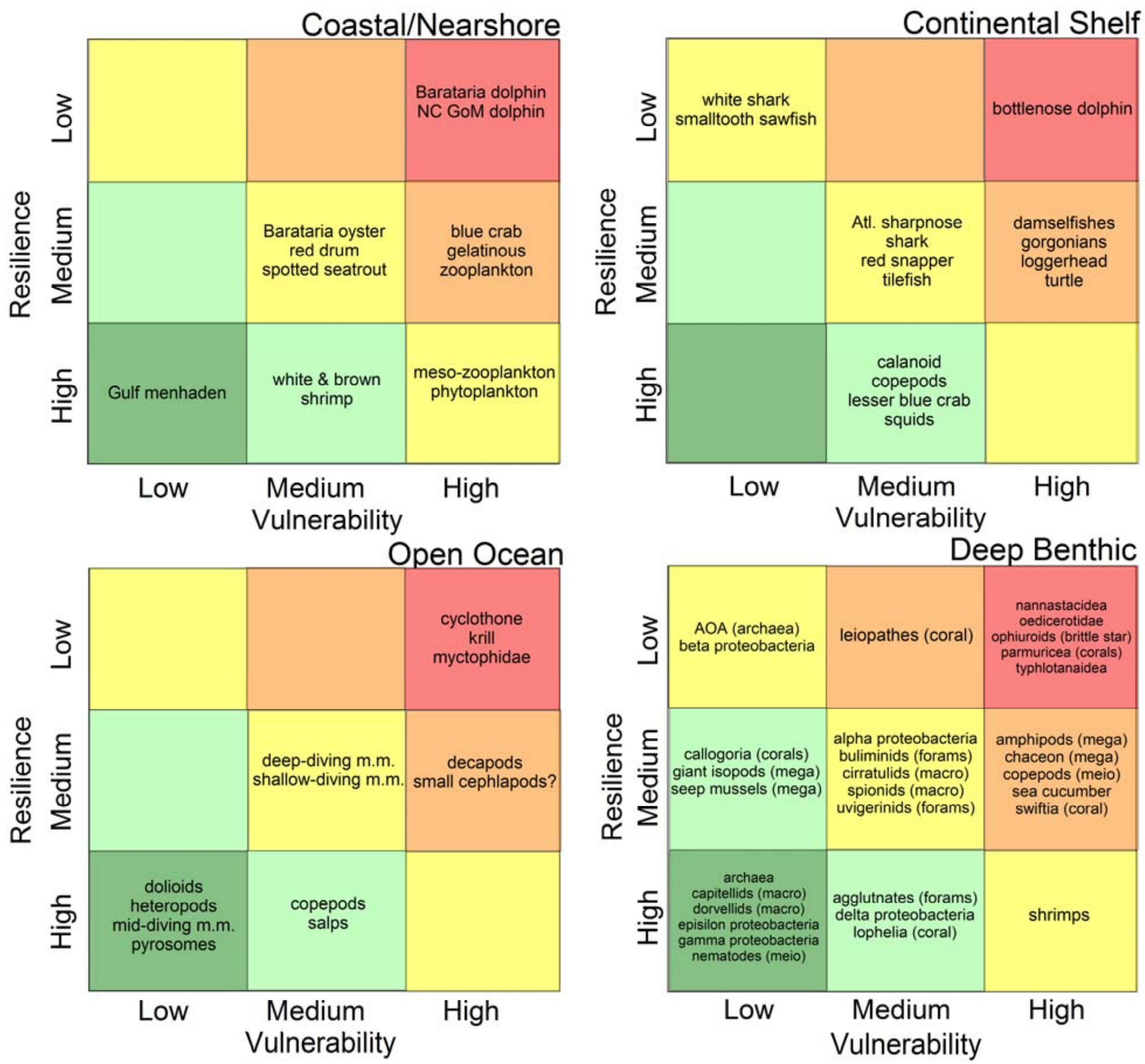
Turner, R.E., N.N. Rabalais, E.B. Overton, et al. 2019. Oiling of the continental shelf and coastal marshes over eight years after the *Deepwater Horizon* oil spill. Environmental Pollution 252.

Vulnerability-Resilience Analyses of "Key" Species in all Ecotypes

Attribute	Vulnerability to DWH	Resilience
1	Ontogenetic shifts in habitat specificity	Abundance (relative to carrying capacity, K)
2	Ability to detect and respond to (avoid) hydrocarbons	Life span
3	Site fidelity	Age at first reproduction
4	Spatial/temporal (horizontal and vertical distribution) overlap of population with toxic exposures	Frequency/timing of spawning/reproduction
5	Exposure vectors (inhalation-aspiration, ingestion, prey, dermal) relevant to species	Fecundity
6	Duration and frequency of acute/chronic exposure (persistence)	Adult dispersal/larval life span
7	Sensitive life stages present	Modularity/connectivity with other ecosystem regions
8	Detoxifying capacity and tolerance of exposure (e.g., depuration rates)	Level of population depletion and changes in density-dependent population demographics due to injury
9	Sensitivity to management interventions (moving turtle nests, cleaning birds, fishery closures)	Potential for regime shifts or alternative stable states
10	Sensitivity to oil spill countermeasures (freshwater, dispersants, sand berms, burning)	Co-varying stressors (fishing, climate change, HABS, other pollutants, pathogens)
11	Effects on trophically-linked resources	Capacity of restoration approaches to be effective.
12	Degree of diet specificity (e.g., specialist or generalist?)	
13	Pre-exposure condition of population (physiology/adaptability)	

Vulnerability/Resilience Analysis - V/R

Q: are there more vulnerable or resilient ecotypes?



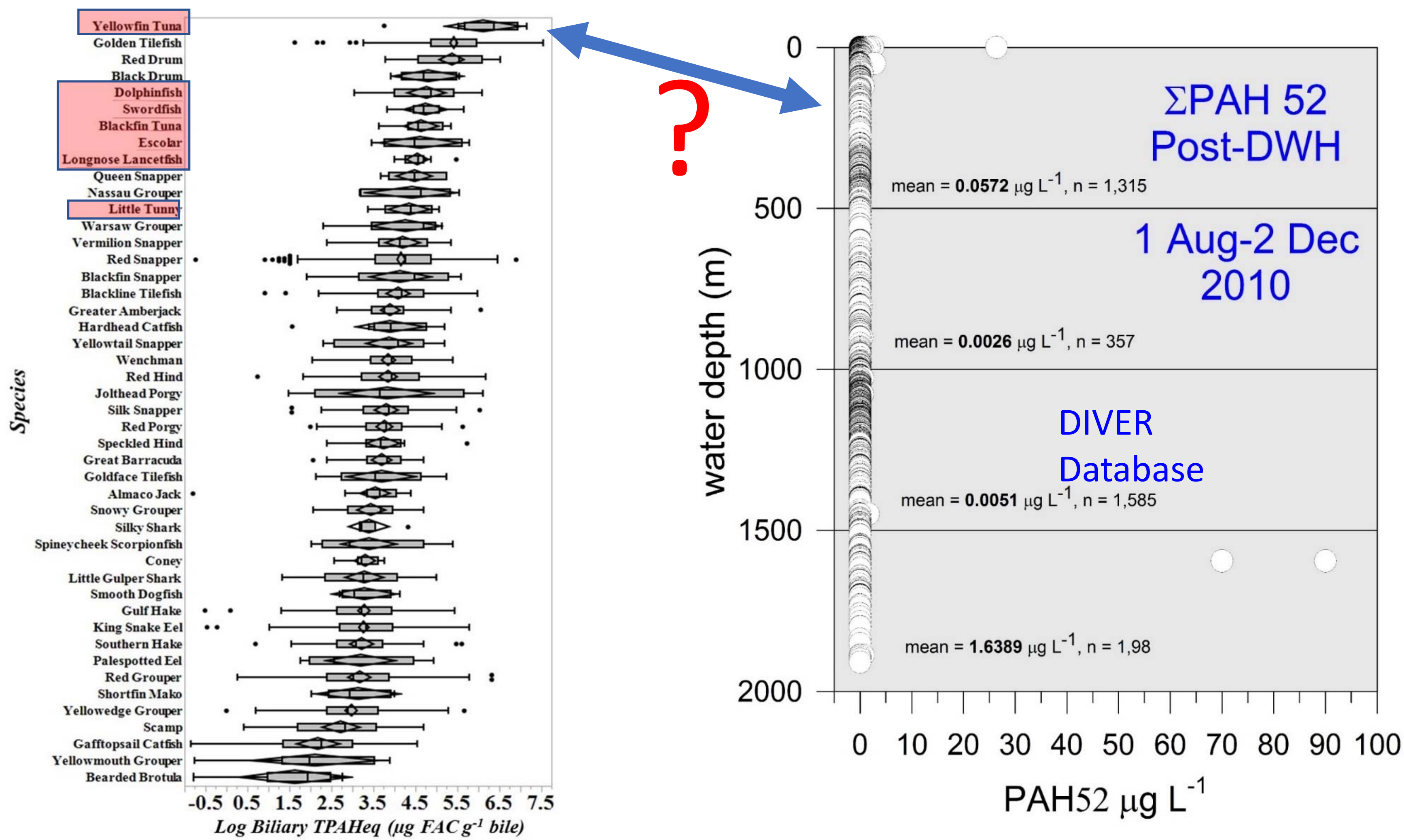
Conclusions from Field Monitoring…..

- Four major interconnected "ecotypes" (= habitats) exhibited a wide array of impacts to species and communities of organisms, ranging from trivial to catastrophic, *and unknown,*
- Even 10+ years subsequent to DWH, many affected resources have not fully recovered and recovery times for some may range from decades to perhaps a century or more or *will not recover; some ecosystem tipping points are exceeded, and we are faced with emerging global co-stressors,*
- Nearshore resources, in particular, were significantly impacted by a combination of the oil spill and *various spill countermeasures* that were deployed, some of which may have had more consequential negative impacts than the oil contamination itself,
- Long time series data for the coastal/inshore and continental shelf areas allow contextualizing spill effects with trends in other drivers such as fishing pressure, invasive species and climate change/variability,
- Longitudinal post-spill surveys document large pools of partially weathered DWH oil long after the spill, in many cases continuing to affect ecological resources (e.g., in marshes, deep sea benthos),
- Deep ocean biota is poorly understood even though the deep ocean will produce the majority of future hydrocarbons in the GoM,

Conclusions.....continued......

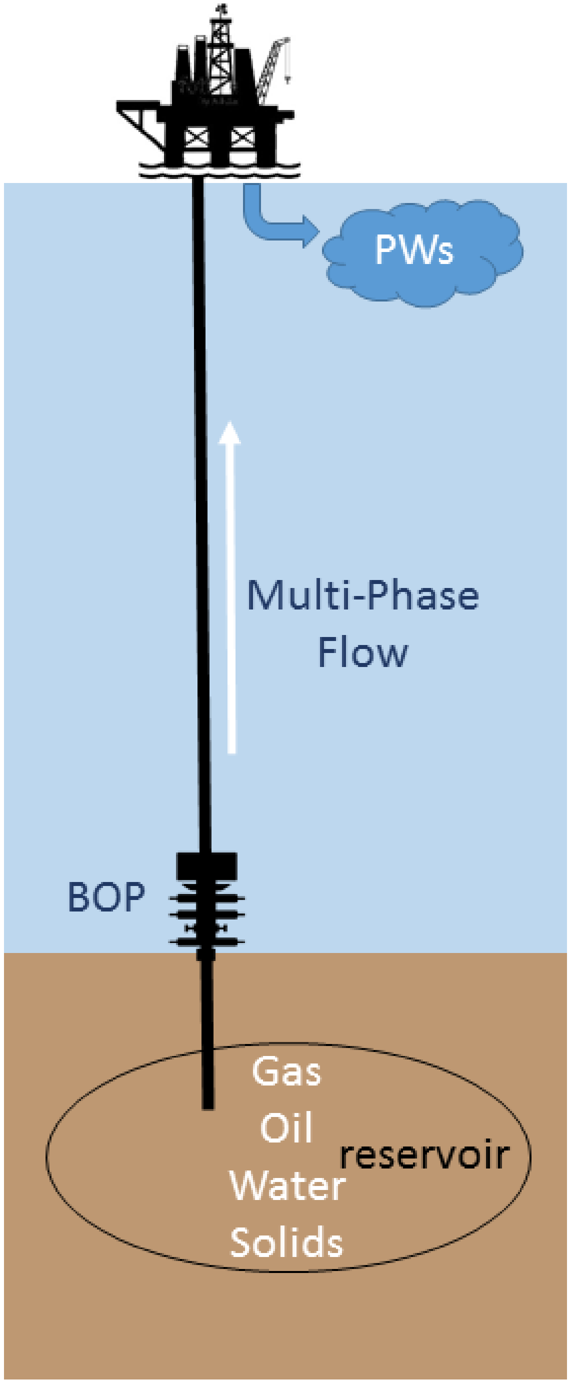
- Long-term ecosystem remediation programs (e.g., marsh reconstruction) may very well have consequential long-term negative impacts for a range of ecologically and economically important resources initially affected by the DWH scenario (e.g., oyster, bottlenose dolphin, fishes and others),
- The development of criteria for assessing of the *vulnerability* of resource populations to the DWH spill and corresponding *resilience* to its effects provides an important new approach for understanding of how species & ecosystems of the Gulf may be impacted by future large-scale perturbations,
- However, the vulnerability of resources to a particular oil spill will be idiosyncratic to where, when, how much and what type of oil is spilled (thus life history correlates are insufficient, by themselves, to predict vulnerability),
- We are much better prepared to evaluate the impact of oil spills on marine life and marine health given the substantial investment in new knowledge), but not necessarily better prepared to mitigate the risks of a spill to marine life,
- The next large spill will produce yet additional 'black swans' related to oil impacts on the natural world…

If the concentrations of PAHs are low in epi-pelagic waters, why are these species so polluted?

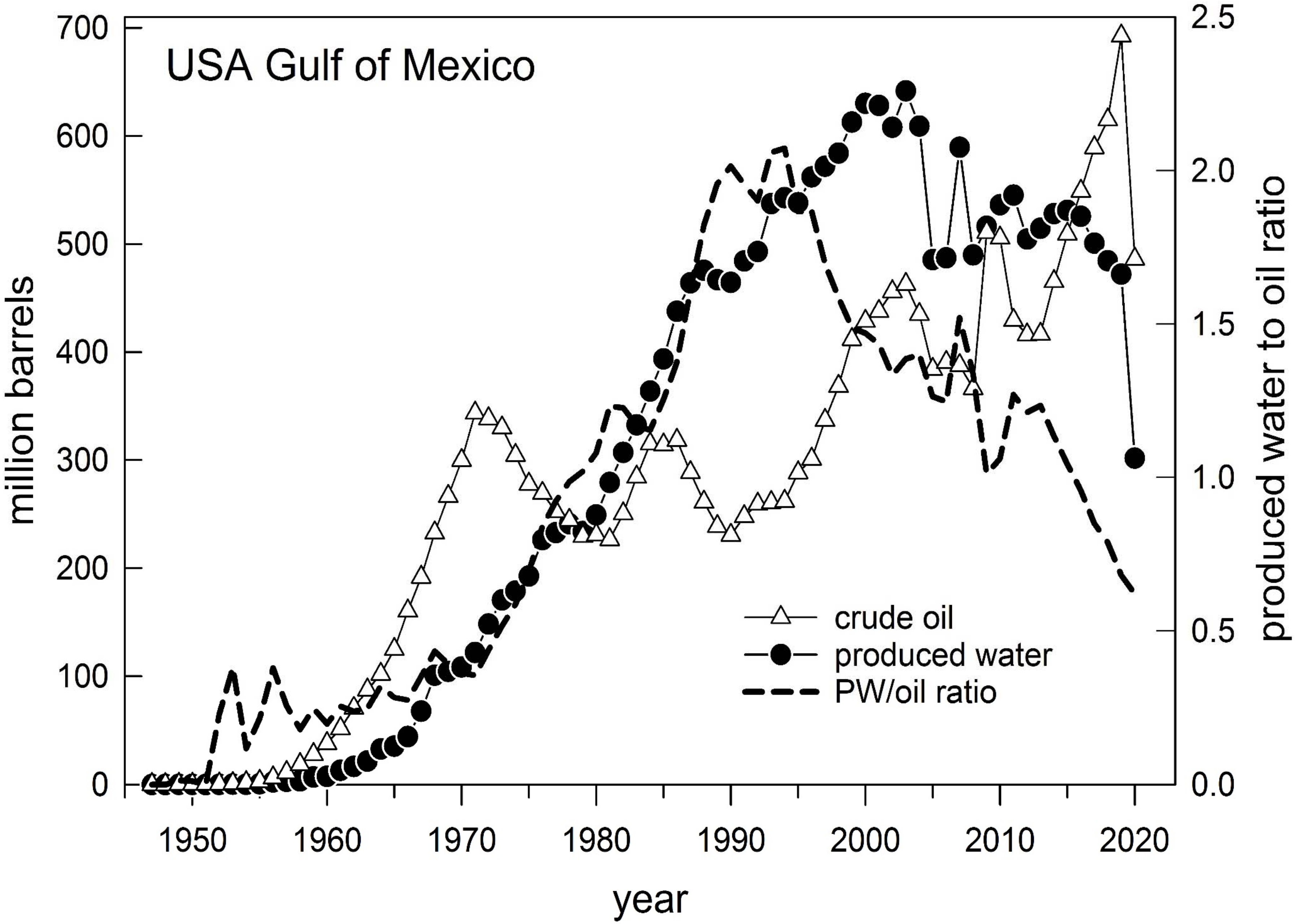


Pulster, E.L., A. Gracia, M. Armenteros, G. Toro-Farmer, S.M. Snyder, B.E. Carr, M.R. Schwaab, T.J. Nicholson, J. Mrowicki, and S.A. Murawski. 2020b. A first comprehensive baseline of hydrocarbon pollution in Gulf of Mexico fishes. *Scientific Reports 10:6437* doi.org/10.1038/s41598-020-62944-6

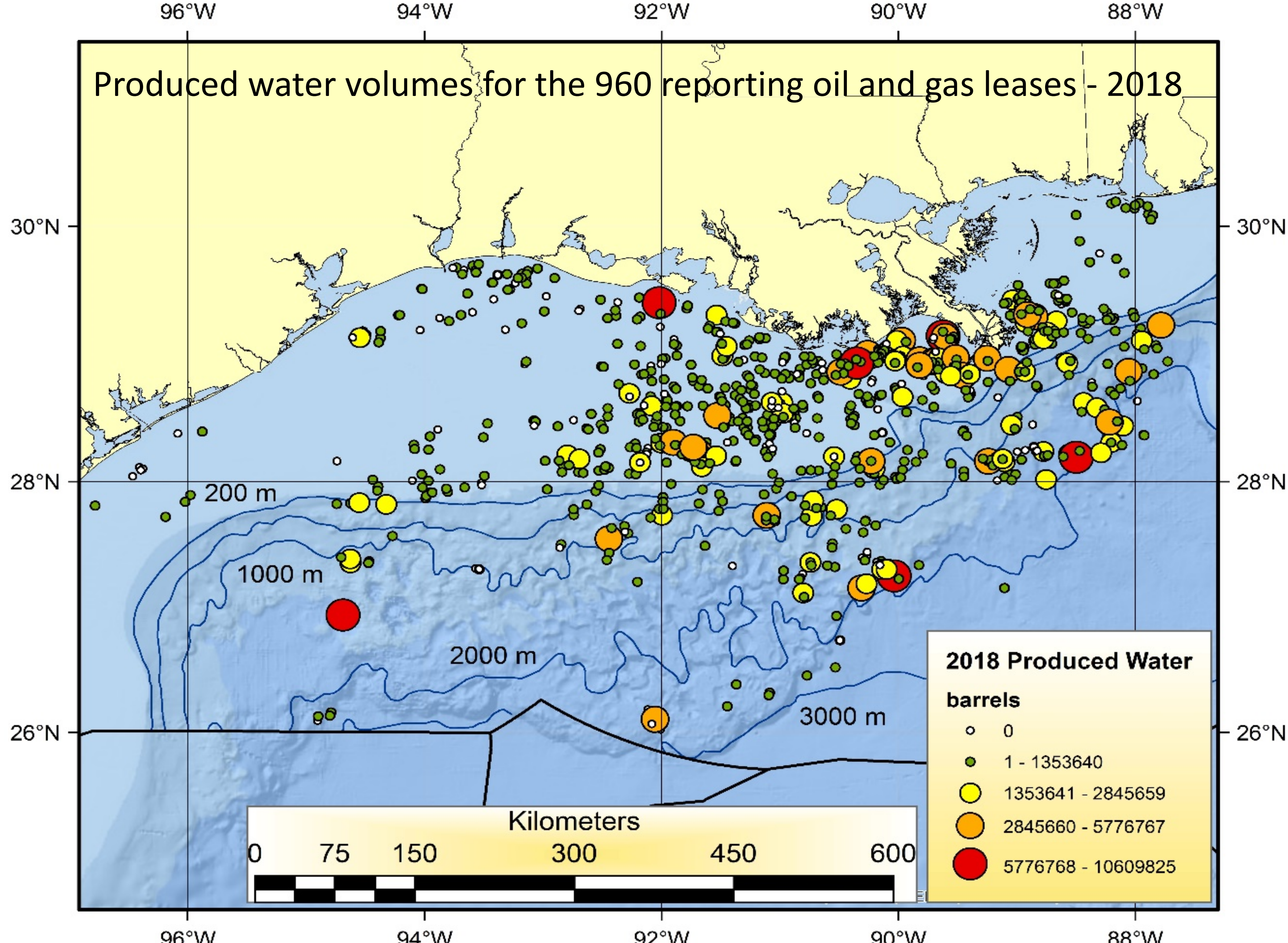
Produced Waters: A Primer



- ✓ Generated contemporaneously with gas, oil, condensate and solids from reservoir formations – volumes reported by facility monthly and available online @ BOEM's Data Center
- ✓ Wells in production for extended periods generate increasing proportions of PW to oil, gas and condensates
- ✓ Average ratio of PW to oil in GoM 1990-2020 = 1.29
- ✓ Virtually all PWs in the GoM OCS are discharged into the ocean at or near the surface
- ✓ Various technologies are used to reduce total oil and grease concentrations to meet performance standards for at-sea disposal of PWs
- ✓ Current regulatory standards for PWs are 29/42 ppm of "oil and grease" (monthly average with 1 exceedance to 42 ppm)
- ✓ Operators must provide average monthly PW concentrations of oil and grease. However, values are NOT reported to EPA's Echo online database (i.e., no publically available data on performance in meeting standards)
- ✓ PW volume from a facility cannot exceed 1,000 barrels h^{-1}. Discharges of PWs under regulated under EPA NPDES Permit 460000 (Region 4), NPDES GMG290000 (Region 6).



