Salmon Conservation in Toxic Urban Watersheds