USA Gulf of Mexico
million barrels
0
100
200
300
400
500
600
700
produced water to oil ratio
0.0
0.5
1.0
1.5
2.0
2.5
1950
1960
1970
1980
1990
2000
2010
2020
year
crude oil
produced water
PW/oil ratio



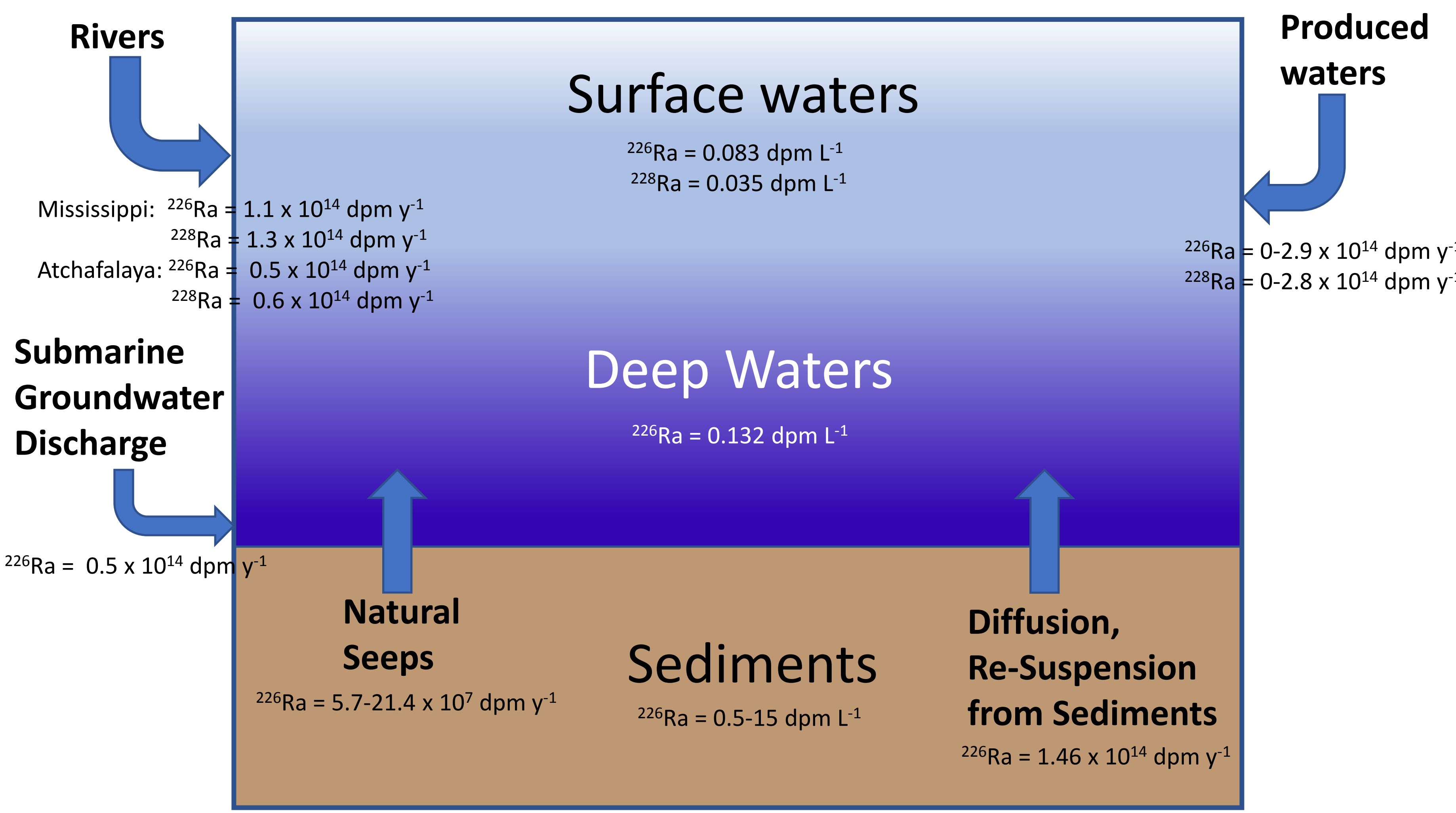
Produced water volumes for the 960 reporting oil and gas leases - 2018
96°W
94°W
92°W
90°W
88°W
30°N
28°N
26°N
200 m
1000 m
2000 m
3000 m
Kilometers
0 75 150 300 450 600
2018 Produced Water
barrels
0
1 - 1353640
1353641 - 2845659
2845660 - 5776767
5776768 - 10609825

Pollutant Concentrations in Some Produced Water Samples

Pollutant	Location	PW Conc.	Ambient Conc.	Concentration Factor
^{226}RA ½ life 1,600 yr	Offshore US GoM	91.2-1,494 pCi/L	0.027-0.04 pCi/L	2,280 – 55,333 Times ambient
^{228}RA ½ life 5.75 yr	Offshore US GoM	162-600 pCi/L	0.005-0.03 pCi/L	5,400-120,000 Times ambient
TPAHs	US GoM	40-600 µg/L	Mean 0.09 µg/L*	444-6,666 Times ambient
Naphthalene	US GoM	5.3-90 µg/L	Mean 0.008 µg/L*	663-11,250 Times ambient
Barium	GoM	81,000-342,000 µg/L	3-34 µg/L	2,382-114,000 Times ambient
Manganese	GoM	1,000-7,000 µg/L	0.03-1.0 µg/L	1,000-233,333 Times ambient
Salinity	Offshore GoM	5-299.9 PPT	36 PPT	0.14-8,333 Times ambient

From: K. Lee and J. Neff, 2011. Produced Waters: Environmental Risks and Advances in Mitigation Technologies, Springer. 608 pp.

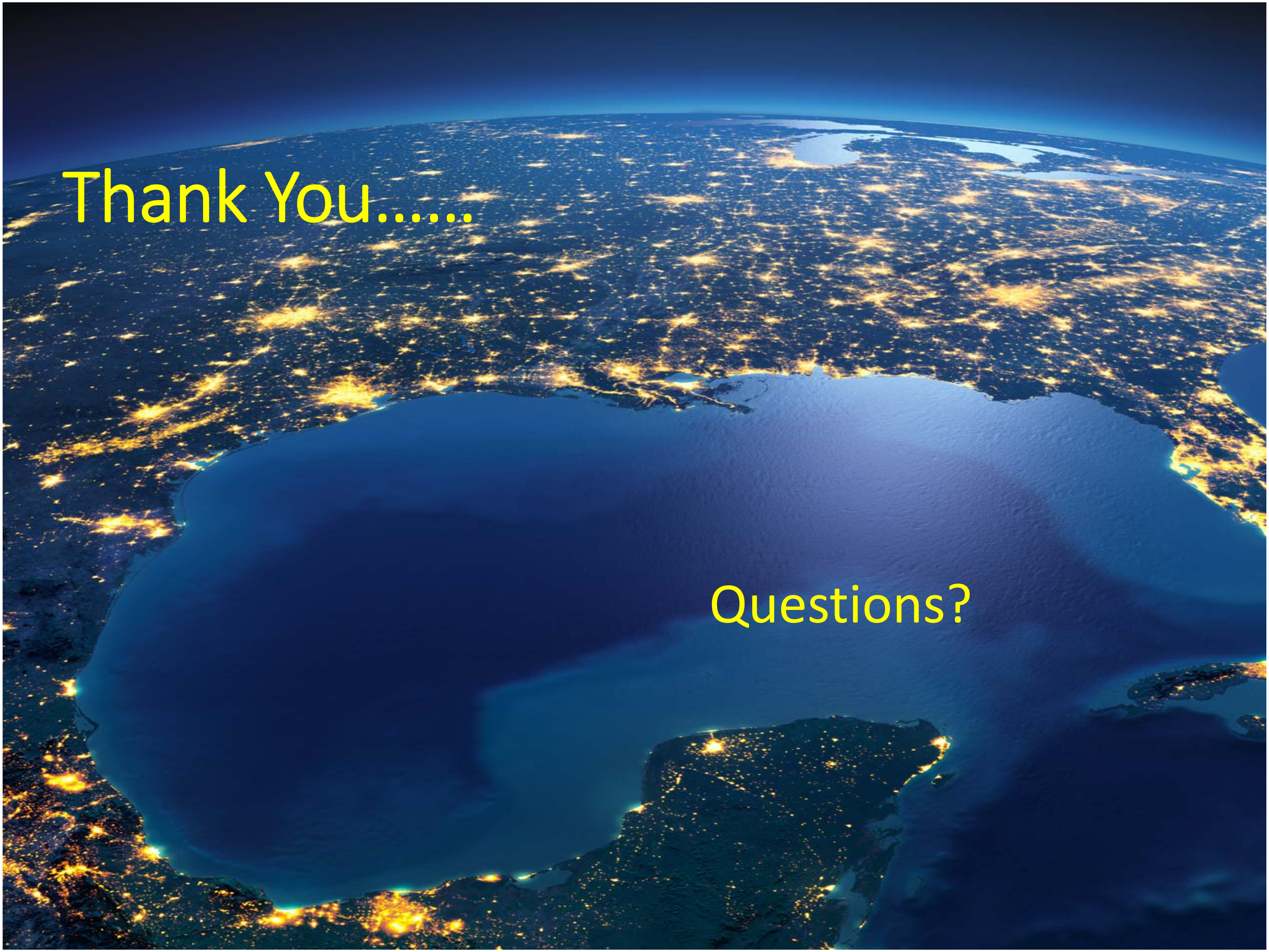
Inputs of ^{226}Ra and ^{228}Ra into the Northern Gulf of Mexico



Source: P. Schwing

Current issues in PW management…

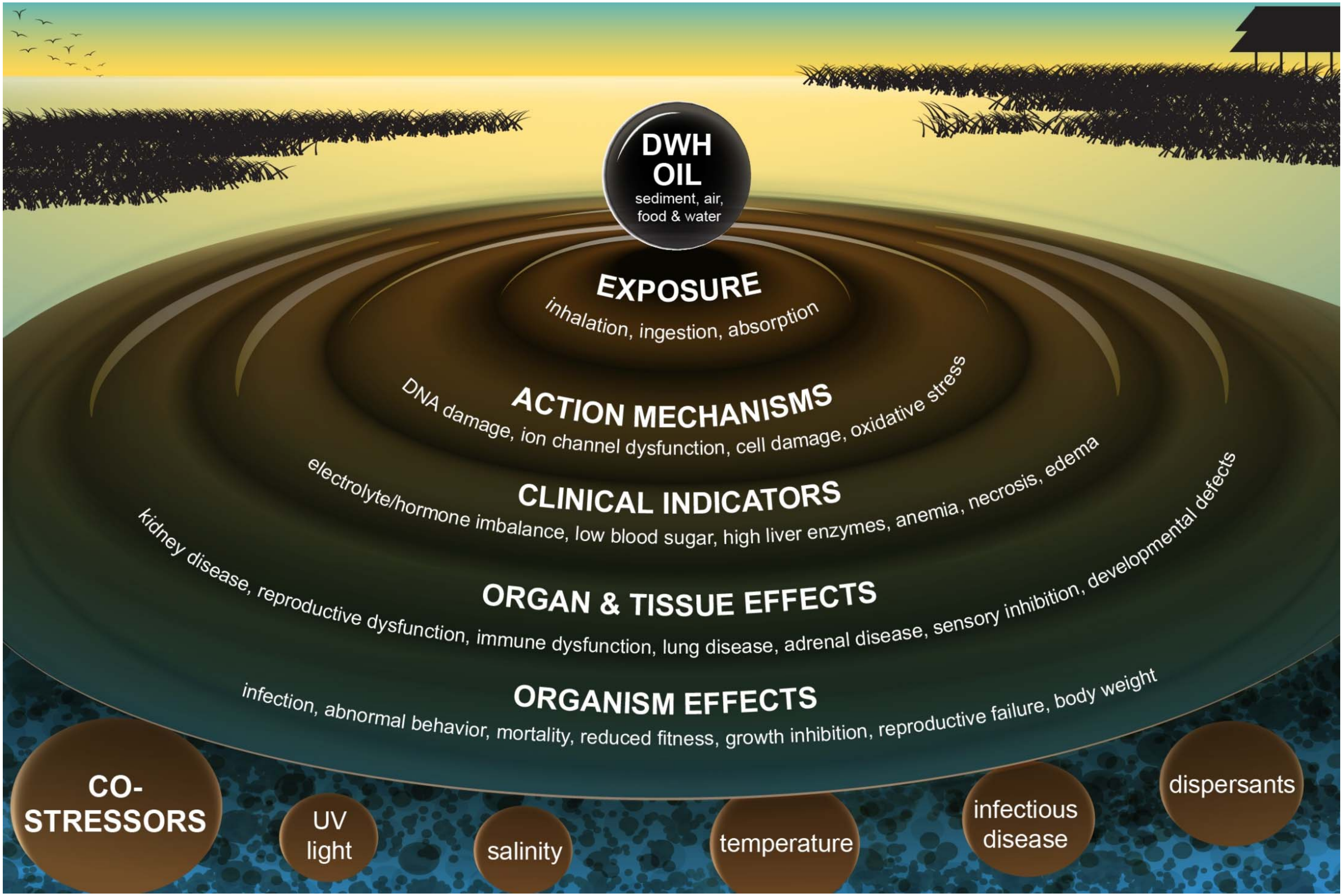
- Using the 1990-2020 average of PW discharge and assuming "oil and grease" concentrations at regulated levels, c.a. 14,500 bbl y^{-1} discharged as PWs,
- Inconsistent regulatory approaches among EPA regions (4&6),
- PW pollutant data required by EPA monthly but data unavailable in ECHO or other public-facing databases,
- Little attention paid by regulators to potential impacts of NORMs,
- Conduct and analyze systematic study of water column to determine concentrations & sources (budget) of $^{228+226}Ra$, metals and PAHs from the entire GoM,
- Model residence time, ½ life decay and transport dynamics of Radium and Metals in the GoM,
- Collaborate with Mexican and Cuban Scientists to extend water column & sediment surveys Gulf-wide.


Thank You……
Questions?

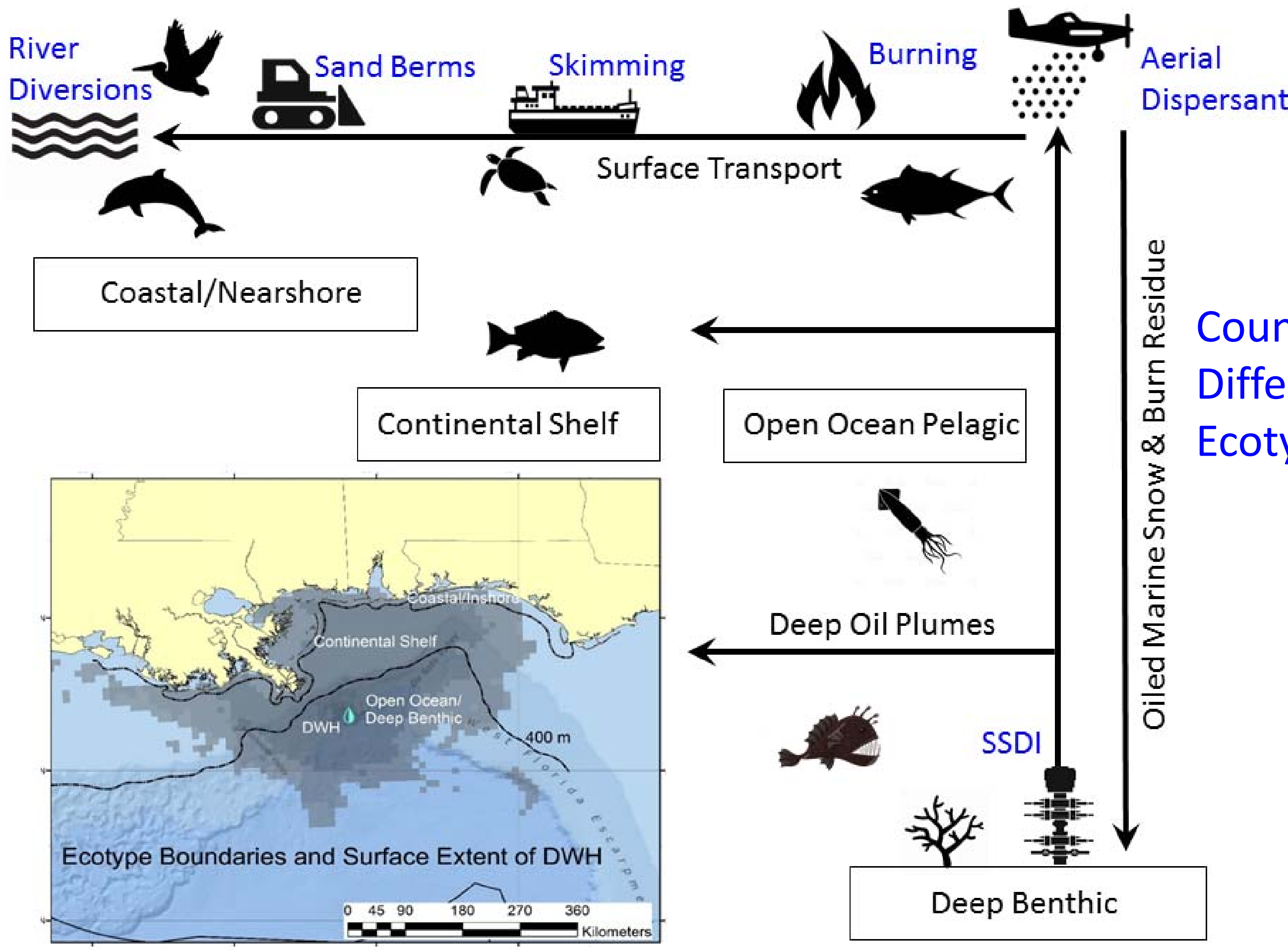
Back-Up Slides

cross-cutting ecological issues

- Ecotoxicology (acute and chronic exposure routes, rates, concentrations, pathways, and impacts)
- Species Interactions (trophic cascades?)
- Habitat Modifications (toxic source reservoirs)
- Multiple Stressors (cumulative effects, synergy)
- Resource Recovery (trajectories, resilience, r-K)
- Impacts of Mitigation (oil spill counter-measures)
- Connectivity (horizontal and vertical, including water mass movements of chemicals, dispersal/entrainment of plankton, larvae, movement patterns of animals)

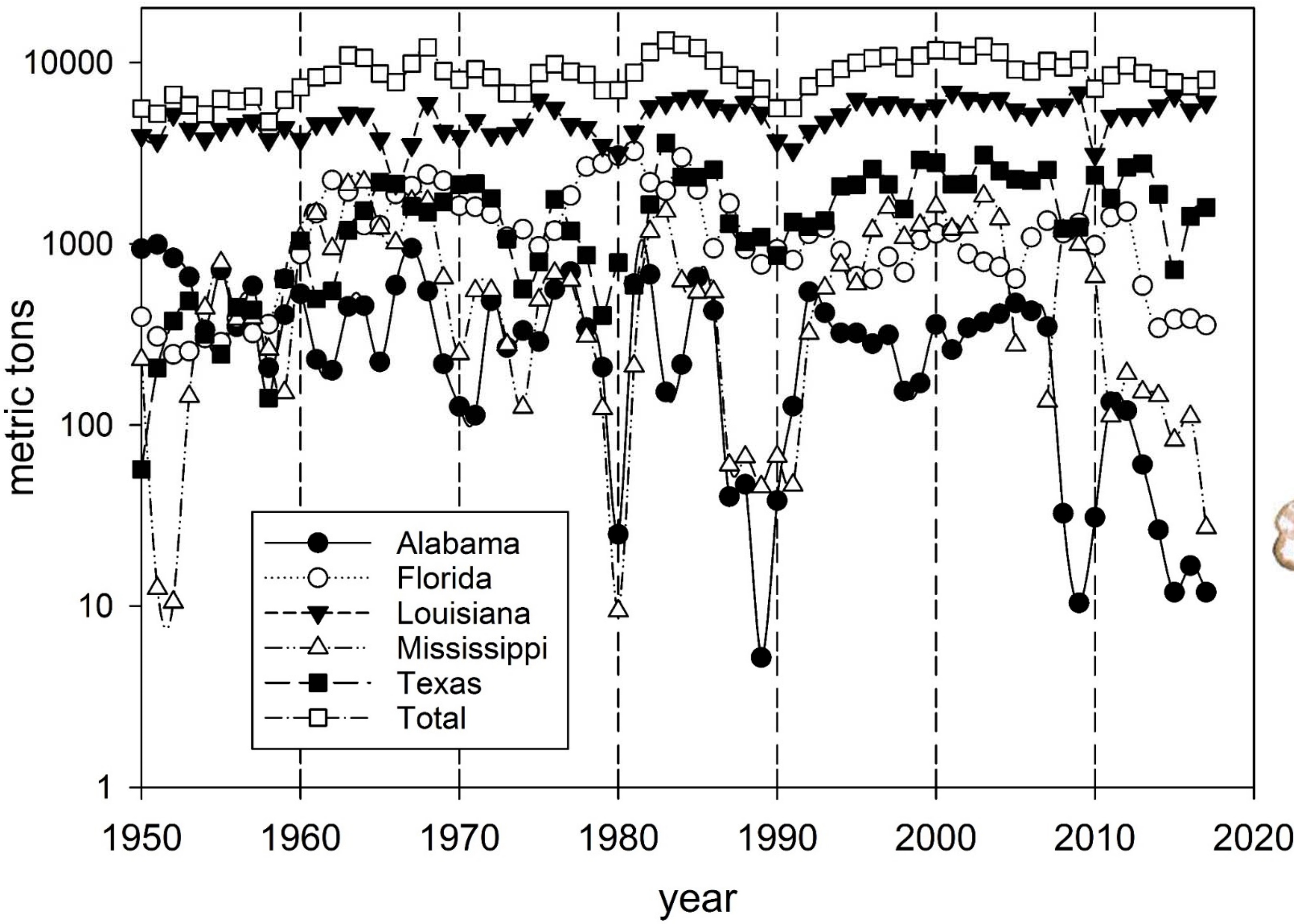


Murawski, S.A., M. Grosell, C. Smith, T. Sutton, K. Halanych, R. Shaw and C.A. Wilson 2021. Ecotoxicology: Impacts of Petroleum, Petroleum Components and Dispersants on Organisms and Populations. Oceanography (in press).

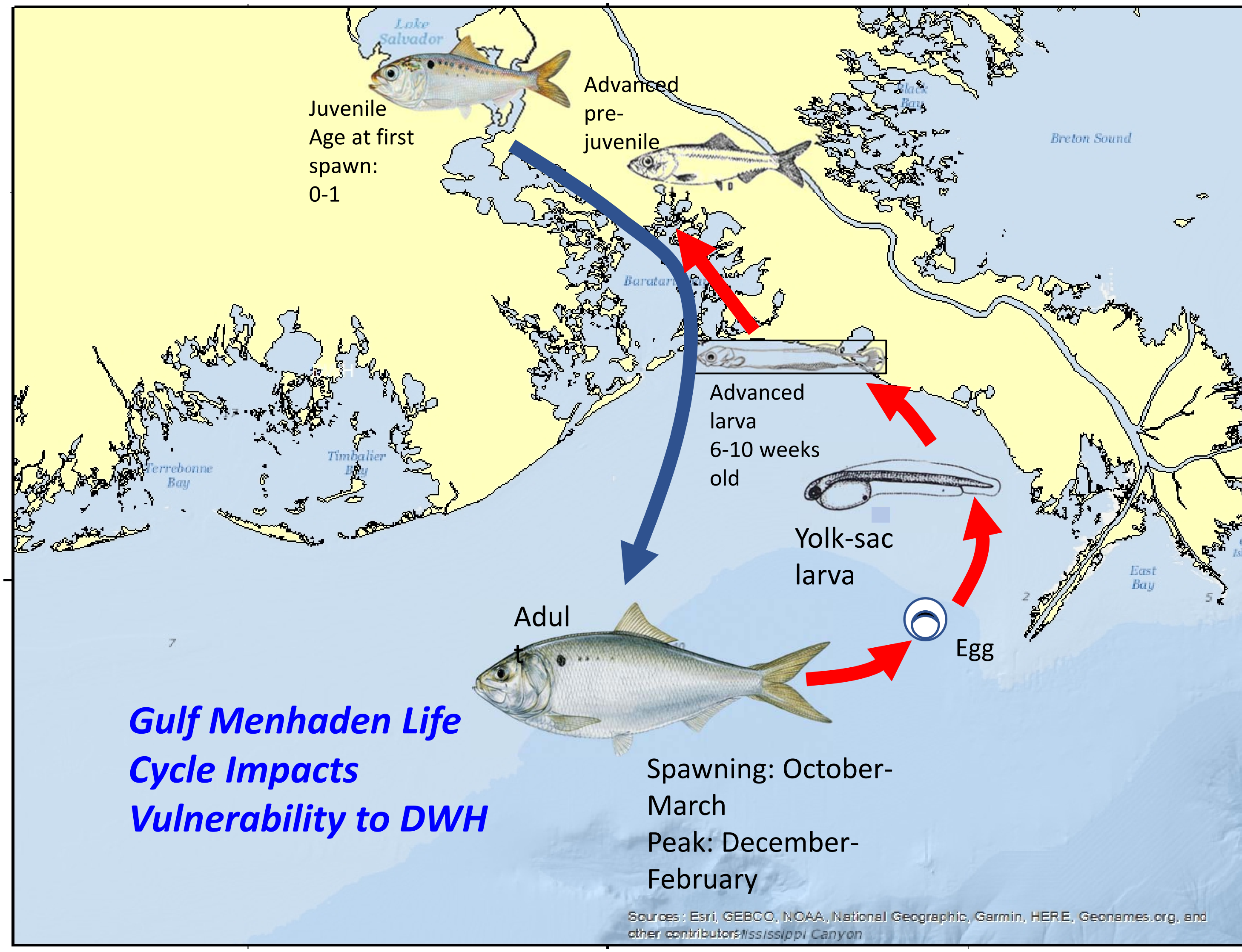


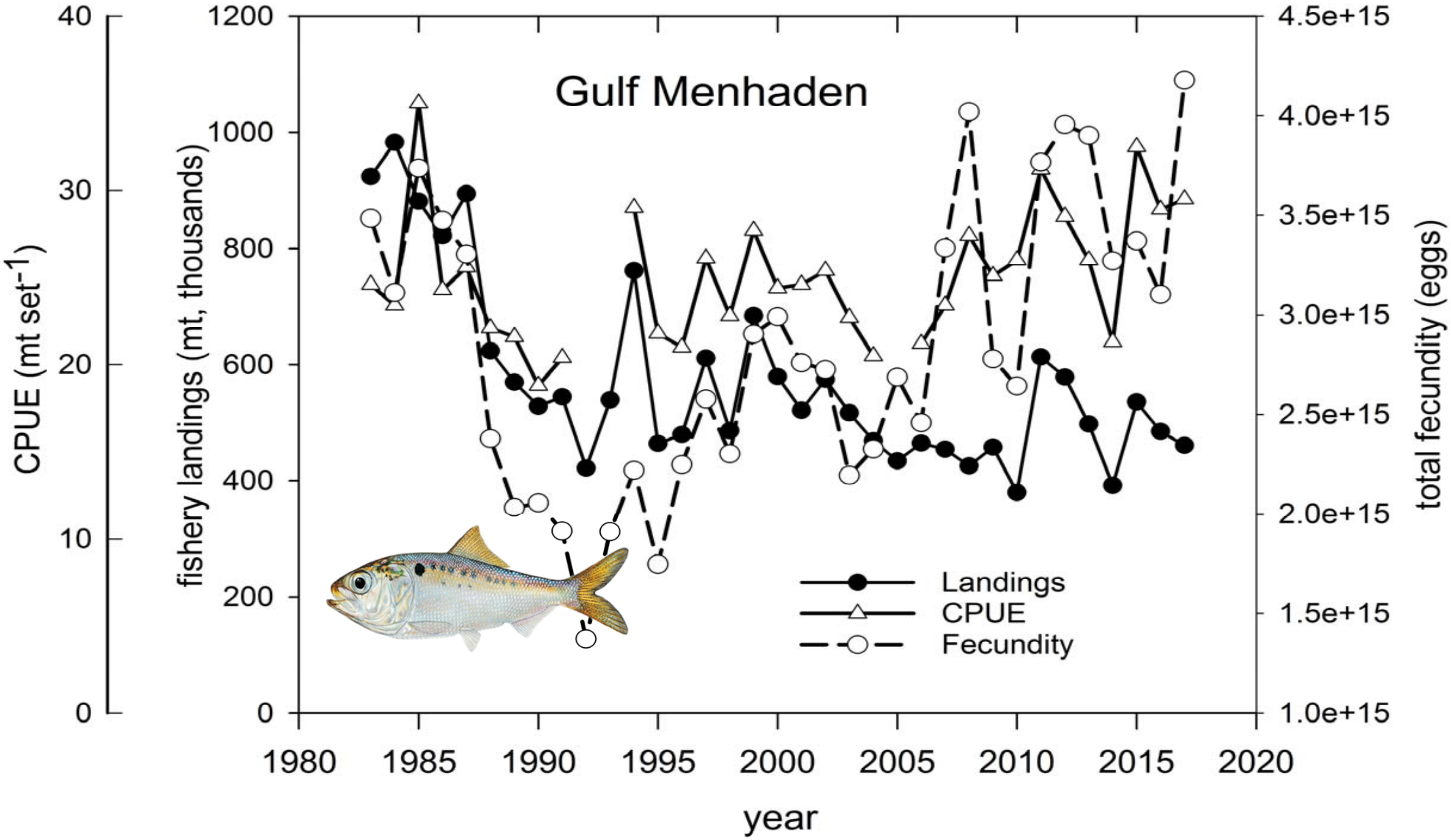
Countermeasures Deployed Differentially Affected Ecotypes

American Oyster State-by-State Fishery Landings 1950-2018



Timing was everything.....



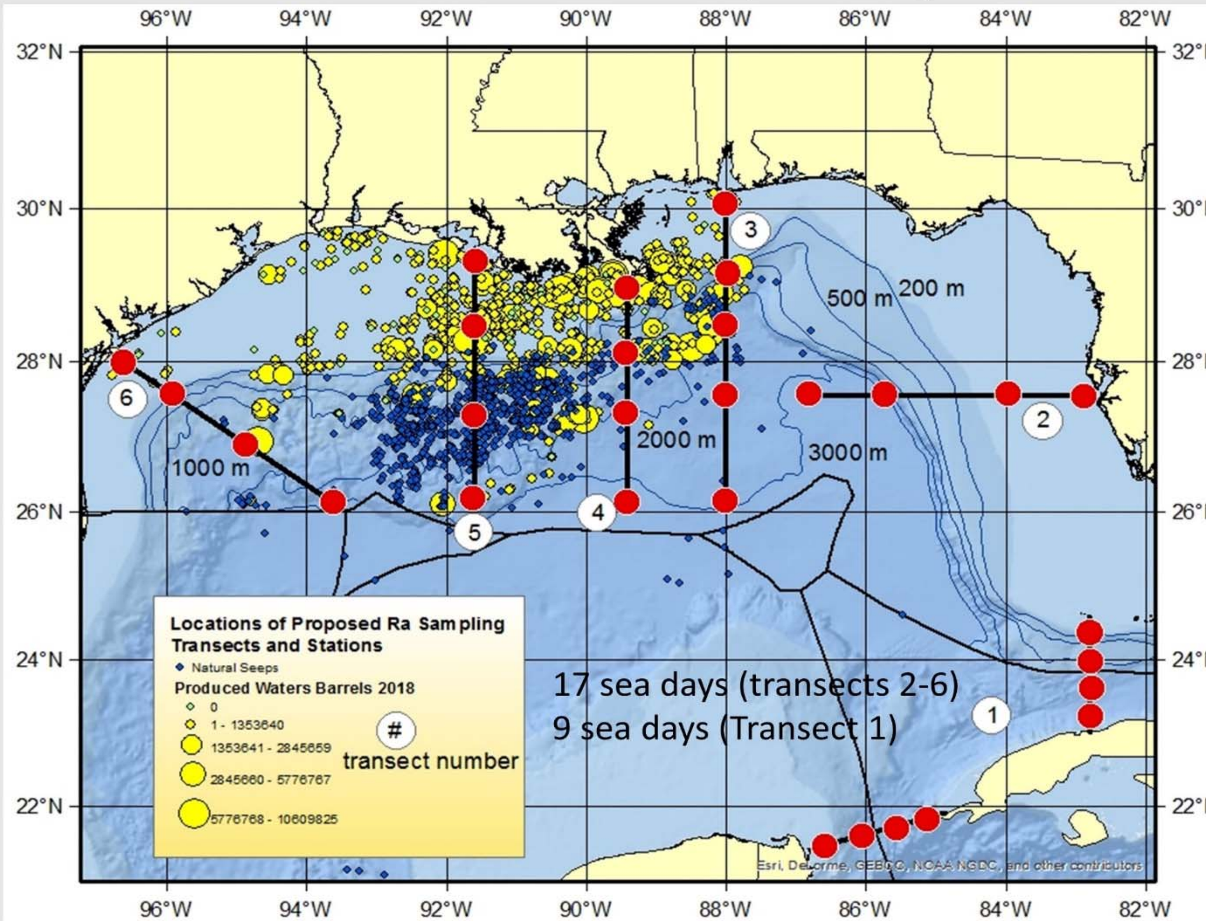

Gulf Menhaden
CPUE (mt set-1)
fishery landings (mt, thousands)
total fecundity (eggs)
year
Landings
CPUE
Fecundity
0
10
20
30
40
0
200
400
600
800
1000
1200
1.0e+15
1.5e+15
2.0e+15
2.5e+15
3.0e+15
3.5e+15
4.0e+15
4.5e+15
1980
1985
1990
1995
2000
2005
2010
2015
2020

In total, these diversions will have the capacity to divert up to ~**194,000** cfs, **more than 10 times the maximum diversion rates seen during DWH.**

Louisiana's Comprehensive Master Plan for a Sustainable Coast

Coastal Protection and Restoration Authority of Louisiana (2017). Louisiana's Comprehensive Master Plan for a Sustainable Coast, Effective June 2, 2017. http://coastal.la.gov/wp-content/uploads/2017/04/2017-Coastal-Master-Plan_Web-Single-Page_CFinal-with-Effective-Date-06092017.pdf.

Proposal for a Comprehensive Water Column Survey for Radionuclides, Metals and Oil Concentrations: transects determined to help resolve significance of source inputs



Depths to be Sampled

0 m

50 m

100 m

200 m

500 m

1,000 m

2,000 m

Bottom-10 m

29

Please be back by 3 pm ET!

NCCOS | NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

Toxicity of Oil in the Estuarine Environment

Ed Wirth

NOAA, NOS, National Centers for Coastal Ocean Science, Charleston, SC

Team members include:

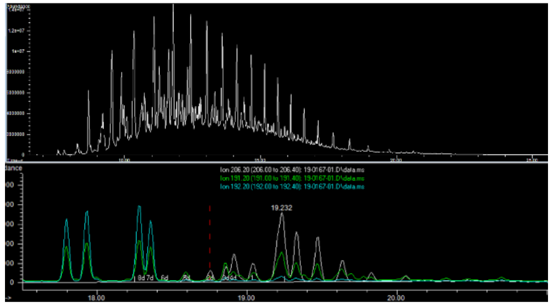
Marie DeLorenzo, Pete Key, Paul Pennington, Dennis Apeti, Katy Chung, Emily Pisarski, James Daugomah, Blaine West

Programmatic NCCOS Objectives

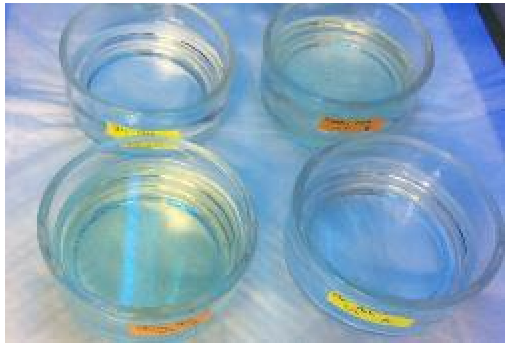
- Determine toxicity thresholds associated with oil pollution
- Develop sublethal indicators of exposure and stress
- Develop sensitive analytical methods for quantification of oil and oil spill mitigation products
- Characterize oil transport and fate
- Evaluate efficacy of oil spill mitigation products and marsh restoration methods
- Provide science to support NOAA's mandate for spill response and restoration
- Lead long-term monitoring for spatial and temporal comparisons of PAHs and other contaminants in sediments and mussel tissues

Research Highlights

- **Laboratory**
  - Acute effects of oil on fish and invertebrates
  - Developmental, reproductive, and multi-stressor effects
  - Oil chemical fate and modeling
- **Mesocosm**
  - Marsh restoration post-oil spill
- **Field**
  - Mussel Watch Program

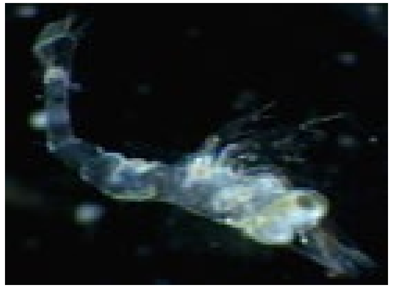


Developmental and reproductive effects in grass shrimp (*Palaemon pugio*) following acute larval exposure to a thin oil sheen and ultraviolet light



Background

- UV light can enhance toxic effects of PAHs by 10-100x
- Toxicity can be enhanced by UV light in early life stages of aquatic organisms due to their translucence and occupation in the photic zone of the water column
- Few studies have addressed multi-generational impacts of short term oil exposure



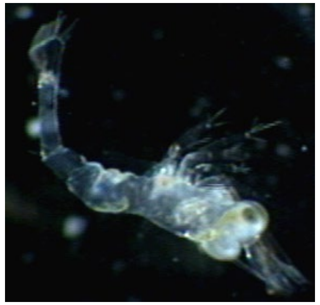
Objectives

- Characterize toxicity of thin oil sheens to early life stages of aquatic species
- Determine interactive effects of sheen with UV light
- Describe potential for long term effects following a short term exposure

Methods

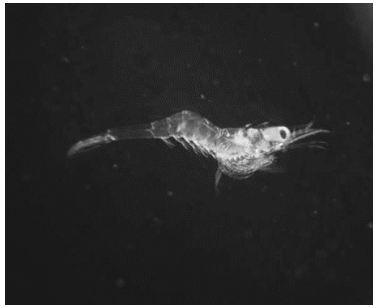
Exposure
10 Oct

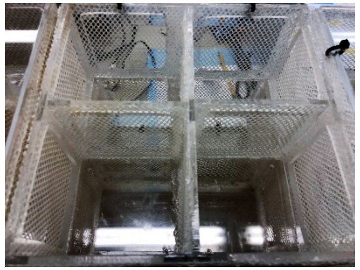
Zoea



Clean Seawater
11 Oct

Postlarvae
28 Oct-25 Nov





Adults Paired
5 Mar

Females Gravid
13 Mar-28 Apr

End
12 May

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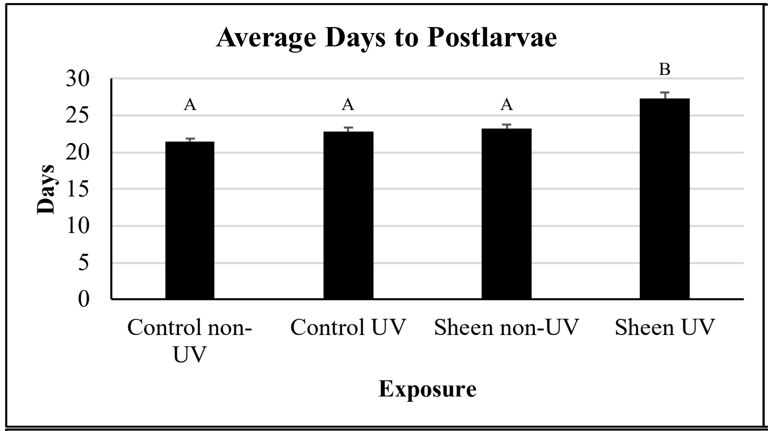
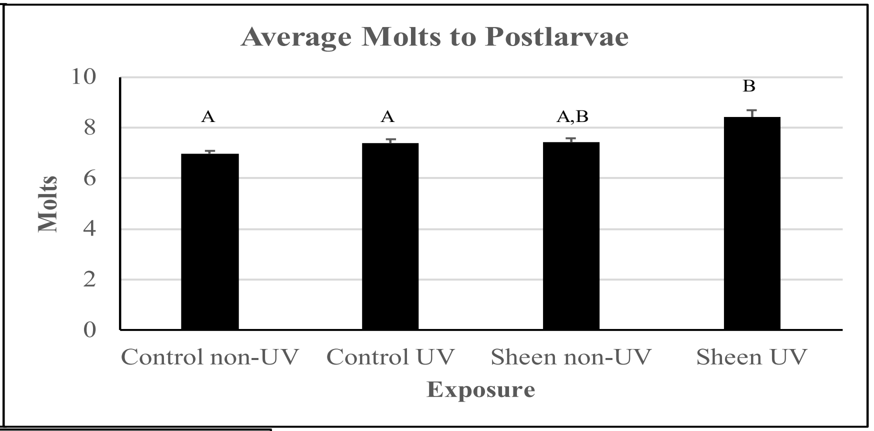
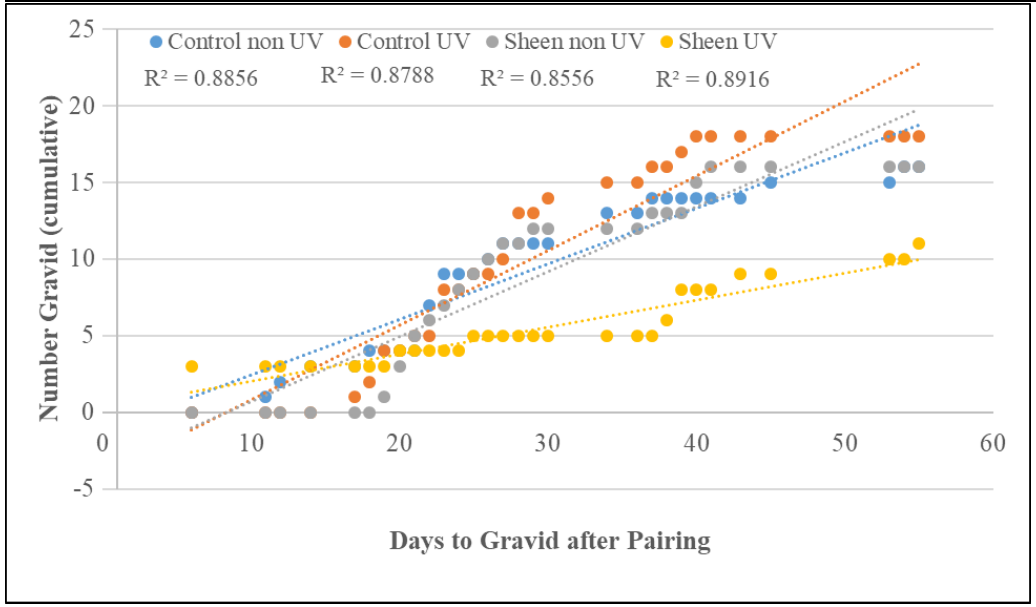
Results

Treatment	% Larval Survival after 24 h Exposure	% Survival to Postlarvae	% Larvae becoming Postlarvae by Day 21
Control non-UV	100	98	55
Control UV	100	93	40
Sheen non-UV	98	88	27
Sheen UV	98	85	10







- The key message is that development and reproduction is impacted when shrimp are exposed to oil and UV light relative to controls or oil

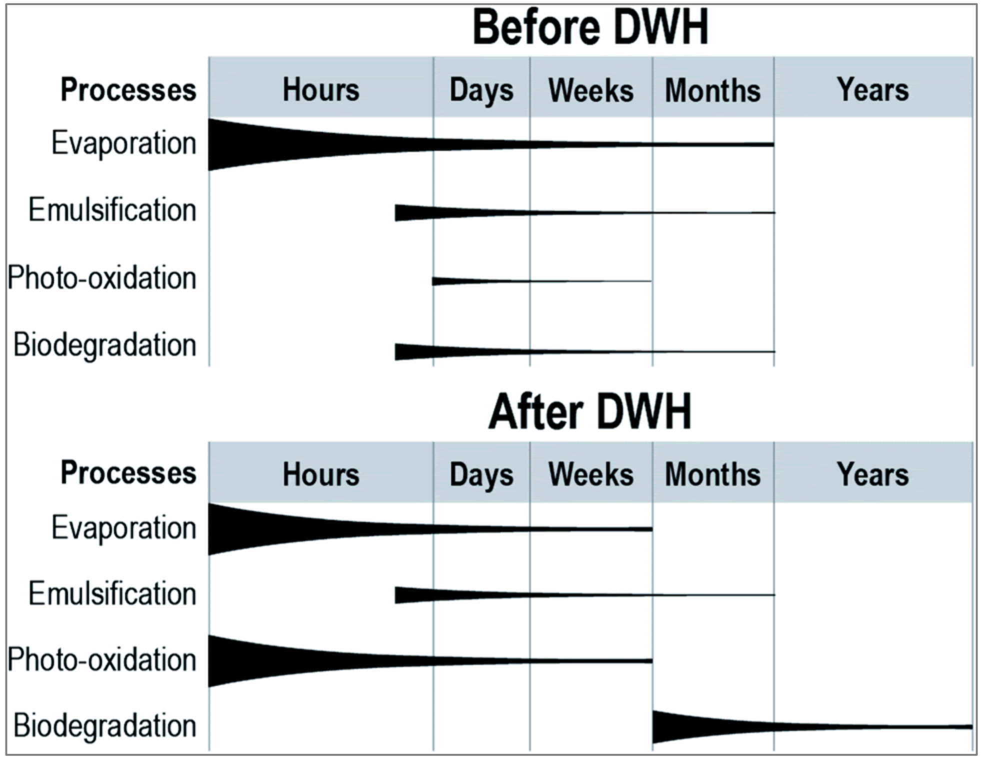
Conclusions

- Short-term oil sheen-UV exposures as larvae can have consequences on adult shrimp reproductive health
- Degree of negative effects to aquatic organisms may be underestimated if based on standard laboratory fluorescent lighting
- Consistent delays in reproduction and development can impact populations over multiple generations.

Analysis of Floating Oil Under UV Light at Different Environmental Conditions

Background: Recent shift in oil spill weathering paradigm

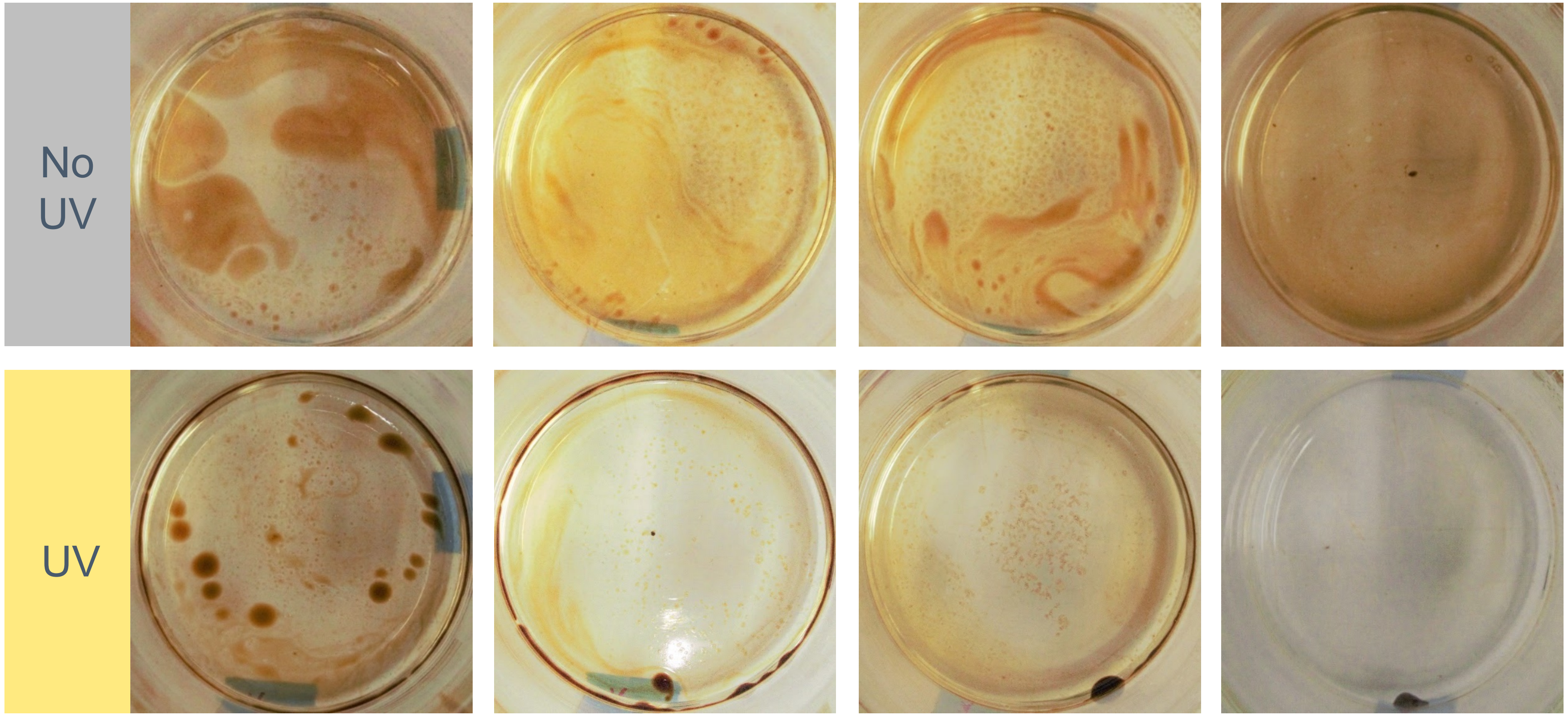
- Photo-oxidation still not well understood



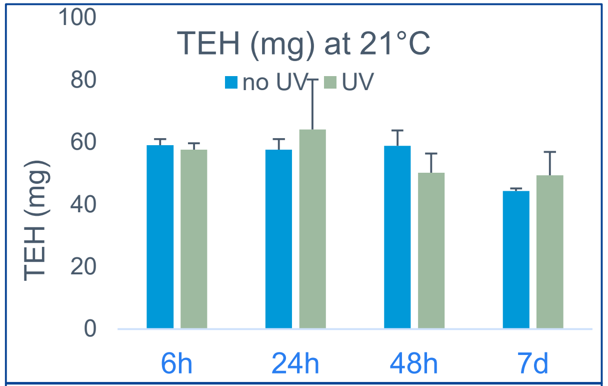
Objective: Determine how the chemical and physical properties of oil change under different environmental conditions

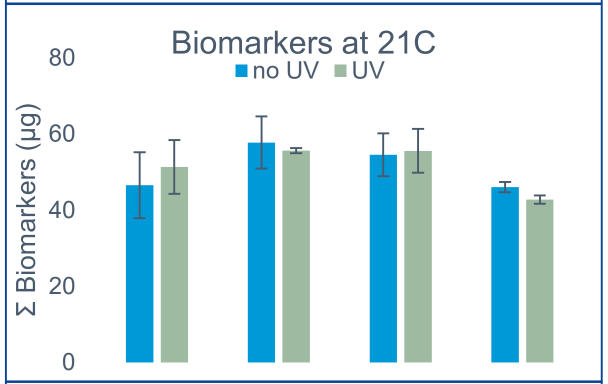
- Ultraviolet Light (UV-A), Temperature(10, 21, and 30°C) and multiple oil types

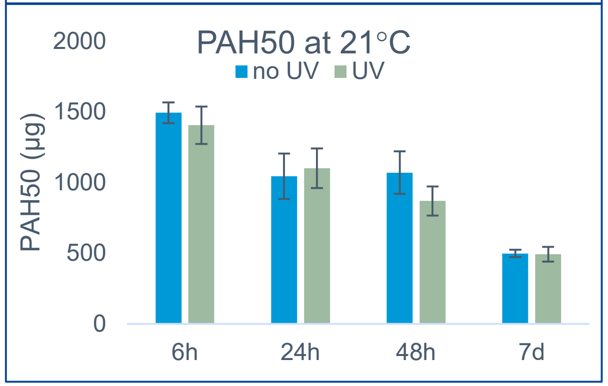
Results



6 h | 24 h | 48 h | 7 d

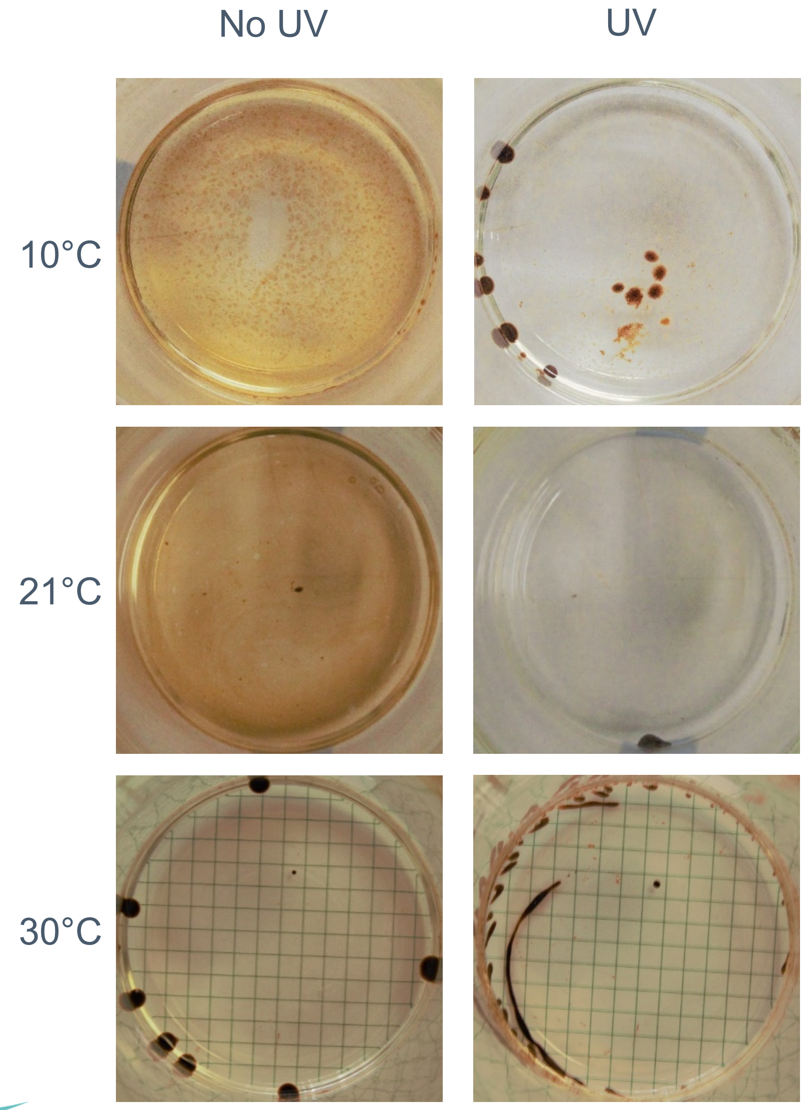






Conclusions

- UV light is a factor in tar ball formation
- Physical changes
  - UV → tar ball; no UV → sheen-like
- Chemical changes
  - TEH and Biomarkers: UV ≈ no UV
  - PAHs: high molecular weight / more alkylated PAHs affected by UV light
    - LSC oil composition ~1-2% PAHs; vast majority are low molecular weight



Defining Protocols for Replanting as an Oil Spill Response Tactic in Coastal Marshes

Background:

- A number of restoration tactics have been implemented in actual spills
- While several approaches show potential, replanting methods following oil spills have not been defined or optimized formally
- The purpose of the research is to provide scientific context to formalize replanting methodologies

Objective:

- What combination of marsh grass (*Spartina alterniflora*) restoration tactics produces the best outcome for a marsh oiled with fuel oil?
    - Pilot Studies
    - Long-term Mesocosm Study


NOAA ORR


NOAA ORR

Methods

Long-term Mesocosm Study

- 4 treatments, 5 replicate mesocosms each
    - Control
    - Fuel Oil Dose – No replanting
    - Fuel Oil Dose – Local Transplants
    - Fuel Oil Dose – Nursery Plants
- Dose enough to cause a complete kill of *Spartina*
- Oil dosed systems will receive both plugs and bare-root planting (split plot design).
- Oil weathering and degration will be characterized chemically (PAHs and TEH).
- Determine effects on stem density and height, above and below ground biomass, root structures, chlorophyll, and sediment microbiota

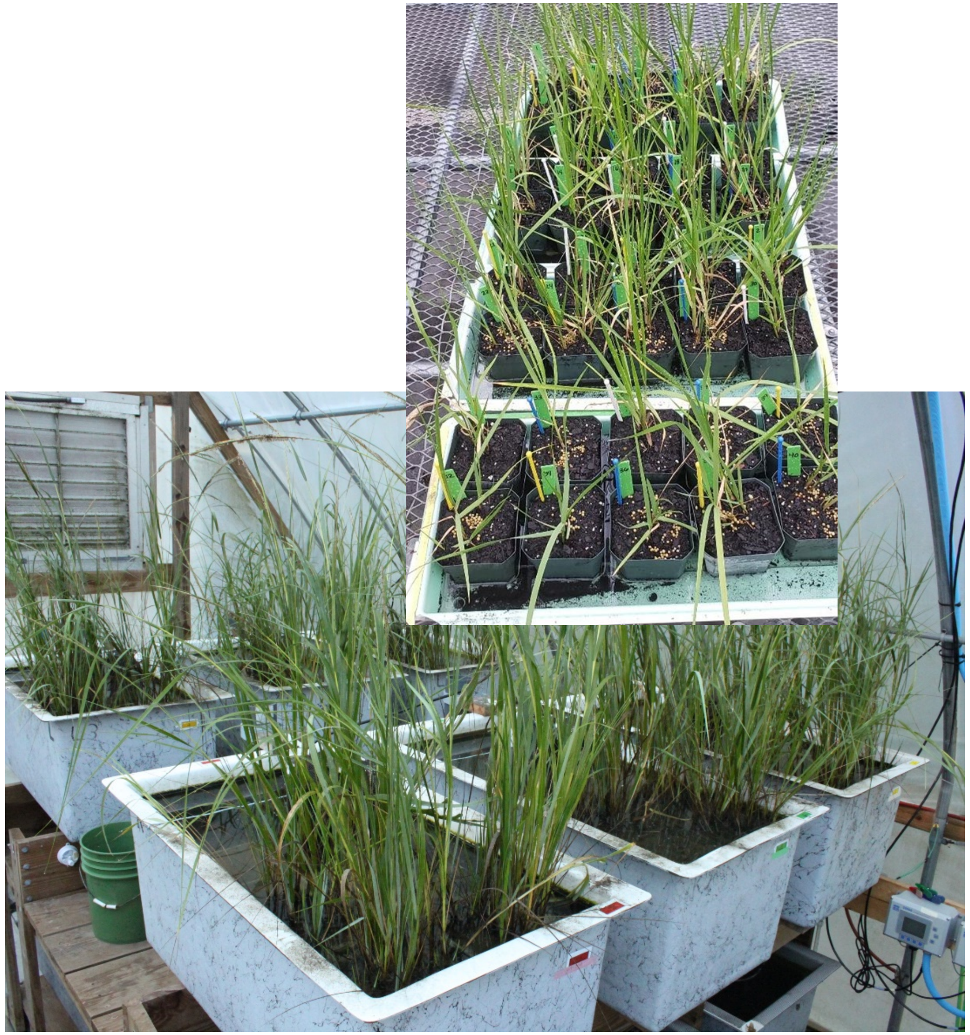
Expected Outcomes

Based on Pilot Studies:

- No. 2 Fuel Oil (diesel) will be used for the mesocosm testing
- The systems will receive tidal flux to allow for:
  - Oil coverage on standing AGB
  - Oil penetration in sediments
- Addition of fertilizer significantly stimulated plant growth based on above ground biomass

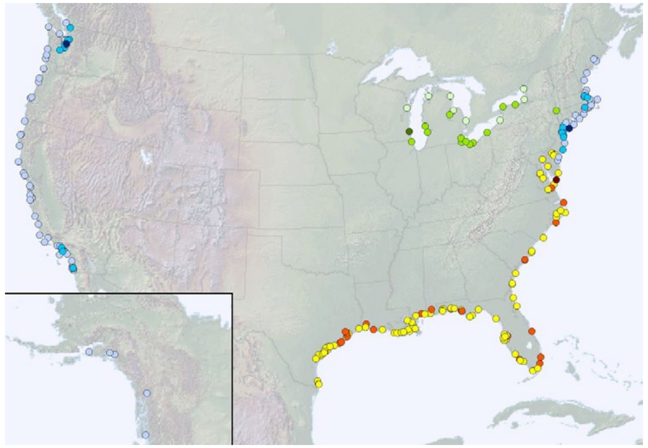
Mesocosm Study to be performed in coming Months:

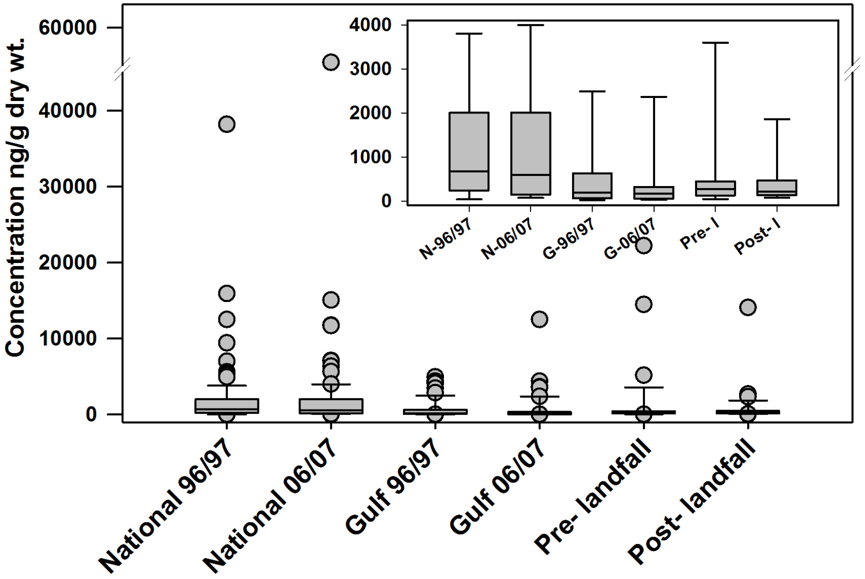
- Assess recovery of structure and function of replanted marsh grasses and compare different clean-up treatments relative to unoiled reference conditions.
- Characterize how replanting influences weathering and degradation of the oil
- Inform decision making in the aftermath of an actual spill by NOAA ORR



Mussel Watch Program

Nationwide Pollution Monitoring Program
Since 1986 – Based on collection and analysis of bivalves (oysters, mussels) and sediment - Lower 48, AK, HI, Puerto Rico





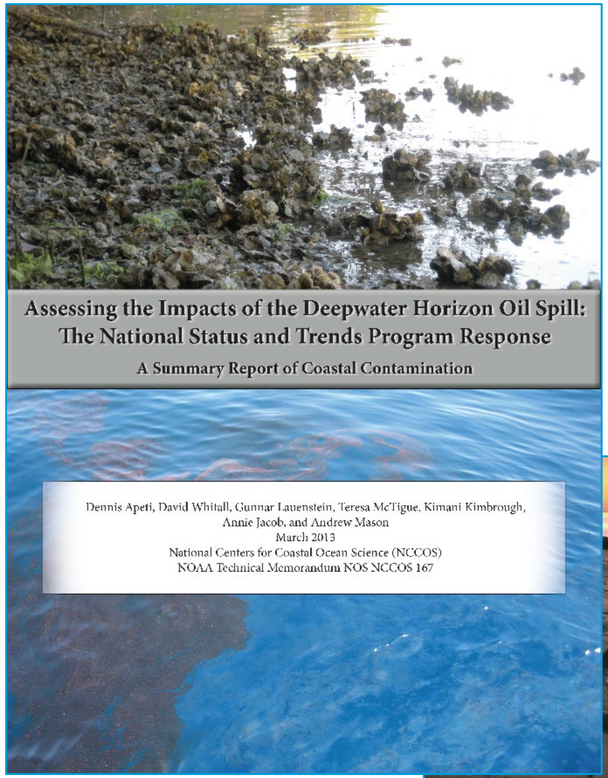
Apeti et al., 2013. Assessing the Impacts of the Deepwater Horizon Oil Spill: The National Status and Trends Program Response. NOAA Technical Memorandum NOS NCCOS 167.

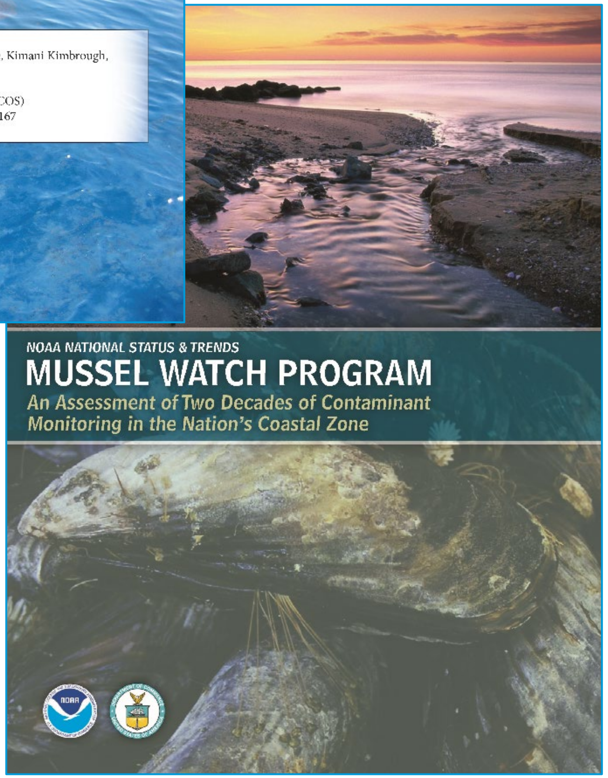
This national record of contaminant data builds a record of baseline chemical concentrations and can be integral in understanding the risk posed by changing contaminant levels.

Mussel Watch Program

MWP provides unique and historical trend data that is vital for evaluating:

- The long-term trends from a national perspective
- Impacts of oil spills and hurricanes
- Decisions that address restoration & cleanup
- The effectiveness of regulations that restrict chemical use





Questions?

Selected NCCOS Oil Spill Literature

NCCOS NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

DeLorenzo, M.E., Key, P.B., Chung, K.W., Aaby, K., Hausman, D., Jean, C., Pennington, P.L., Pisarski, E.C., Wirth, E.F. 2021. Multi-stressor effects of ultraviolet light, temperature, and salinity on Louisiana Sweet Crude oil toxicity in larval estuarine organisms. *Archives of Environmental Contamination and Toxicology*. DOI 10.1007/s00244-021-00809-3

Key, P.B., Chung, K.W., West, B., Pennington, P.L., DeLorenzo, M.E. 2020. Developmental and reproductive effects in grass shrimp (*Palaemon pugio*) following acute larval exposure to a thin oil sheen and ultraviolet light. *Aquatic Toxicology* 228, DOI /10.1016/j.aquatox.2020.105651

Lisa A. May, Athena R. Burnett, Carl V. Miller, Emily Pisarski, Laura F. Webster, Zachary J. Moffitt, Paul Pennington, Edward Wirth, Greg Baker, Robert Ricker, Cheryl M. Woodley (In Press) Effect of Louisiana Sweet Crude Oil on a Pacific Coral, *Pocillopora damicornis*, Aquatic Toxicology https://doi.org/10.1016/j.aquatox.2020.105454

van den Hurk, P., Edhlund, I., Davis, R., Hahn, J.J. McComb, M.J., Rogers, E.L., Pisarski, E., Chung, K., DeLorenzo, M. (2020) Lionfish (*Pterois volitans*) as biomonitoring species for oil pollution effects in coral reef ecosystems. *Mar Environ Res* https://doi.org/10.1016/j.marenvres.2020.104915

Baxter, S.E., DeLorenzo, M.E., Key, P.B., Chung, K.W., Beckingham, B., Fulton, M.H. (2018) Toxicity Comparison of the Shoreline Cleaners Accell Clean® and PES-51® in Two Life Stages of the Grass Shrimp, *Palaemonetes pugio*. *Environ Sci Poll Res* 25(11):10926-10936. DOI: 10.1007/s11356-018-1370-2

DeLorenzo, M.E., Evans, B., Chung, K.W., Key, P.B., Fulton, M.H. 2017. Effects of Salinity on Oil Dispersant Toxicity in the Mud Snail, *Ilyannasa obsoleta. Environ Sci Poll Res* 24(26):21476-21483. DOI 10.1007/s11356-017-9784-9

DeLorenzo, M.E., Key, P.B., Chung, K.W., Pisarski, E., Shaddrix, B., Moore, J.G., Wirth, E.F., Pennington, P.L., Wade, J., Franco, M., Fulton, M.H. 2017. Comparative Toxicity of Two Chemical Dispersants and Dispersed Oil in Estuarine Organisms. *Arch Environ Contam Toxicol* 74(3): 414-430. DOI 10.1007/s00244-017-0430-9

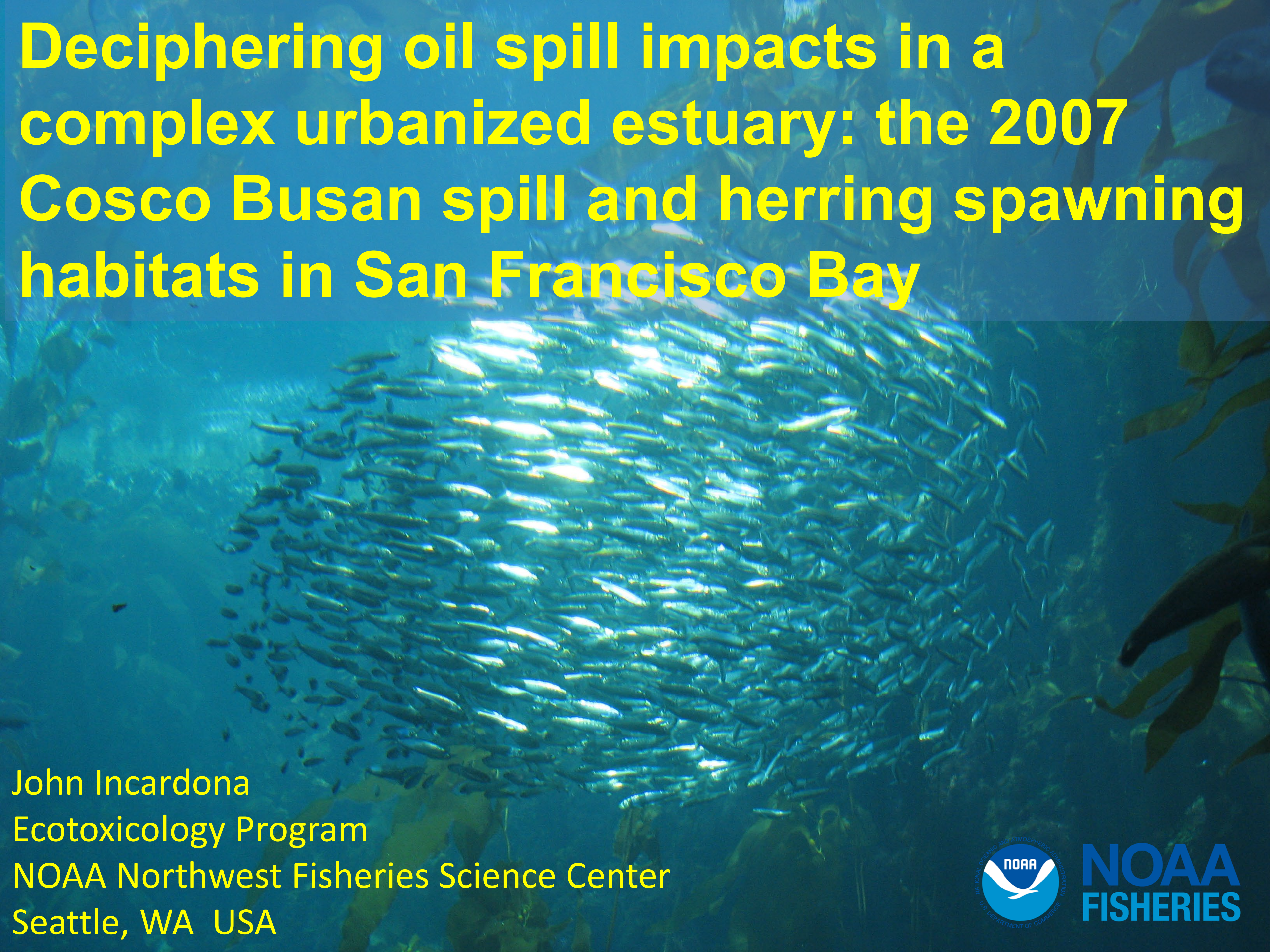
Frometa, J., DeLorenzo, M.E., Pisarski, E.C., Etnoyer, P.J. 2017. Toxicity of oil and dispersant on the deep water gorgonian octocoral *Swiftia exserta*, with implications for the effects of the Deepwater Horizon oil spill. *Mar Poll Bull*. 122:91-99.

DeLorenzo, M.E., Eckmann, C.A., Chung, K.W., Key, P.B., Fulton, M.H. 2016. Effects of salinity on oil dispersant toxicity in the grass shrimp, *Palaemonetes pugio*. *Ecotoxicology and Environmental Safety*. 134:256–263.

Apeti et al., 2013. Assessing the Impacts of the Deepwater Horizon Oil Spill: The National Status and Trends Program Response. NOAA Technical Memorandum NOS NCCOS 167.

DeLorenzo, M.E., Chung, K.W., Key, P.B., Fulton, M.H. (2012). Mixture toxicity of crude oil and Corexit® 9500 to estuarine organisms. *International Journal of Environmental Science and Engineering Research (IJESER)*. 3(3):161-169.

Deciphering oil spill impacts in a complex urbanized estuary: the 2007 Cosco Busan spill and herring spawning habitats in San Francisco Bay



John Incardona
Ecotoxicology Program
NOAA Northwest Fisheries Science Center
Seattle, WA USA

CBOS Fish NRDA

- A “very small spill”
- Our boss said, “we won’t find anything”
- But it’s “in Nancy Pelosi’s back yard”, so “we have to do due diligence”
- Herring spawning was approaching, so we expected a mini-Exxon Valdez, and designed the study as such
- Exceptional partnership and coordination with co-Trustees (NOAA NOS and CalDFG), as well as excellent regional academic partners (UC-Davis Bodega Marine Lab)

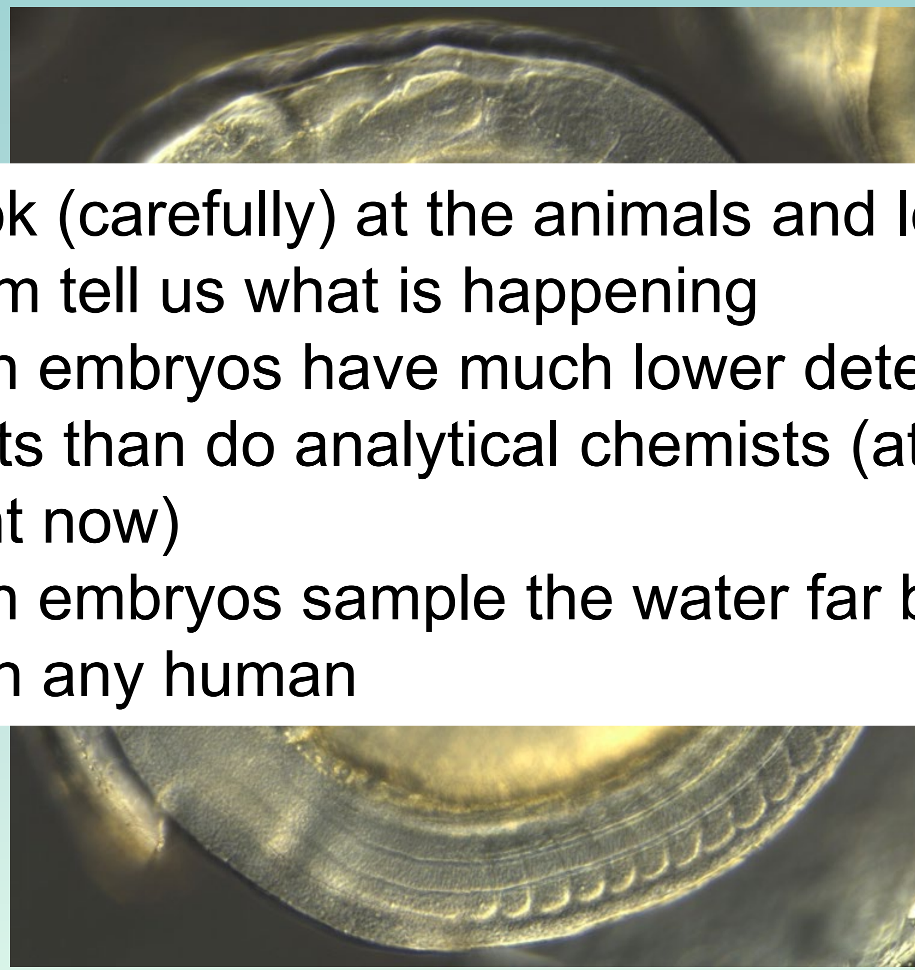
Nat Scholz
Tracy Collier
Gina Ylitalo
Mark Myers
Jana Labenia
David Baldwin
Tiffany Linbo
Heather Day
Barbara French
Bernadita Anulacion
Jennie Bolton
Daryle Boyd
Doug Burrows
Catherine Sloan
Ron Pearce
Nick Adams
Cathy Laetz
Sean Sol
O. Paul Olson
Carla Stehr
Maryjean Willis
Gladys Yanagida

Gary Cherr
Carol Vines
Karl Menard
Stephen Morgan
Theresa DiMarco
Fred Griffin
Joe Newman
Ed Smith
Devon Stephens
Jason Herum
Marley Jarvis
Dawn Meeks

Trustee representatives

NOAA-NOS Greg Baker
CDFG-OSPR Mike Anderson

"Our real teacher has been and still is the embryo -- who is, incidentally, the only teacher who is always right."



- Look (carefully) at the animals and let them tell us what is happening
- Fish embryos have much lower detection limits than do analytical chemists (at least right now)
- Fish embryos sample the water far better than any human

Viktor Hamburger 1900-2001

Exxon Valdez spill 1989

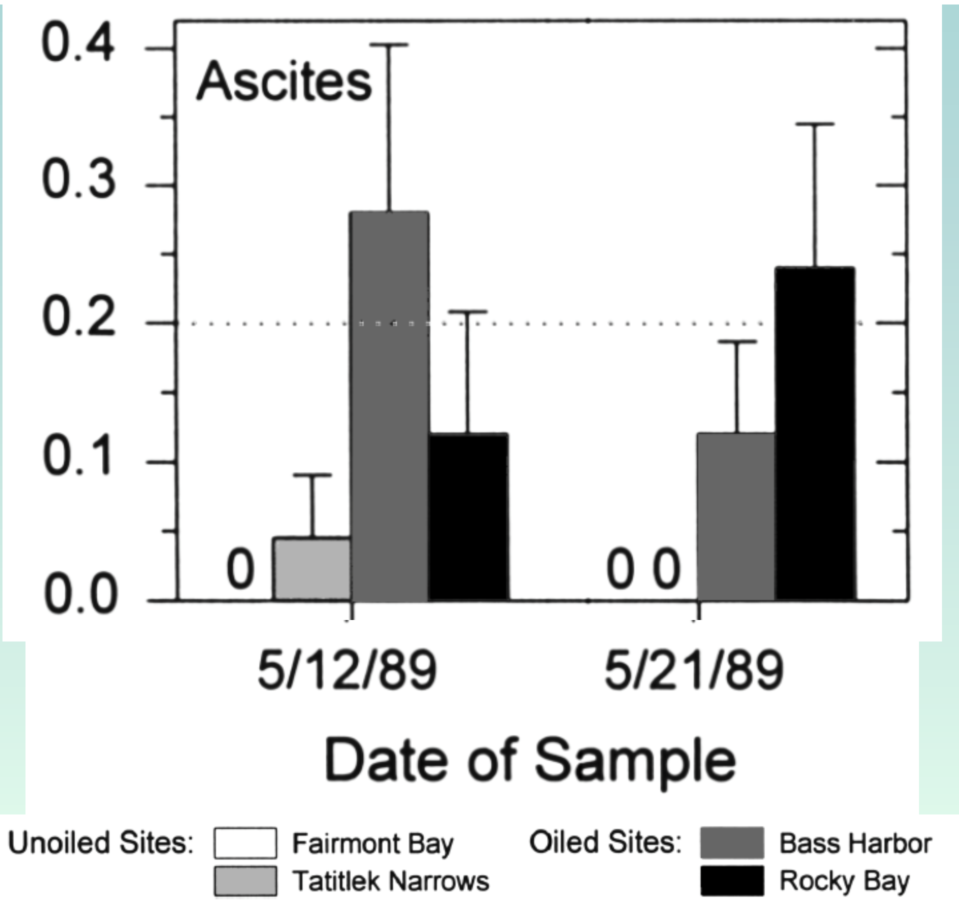
Pacific herring spawning:

- Nearshore intertidal and shallow subtidal
- Sticky eggs attached to macroalgae, eelgrass
- Adjacent to “bathtub ring” of oil

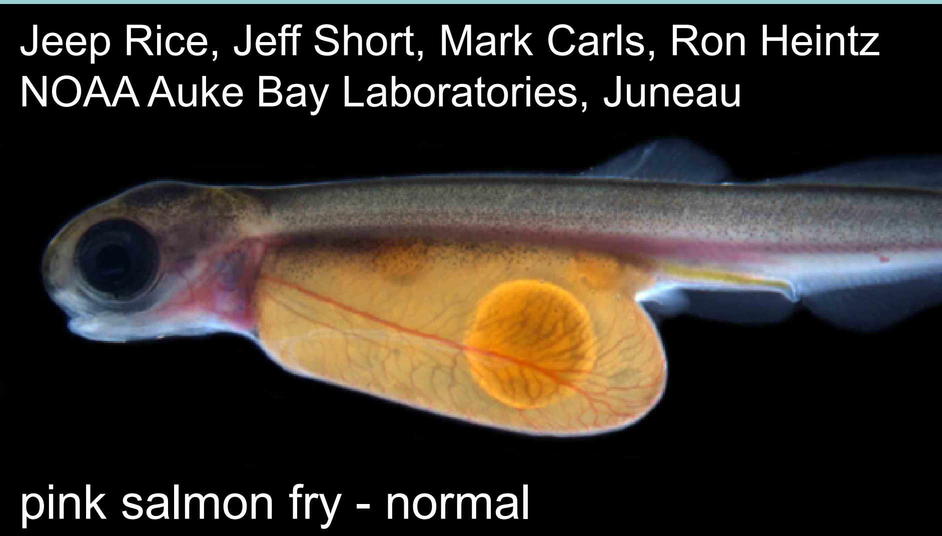
1846
Can. J. Fish. Aquat. Sci. **54**: 1846–1857 (1997)

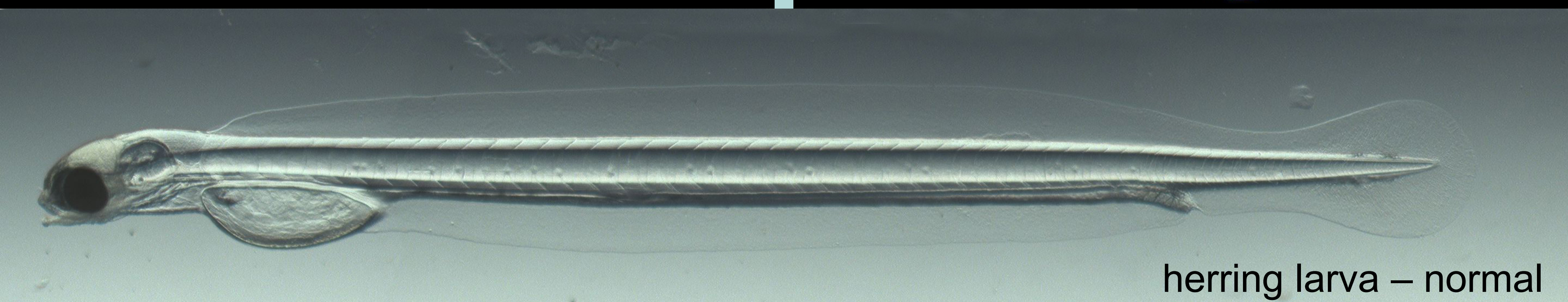
Histopathology and cytogenetic evaluation of Pacific herring larvae exposed to petroleum hydrocarbons in the laboratory or in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill

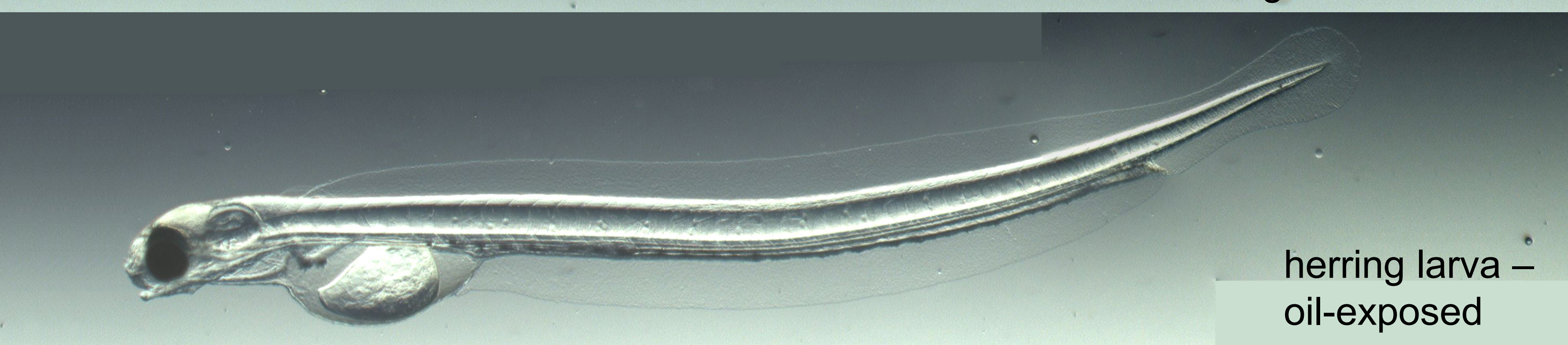
Gary D. Marty, J. E. Hose, Michael D. McGurk, Evelyn D. Brown, and David E. Hinton



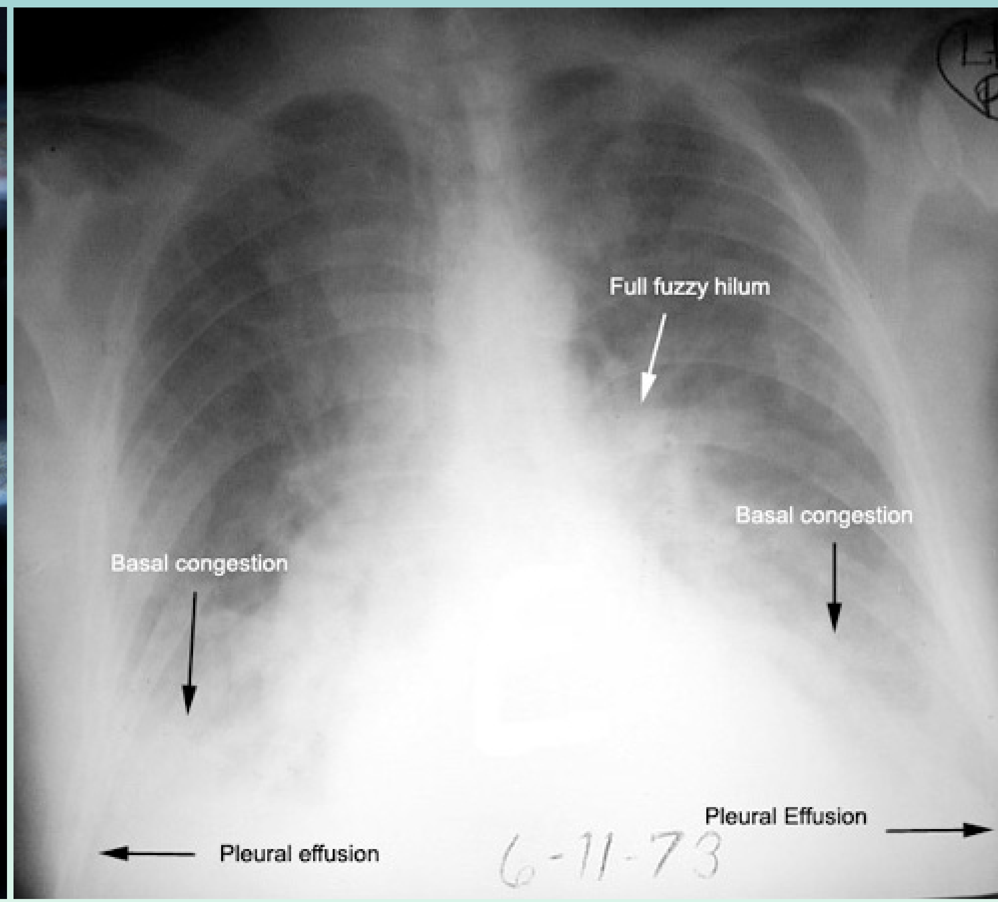
20 years of NOAA science: Oil and baby fish don’t mix







NOAA science 2002-2005: Crude oil is cardiotoxic and embryonic oil exposure causes heart failure



Chest x-ray, congestive heart failure

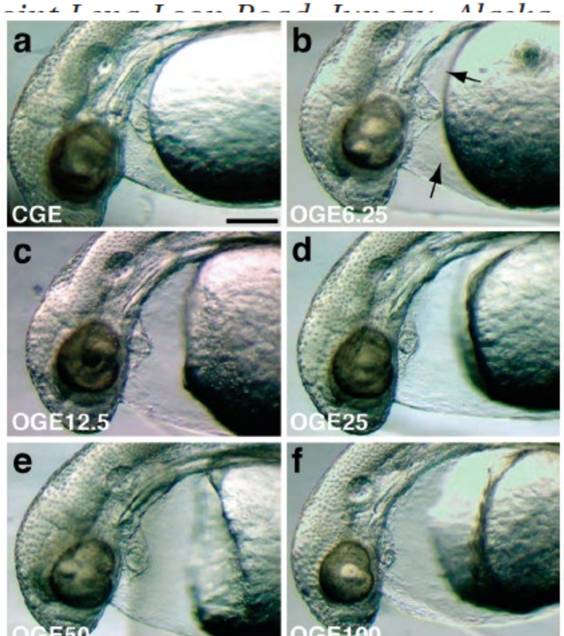
Incardona et al., 2004 Toxicol Appl Pharmacol 196:191
Incardona et al., 2005 Environ Health Perspec 113:1755

Cardiac Arrhythmia Is the Primary Response of Embryonic Pacific Herring (*Clupea pallasi*) Exposed to Crude Oil during Weathering

JOHN P. INCARDONA,*,† MARK G. CARLS,‡ HEATHER L. DAY,† CATHERINE A. SLOAN,† JENNIE L. BOLTON,† TRACY K. COLLIER,† AND NATHANIEL L. SCHOLZ†

Environmental Conservation Division, Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard E., Seattle, Washington 98112;, Alaska Fisheries Science Center, Auke Bay Laboratories, National Oceanic and Atmospheric Administration, 17109 P

99801



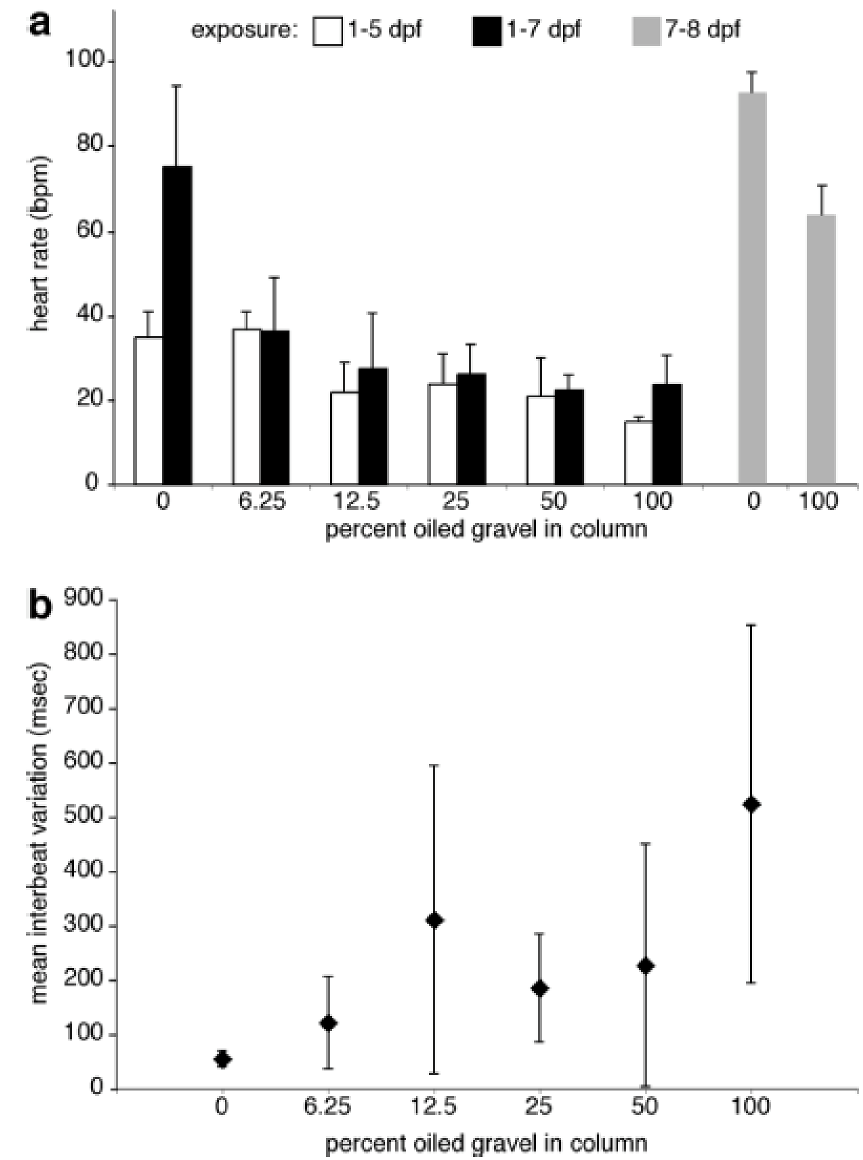


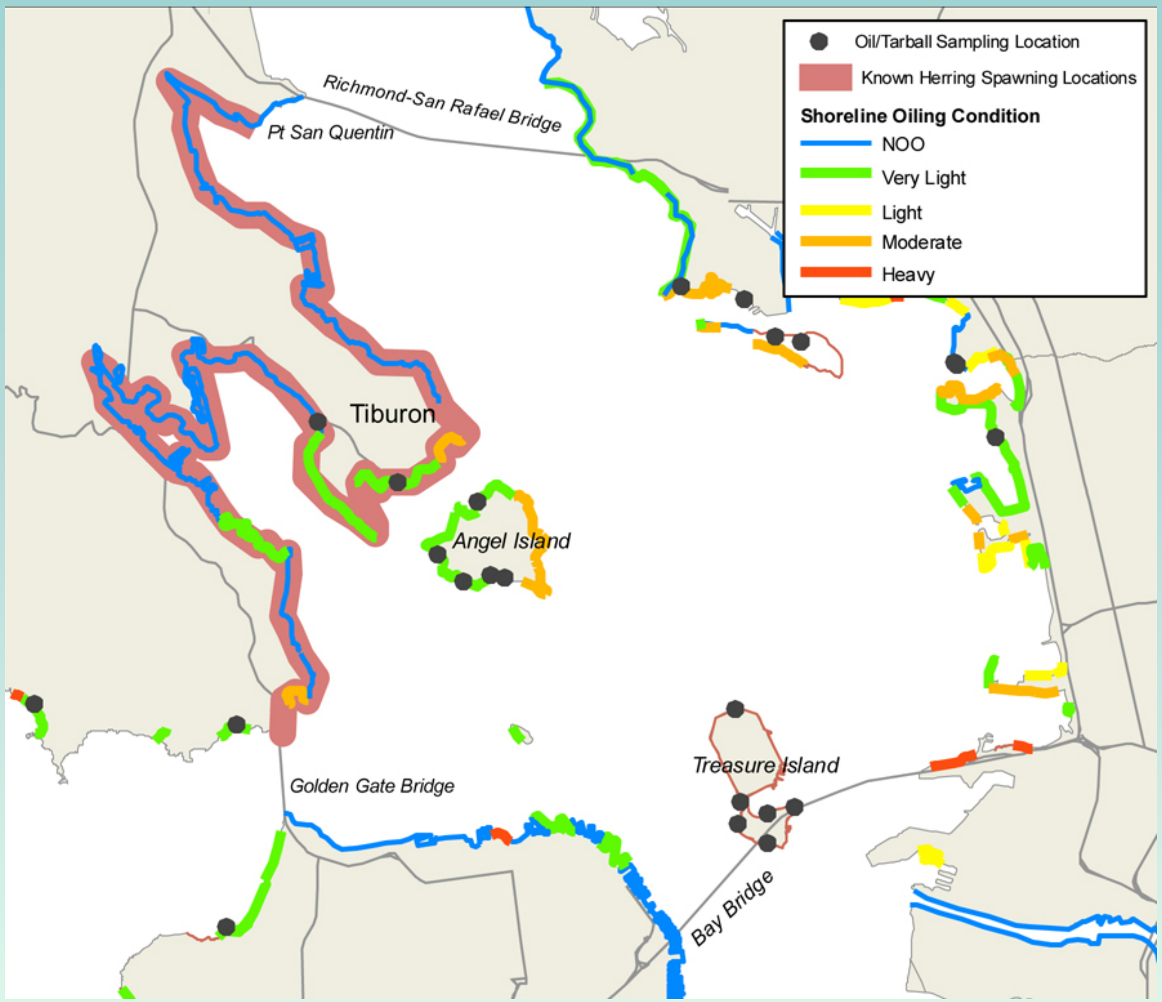
FIGURE 2. Dose-dependent bradycardia and irregular arrhythmia. (a) Heart rates were determined from digital video

Environ. Sci. Technol. **2009**, *43*, 201–207

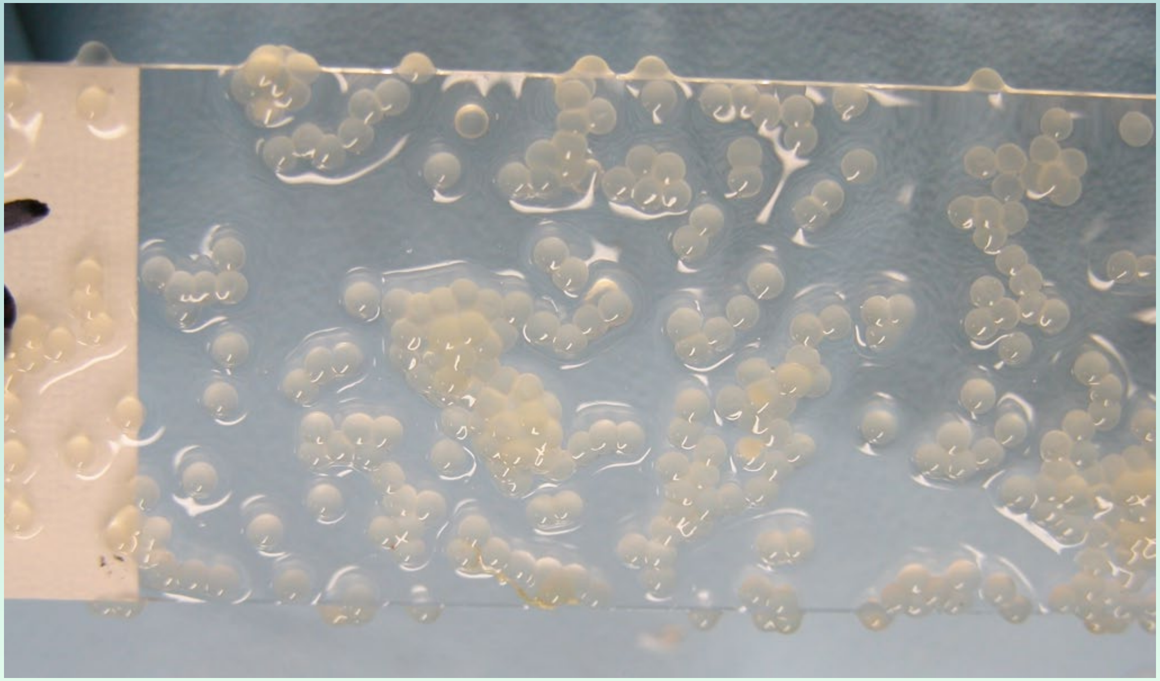
Cosco Busan Oil Spill, San Francisco Bay
November 7, 2007

~ 55,000 gallons of residual fuel oil (bunker fuel)

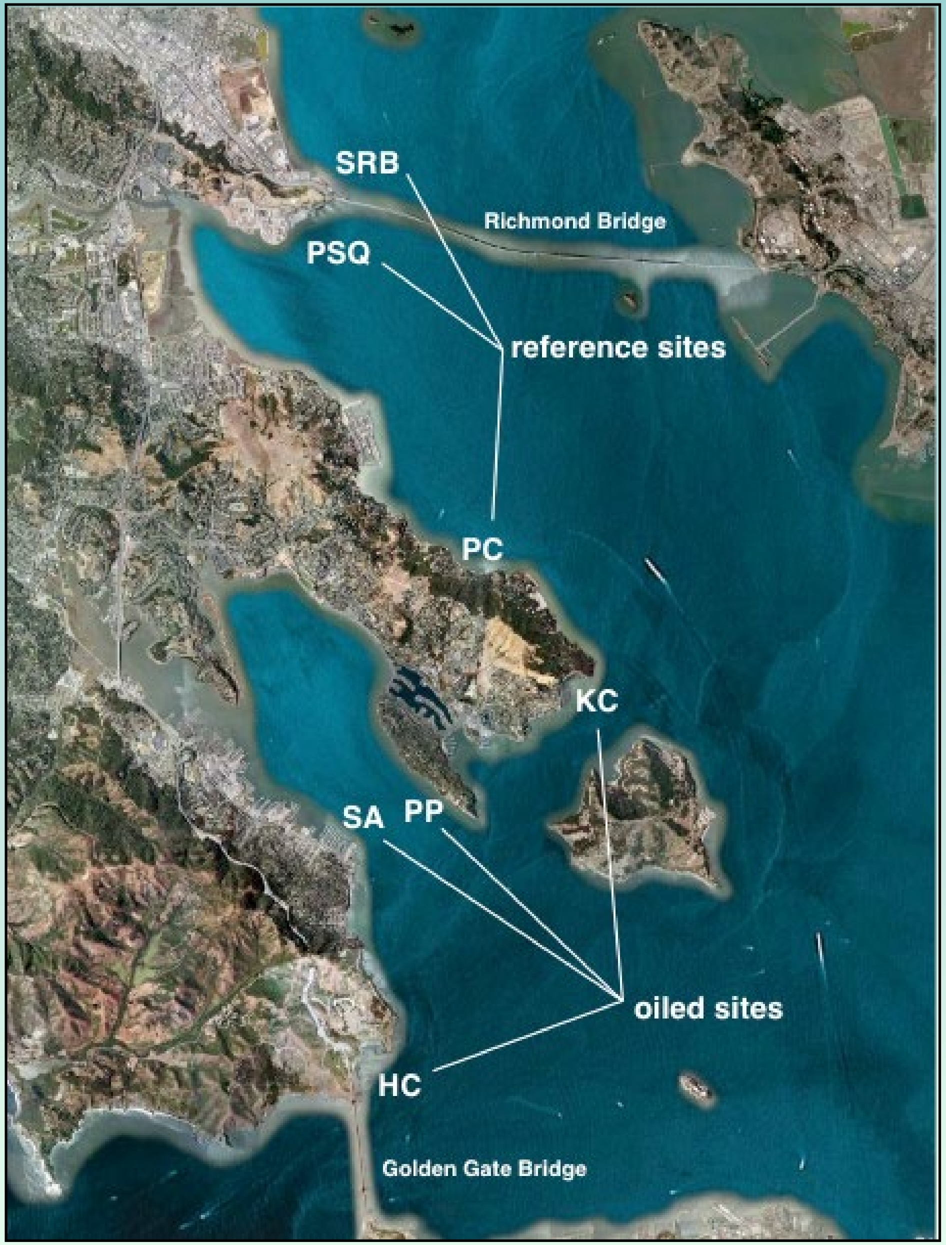
Cosco Busan fish injury assessment – a focus on herring



- Keystone and representative forage fish species
- Spill occurred weeks before the usual spawning season
- Extensive oil toxicity insights from *Exxon Valdez*
- Last remaining commercial finfish fishery in SF Bay



Field sites in San Francisco Bay



Reference (unoiled) sites:

SRB – San Rafael Bay
PSQ – Point San Quentin
PC – Paradise Cove

Oiled sites:

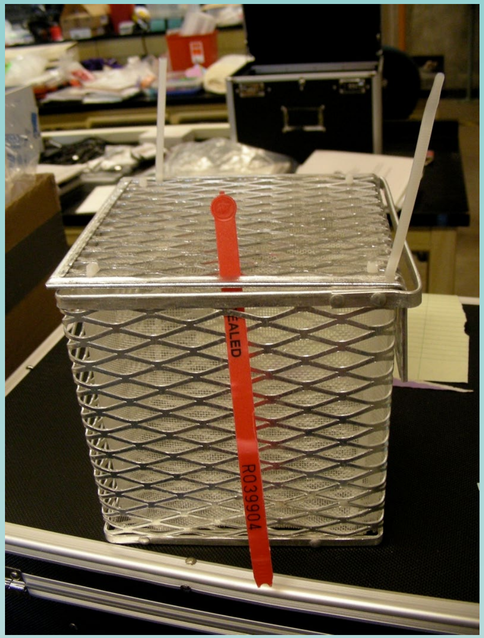
KC – Keil Cove
PP – Peninsula Point
SA – Sausalito
HC – Horseshoe Cove

Land use and maritime activities at study sites

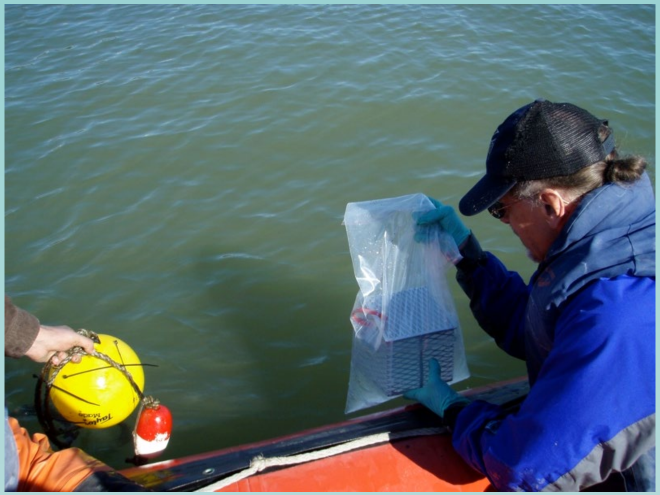
Site	SCAT	Cleanup	Characteristics
Horseshoe Cove (HC)	moderate-light oil	extensive wiping of rip-rap	marina, adjacent to major highway
Sausalito (SA)	very light-light oil	some wiping	marina, commercial, residential
Peninsula Point (PP)	light oil	some wiping	residential
Keil Cove (KC)	heavy-light oil	extensive wiping, removal of rock	residential, undeveloped
Paradise Cove (PC)	no oil	NA	residential, public park
San Rafael Bay (SRB)	no oil	NA	commercial, adjacent to major highway
Point San Quentin (PSQ)	no oil	NA	residential, industrial, adjacent to major highway

- Selected oiled and reference sites with appropriate locations for anchoring caged embryos at equal depth (-3 ft mean low low tide)
- Captured ripe adults, fertilized in the lab, deployed cages
- Incubated 5 cages per site to 7 days post-fertilization (dpf), ~ 3 days prior to hatch
- Returned to lab, dechorionated and imaged hearts in 30 embryos per cage (150 per site)

Incubation of caged embryos



fertilize
& deploy



7 day incubation

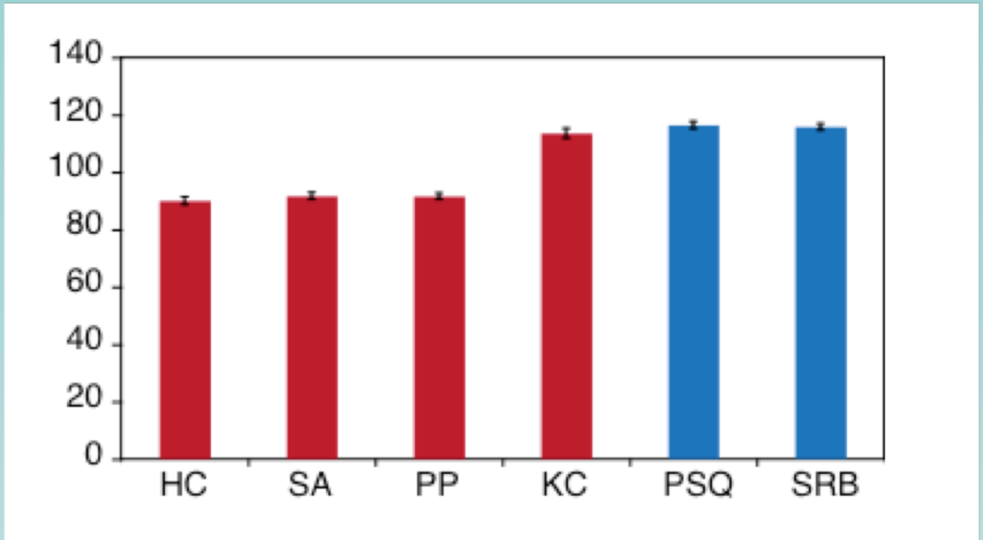
retrieve
& analyze

Cardiac function assessed in digital video collected on temperature-controlled microscope

Bradycardia and pericardial edema in subtidal (caged) embryos at oiled sites

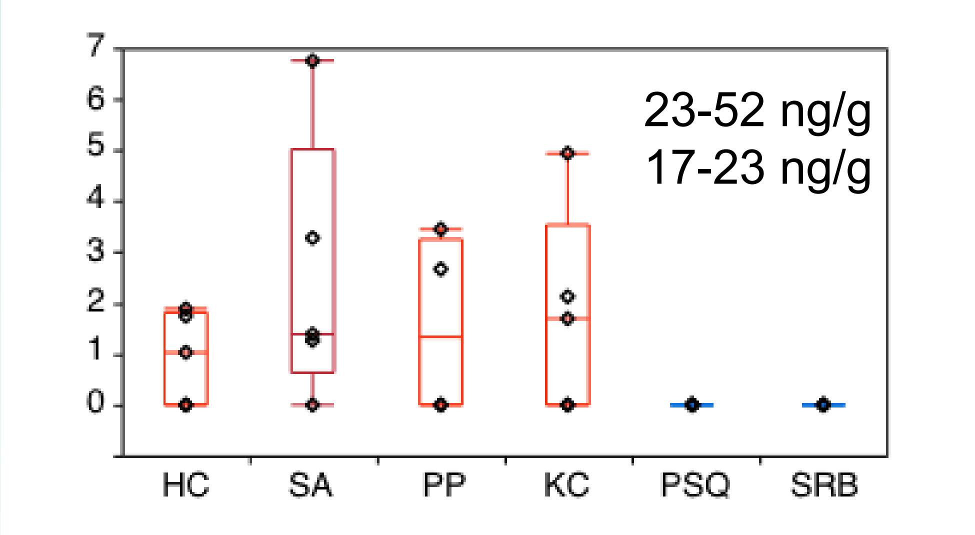
Site mean heart rate

N = 5 cages except 4 at PP and SRB



Oiled sites
Reference sites

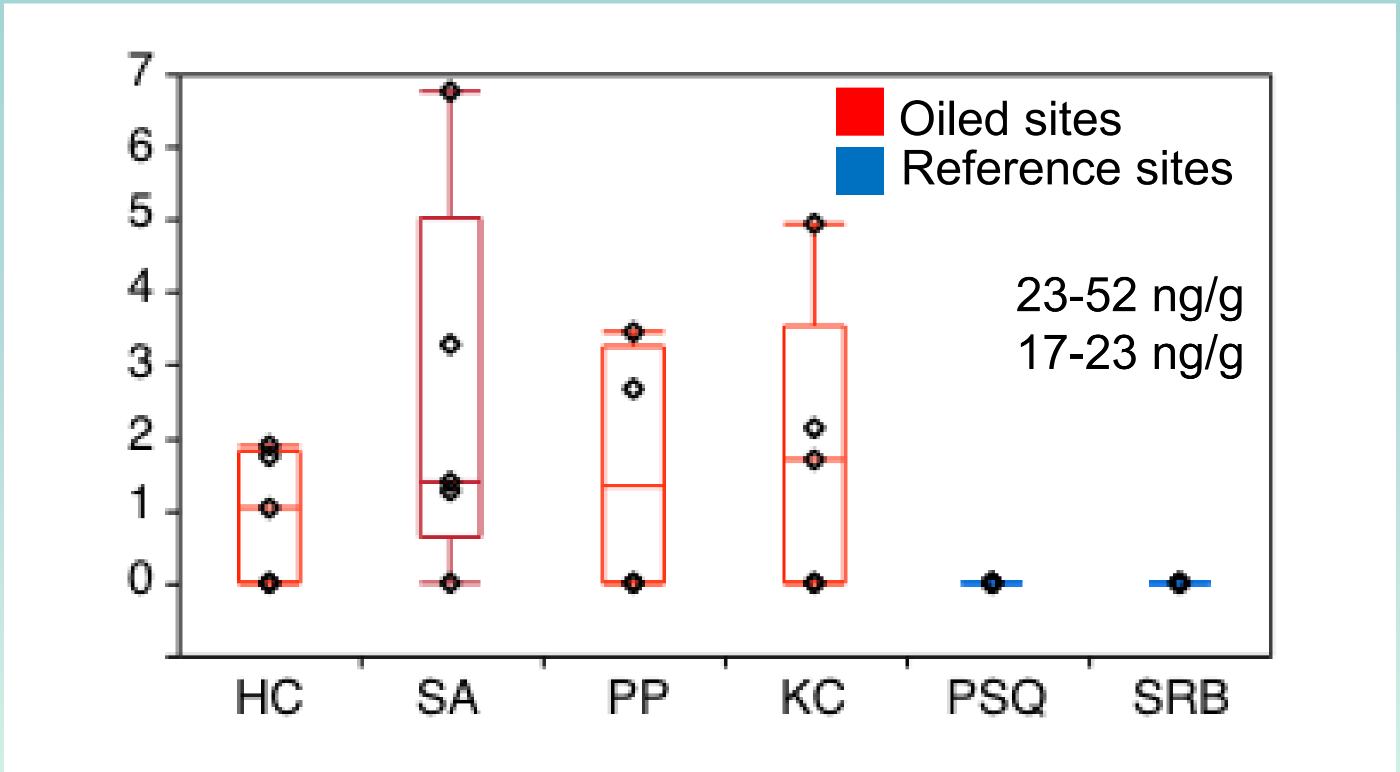
incidence of edema in larvae hatched in lab after cage incubation



Mean of N larvae: 539 351 232 484 308 344

This happens in the real world: Incidence of edema during *in situ* monitoring following Cosco Busan spill, SF Bay 2008

(caged herring embryos)



539 351 232 484 308 344

With enough statistical power, morphological markers are *very* sensitive

Incardona et al., 2012 PNAS 109:E51-58

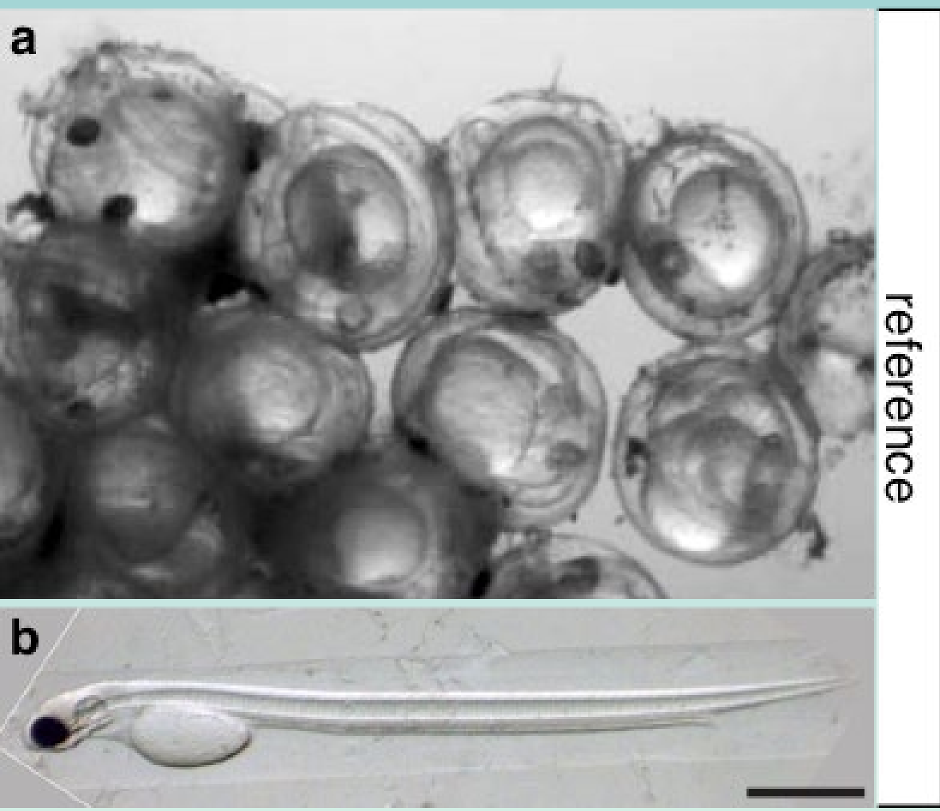
Natural spawn collection

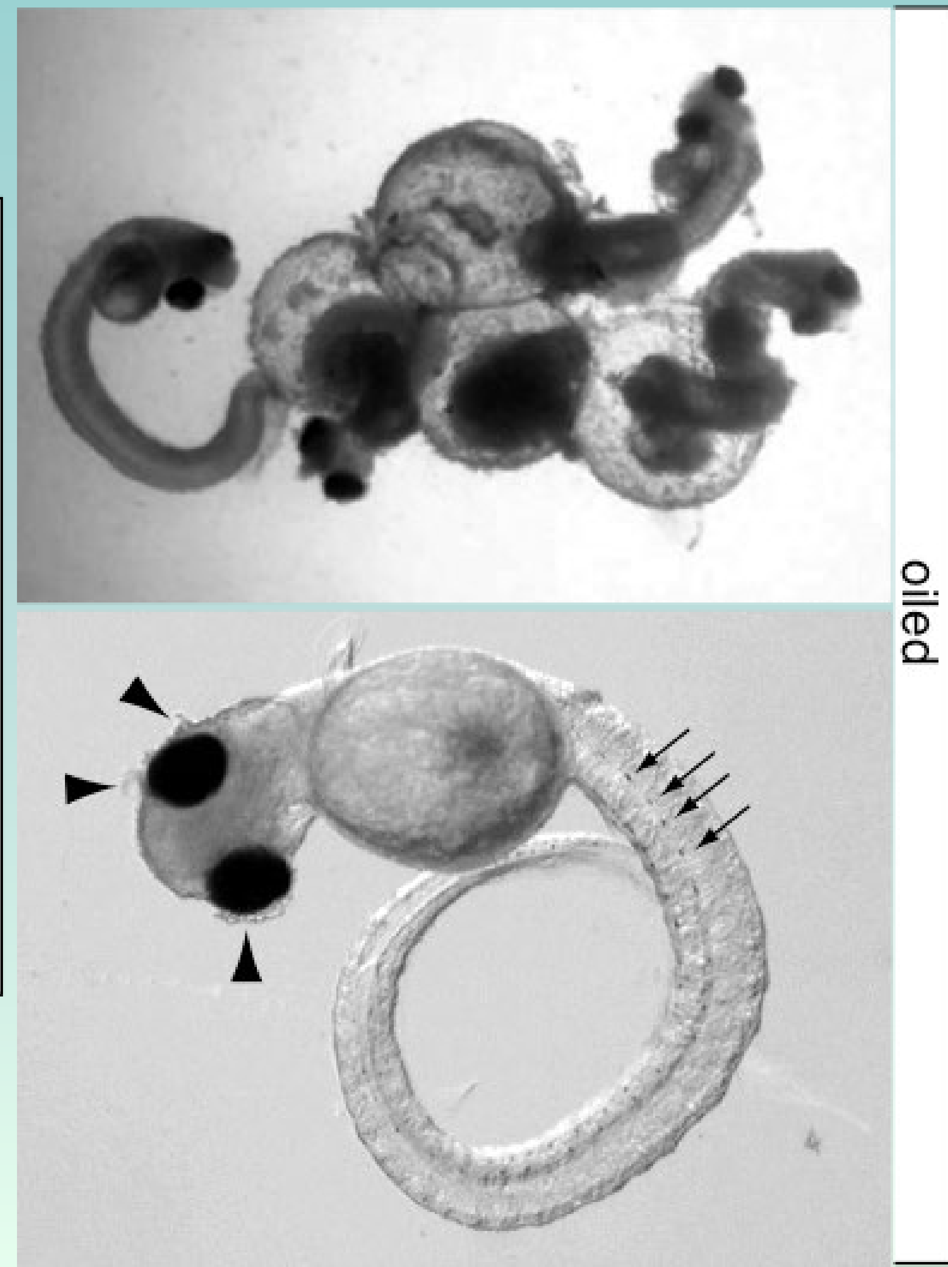
- Sample natural spawn opportunistically at oiled and reference sites
- Rake/snorkel surveys to estimate spawn date
- Collect samples at ~ 7 days post-fertilization
- Return to lab, dechorionate and image hearts

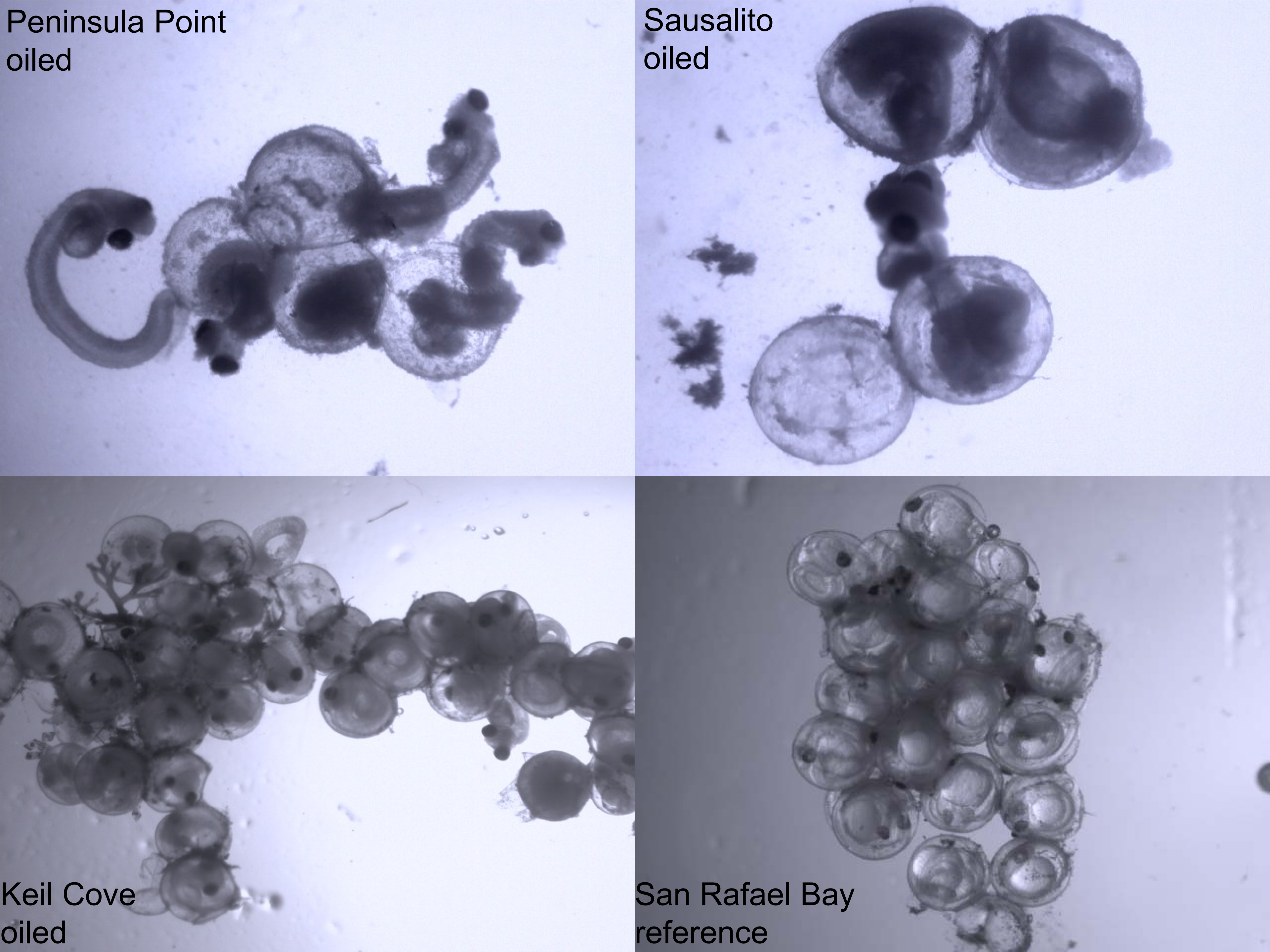
- 8 samples from 100-m transects
- 10 random grabs along transect pooled for 1 sample
- Collected in waders or by snorkel


Keil Cove
Maximum Oiling
Heavy
Moderate
Light
Very Light
No Oil
natural spawn
caged embryos
cage + PEMD
MRR20-KC-N1
MRR20-KC-N2
2/23/08
MRR20-KC-N5
MRR20-KC-N6a
MRR20-KC-N6b
MRR20-KC-A2
MRR20-KC-N7
MRR20-KC-A3
2/13/08
MRR20-KC-A5
MRR20-KC-A1
©2007 Google
Streaming 100%
Eye alt 387 m

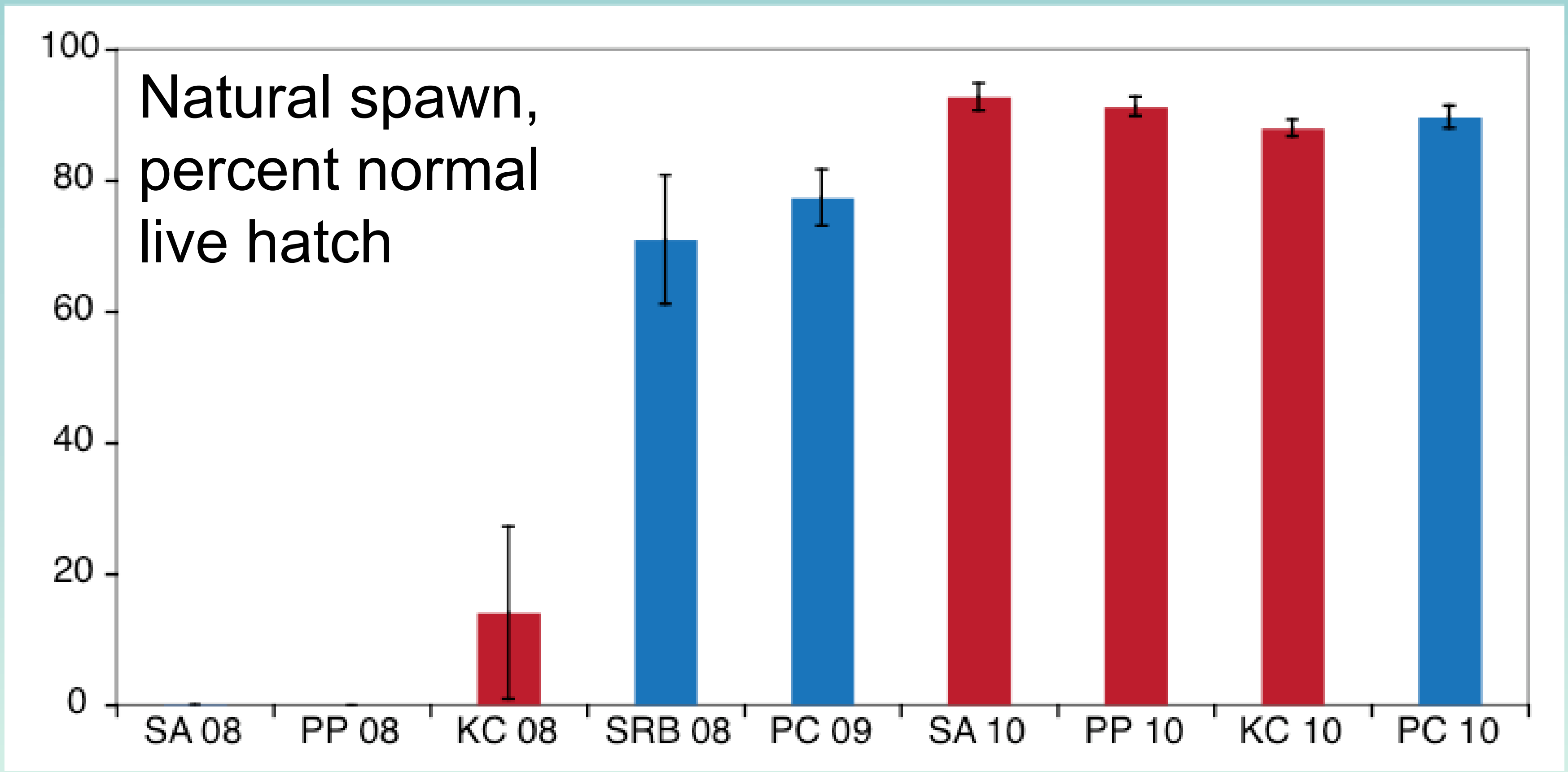
Unexpectedly high mortality at late development in intertidal spawn at oiled sites






Peninsula Point
oiled
Sausalito
oiled
Keil Cove
oiled
San Rafael Bay
reference

Poor larval hatch at oiled sites in 2008, return to reference levels in 2010



1.0 ± 0.3 | 3.5 ± 0.7 P<0.003 | 1.2 ± 0.7

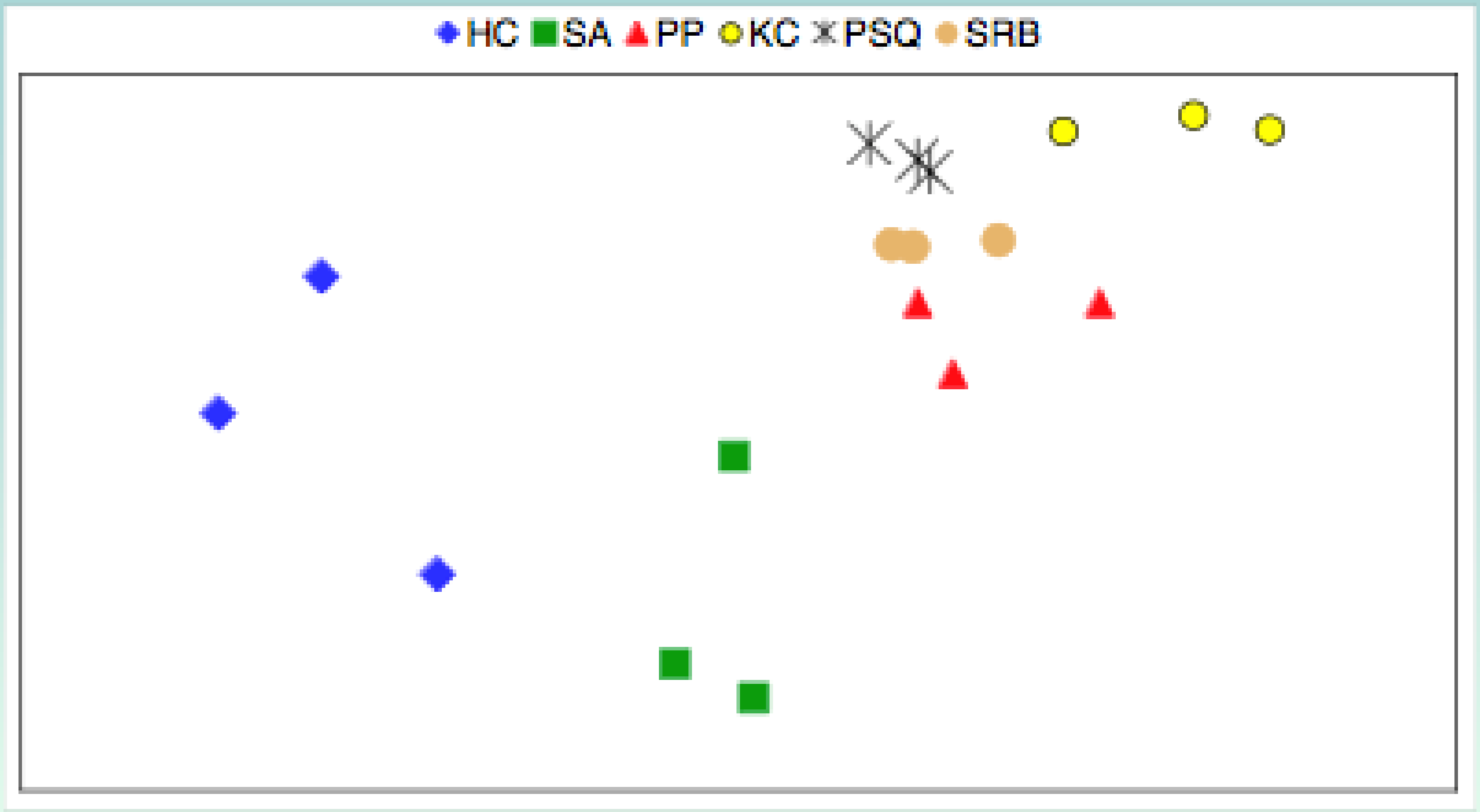
Normal hatching rates are ~ 80-90% (data from pre-spill years)

Complicated analytical chemistry results

- Overall total PAH levels low, ~ 20 ppb at reference sites, 45-80 ppb at oiled sites
- Levels near detection limits plus variability made standard parametric statistics problematic
- Nevertheless, diagnostic ratios and elevated dibenzothiophenes indicative of elevated petrogenic signal above urban background at oiled sites (especially Keil Cove)

Passive samplers (PEMDs) show distinct PAH inputs at each site, KC stands out as petrogenic

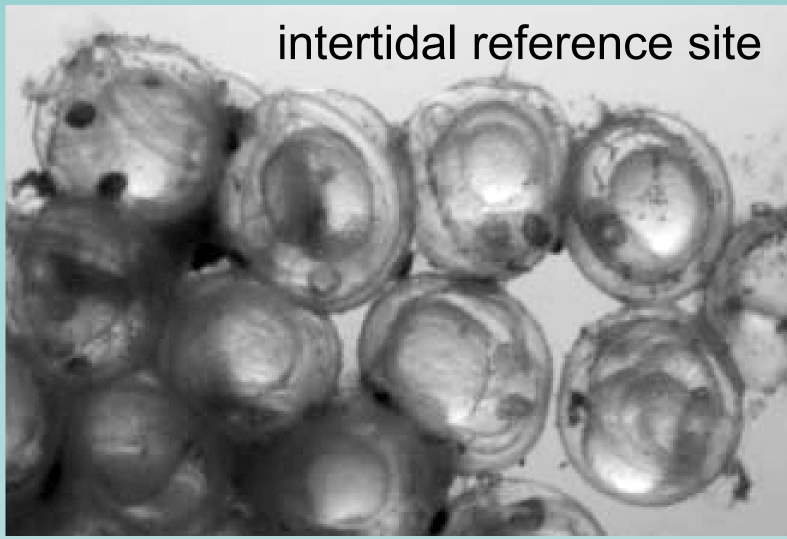
- unitless multidimensional scaling (Primer 6.0)
- stress = 0.05, ANOSIM: HC ~ SA, PSQ ~ SRB, PP, KC unique
- C24P/FL+PY and MP/P ratios show similar results, especially at KC

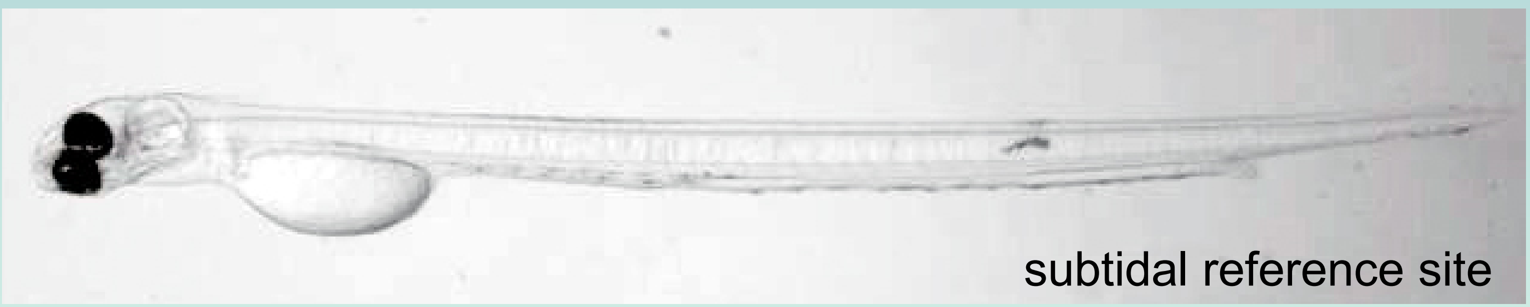


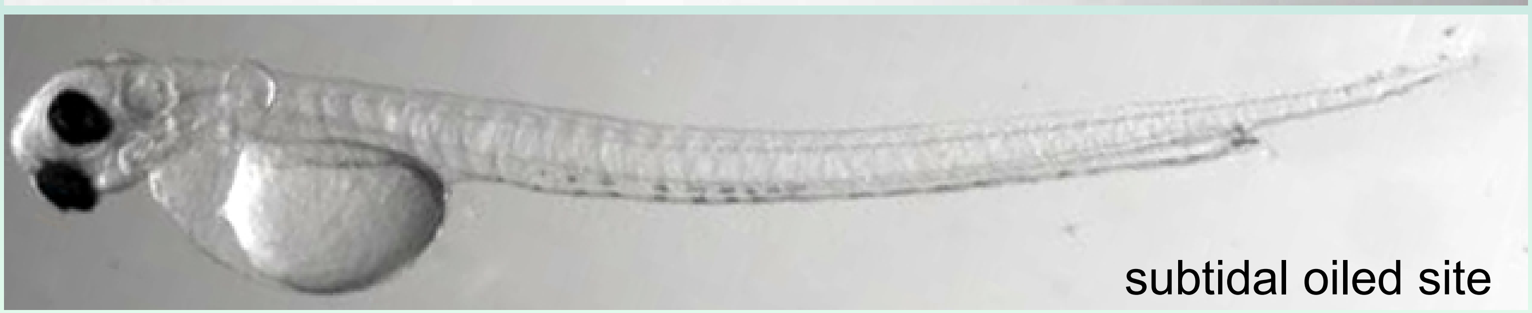
Summary of select PAH levels show increased petrogenic signal in embryos

matrix/yr (N)	site	mean ∑PACs	mean FLA	mean alkyl-DBTs	frequency C2/C3-DBT (%)
spawn/08 (8)	SRB	21 ± 2	1.1 ± 0.2	0.05 ± 0.03	0
spawn/08 (5)	SA1	81 ± 40	2.9 ± 0.7	0.49 ± 0.29	20
spawn/08 (3)	SA2	18 ± 3	0.6 ± 0.1	0	0
spawn/08 (8)	PP	19 ± 5	0.8 ± 0.1	0.12 ± 0.08	25
spawn/08 (8)	KC	45 ± 18	3.8 ± 2.2	0.28 ± 0.09	75
spawn/10 (8)	PC	28 ± 3	0.5 ± 0.1	0.05 ± 0.05	13
spawn/10 (3)	SA2	27 ± 1	1.4 ± 0.1	0	0
spawn/10 (8)	PP	23 ± 1	0.6 ± 0.1	0	0
spawn/10 (8)	KC	34 ± 9	1.8 ± 1.0	0.48 ± 0.16	100
cage/08 (5)	PSQ	23 ± 2	1.0 ± 0.2	0.09 ± 0.06	0
cage/08 (4)	SRB	17 ± 3	0.8 ± 0.3	0	0
cage/08 (4)	HC	52 ± 10	3.7 ± 0.9	0.48 ± 0.23	50
cage/08 (5)	SA	48 ± 6	2.7 ± 0.5	0.51 ± 0.13	80
cage/08 (4)	PP	21 ± 1	0.8 ± 0.1	0	0
cage/08 (5)	KC	24 ± 3	0.7 ± 0.1	0.21 ± 0.10	40

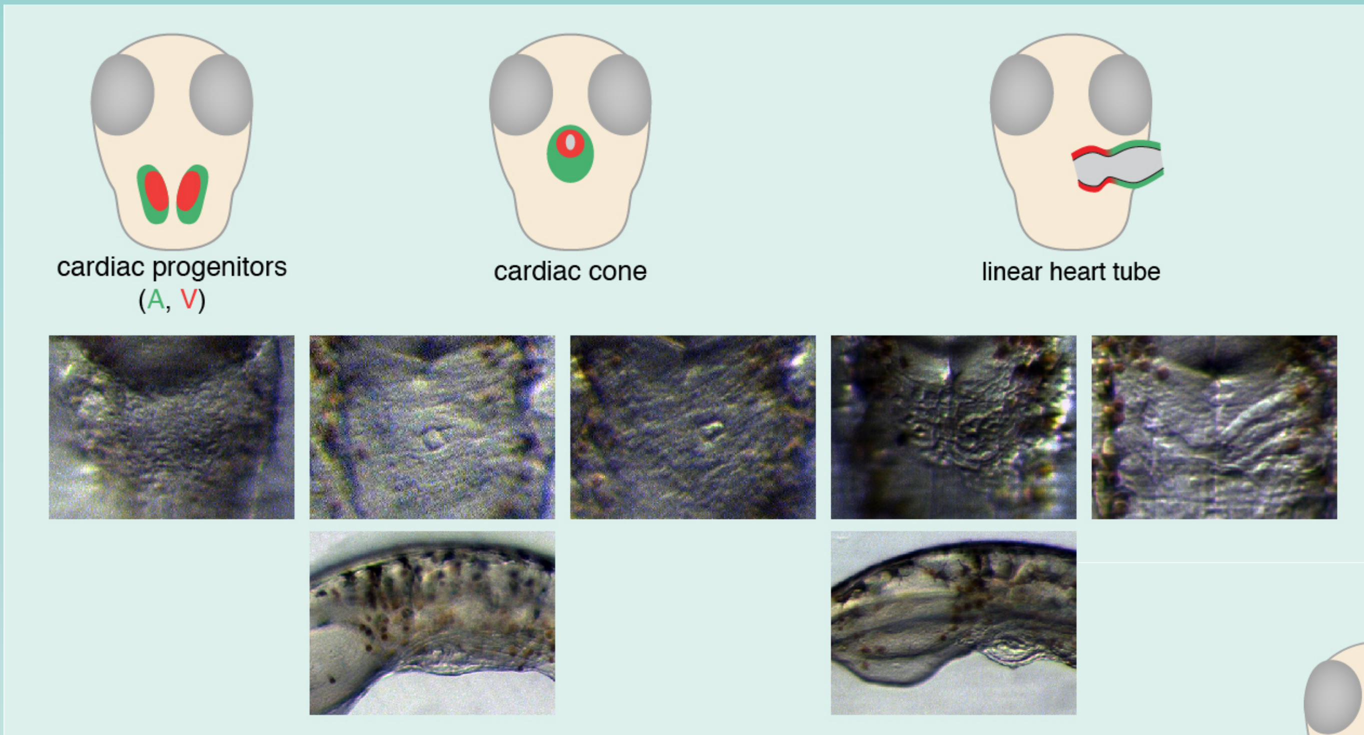
What explains intertidal vs subtidal observations?

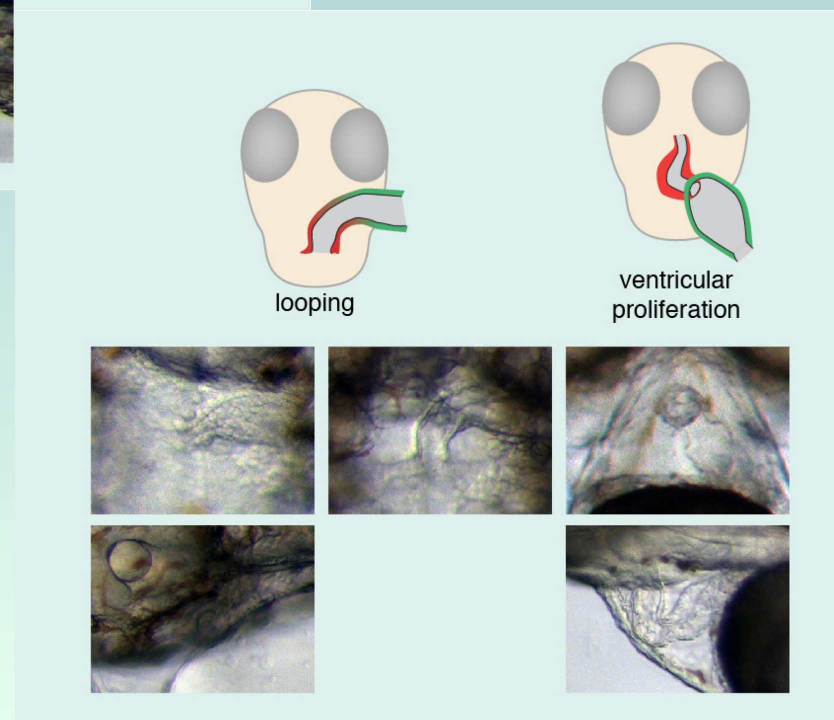




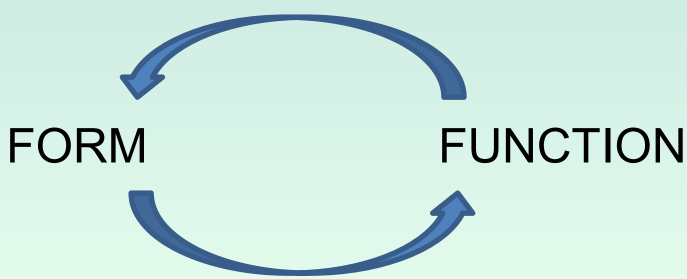


Fish heart development





The heart begins to work as a pump before it is fully formed

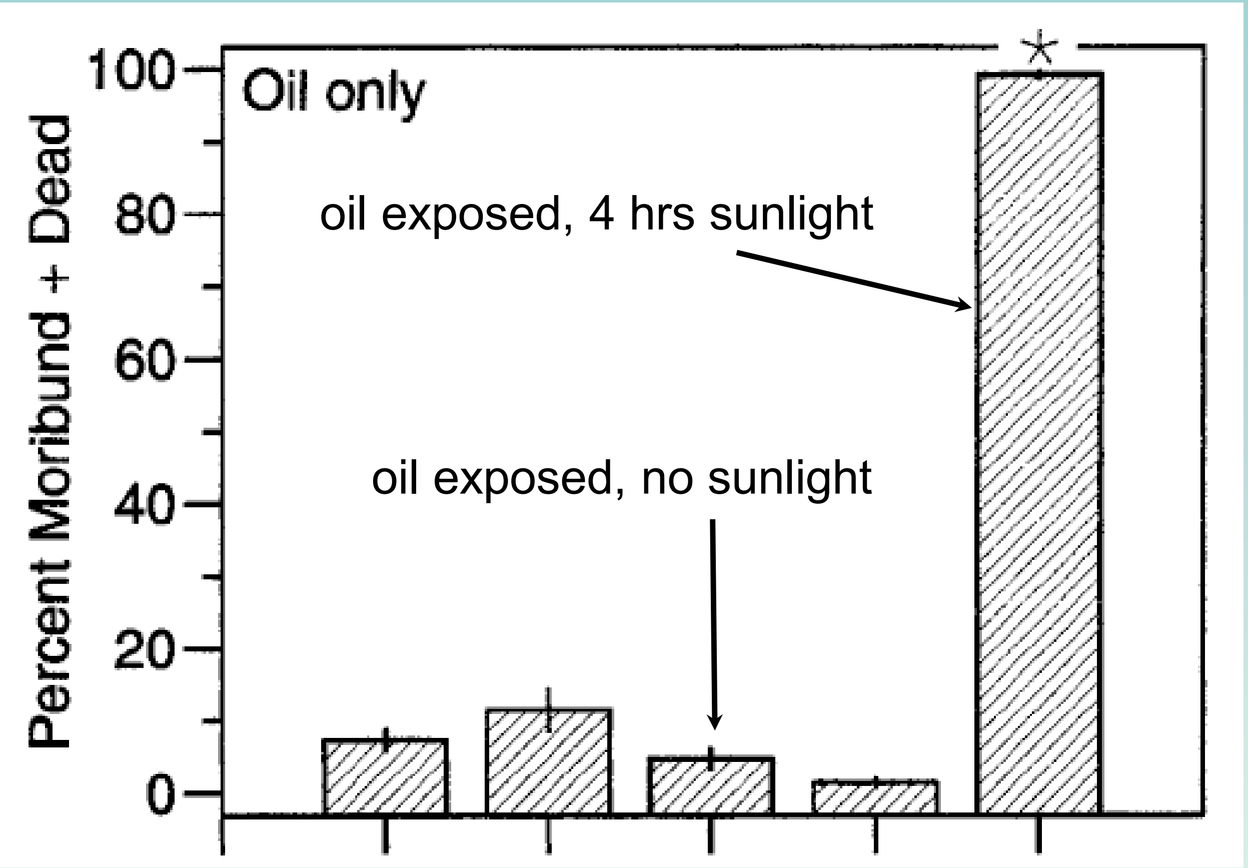


Who dunnit?

- Sewage spill?
- Sub-optimal salinity?
- Poor maternal condition?
- Legacy pollutants, e.g. PCBs, DDTs?

Crude oil can induce acute mortality in herring larvae through phototoxicity (oxidative membrane damage)

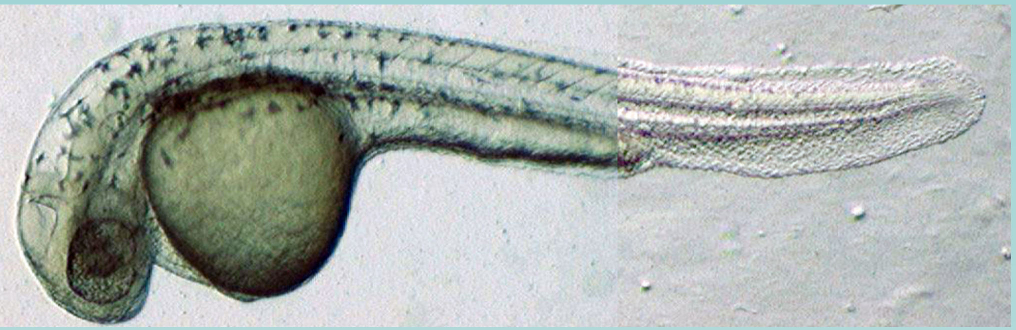
Barron et al., 2003 *ET&C* 22:650



embryos 1.6 µg/g TPAH, no mortality
larvae 35 µg/g TPAH, 95% mortality

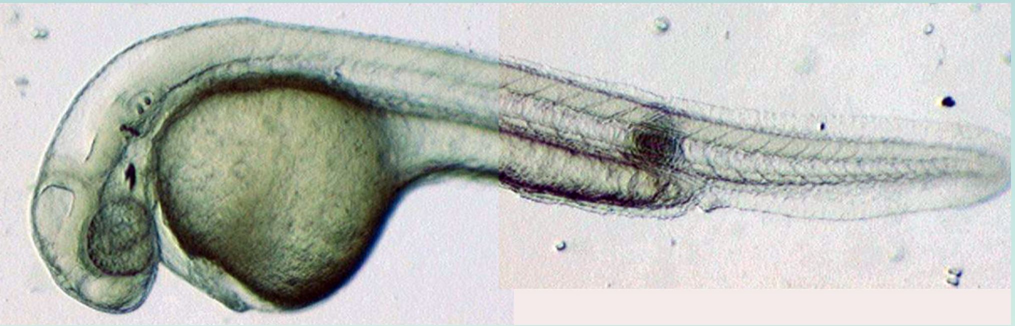
Bunker oil is much more highly phototoxic to zebrafish embryos than crude oil

Hatlen et al., 2010 *Aquat Toxicol* 99:56



crude oil 210 µg/L TPAH + shade

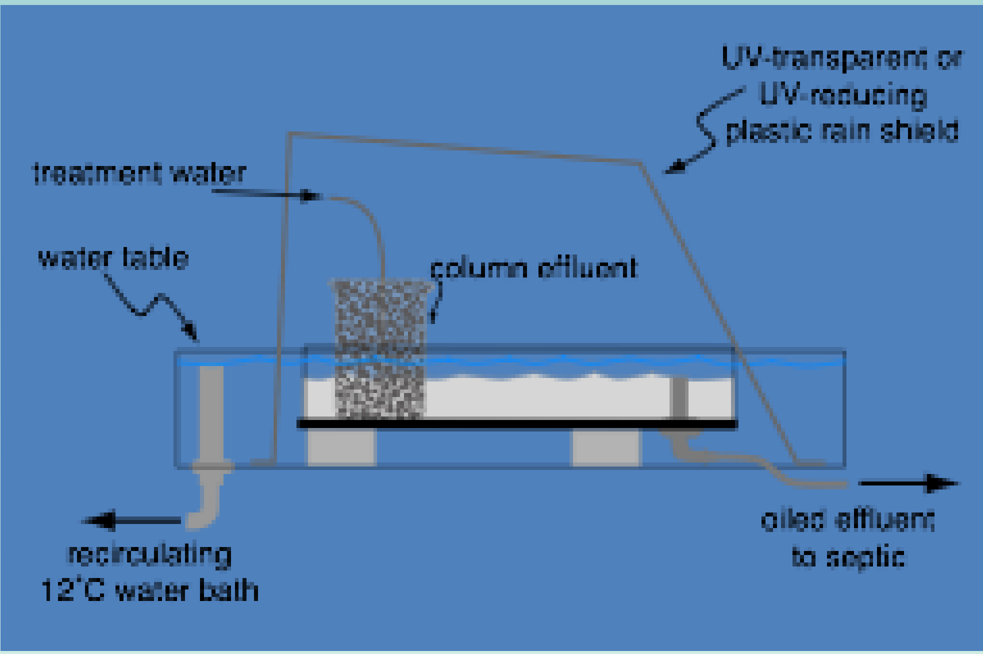
crude oil 210 µg/L TPAH + sun



bunker 240 µg/L TPAH + shade

bunker 240 µg/L TPAH + sun

Busan bunker oil both necessary and sufficient to induce acute necrotic damage to herring embryos when combined with



Oiled gravel column dosing

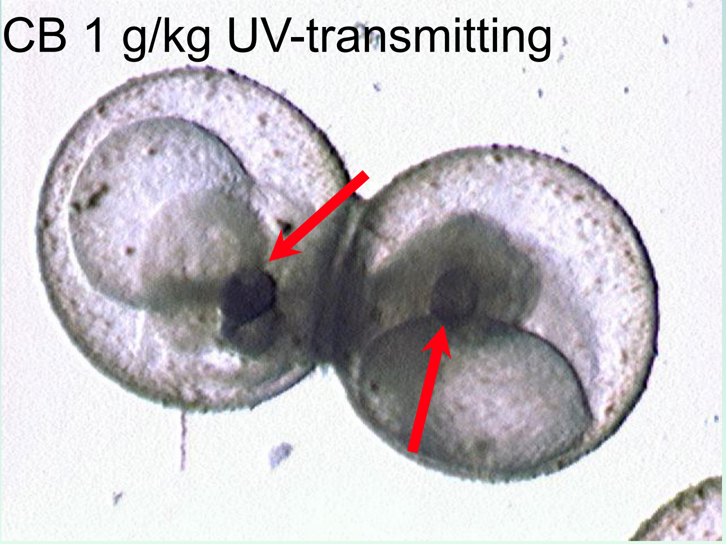
1 g/kg   0.3 g/kg   0.1 g/kg   clean

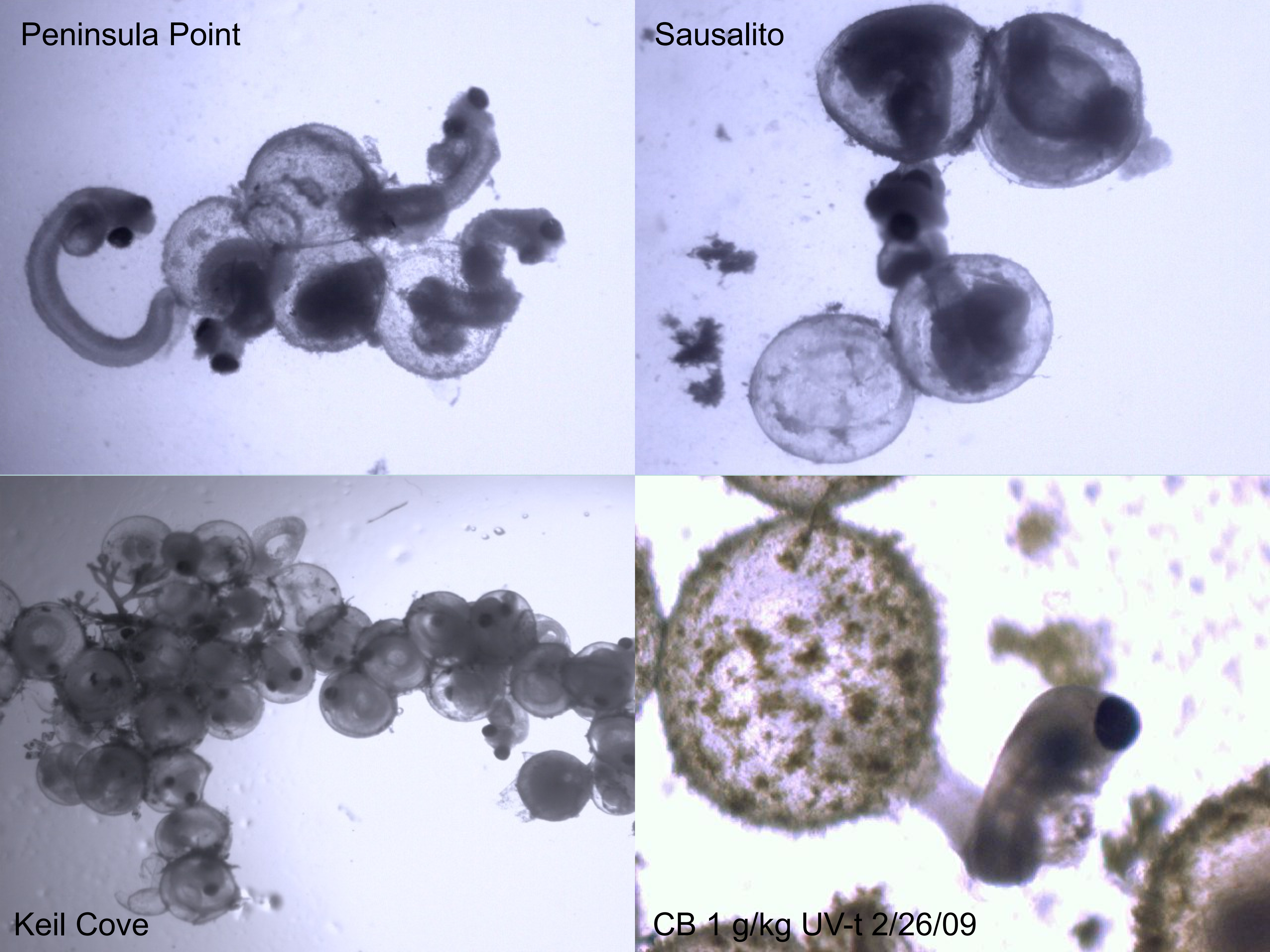
Cosco Busan bunker oil (CBBO) vs. Alaska North Slope crude oil (ANSCO)

Loss of tissue integrity (necrosis) with CBBO + sunlight at 8 dpf

viable eyed embryos 8 dpf

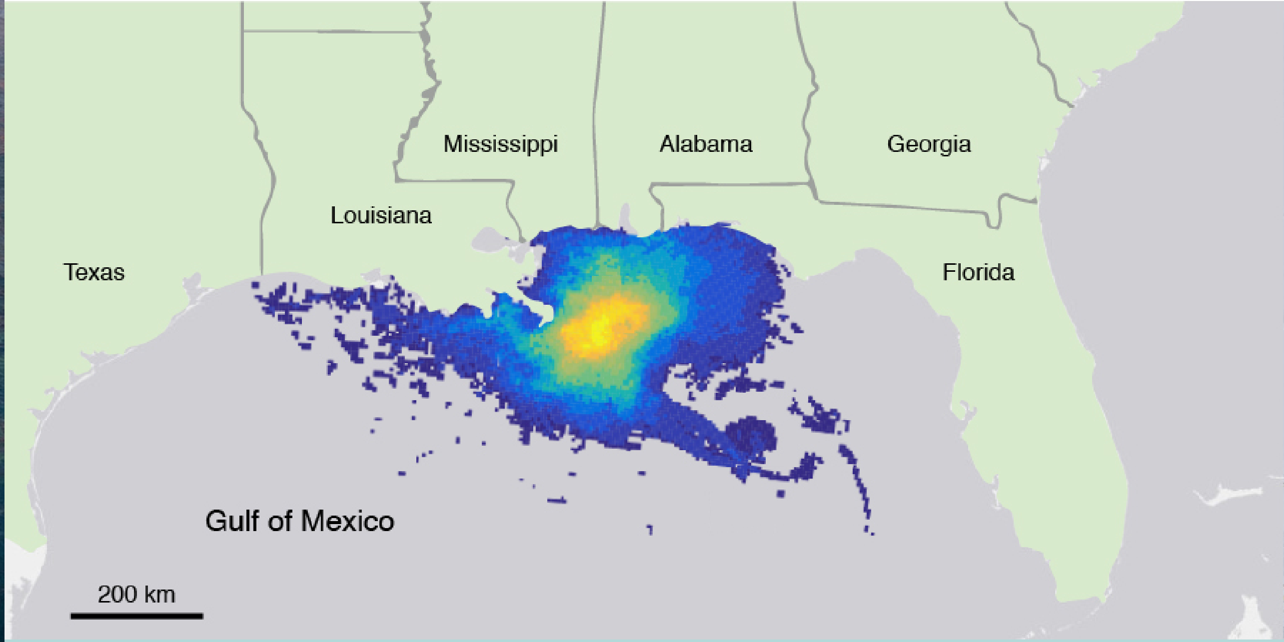
necrotic eyed embryos 8 dpf



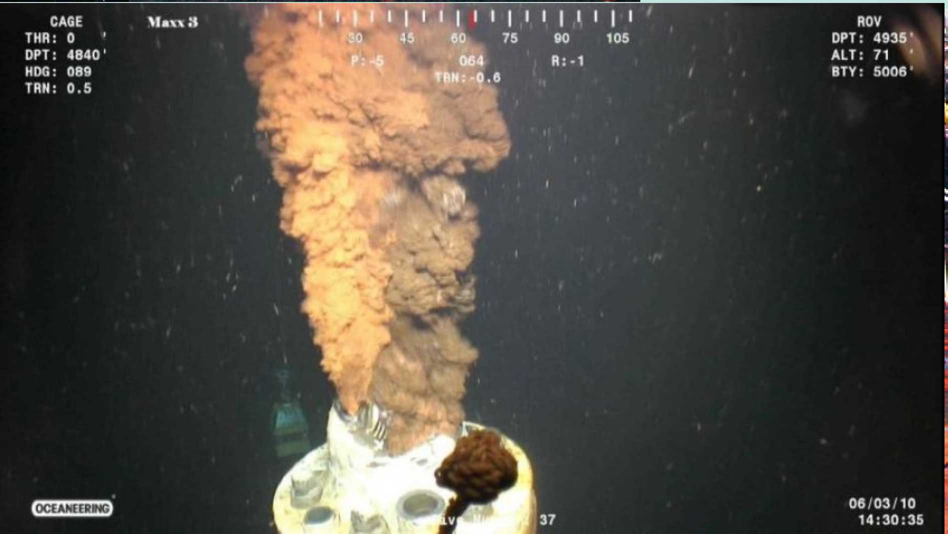

Peninsula Point
Sausalito
Keil Cove
CB 1 g/kg UV-t 2/26/09

Implications of CBOS for oil spills at home and abroad

- Biological receptors (fish embryos) currently have greater resolving power than forensic chemistry
- Need to distinguish effects of urbanization chemically AND biologically
- More coordinated research between chemists and biologists regarding the complex components of different oils
- Bunker fuel is woefully understudied
- Interactions between chemicals and other stressors



Deepwater Horizon: April 20 – Sept 19, 2010



Sampling baby fish

herring eggs

pelagic larvae

salmon eggs/larvae

Sampling baby fish

herring eggs

pelagic larvae

salmon eggs/larvae

What is feasible for real time remote sensing of oil spill impacts?

Biological complexity

Ecophysiological complexity

pink salmon (*Oncorhynchus gorbuscha*)	☃
Pacific herring (*Clupea pallasi*)	☃
Atlantic herring (*Clupea harrengus*)	☃
mummichog (*Fundulus heteroclitus*)	☃☼
Gulf killifish (*Fundulus grandis*)	☃☼
crimson-spotted rainbowfish (*Melanotaenia fluviatilis*)	☼
medaka (*Oryzias latipes*)	☃☼
marine medaka (*Oryzias melastigma*)	☃☼
silversides (*Menidia beryllina*)	☼
zebrafish (*Danio rerio*)	☼
olive flounder (*Paralichthys olivaceous*)	☃☼
Japanese sea perch (*Lateolabrax japonicus*)	☃☼
bluefin tuna (*Thunnus thynnus*)	☃☼
yellowfin tuna (*Thunnus albacares*)	☼
mahi mahi (*Coryphaena hippurus*)	☼
yellowtail amberjack (*Seriola lalandi*)	☃☼
red drum (*Sciaenops ocellatus*)	☃☼
Atlantic haddock (*Melanogrammus aeglefinus*)	☃
Atlantic cod (*Gadus morhua*)	☃
Arctic cod (*Boreogadus saida*)	☃☃
Saithe (*Pollachius virens*)	☃
Atlantic halibut (*Hippoglossus hippoglossus*)	☃

From the Committee and Staff of Oil in the Sea IV,

Thank you!

Questions or Comments?
Please contact Kelly Oskvig @ koskvig@nas.edu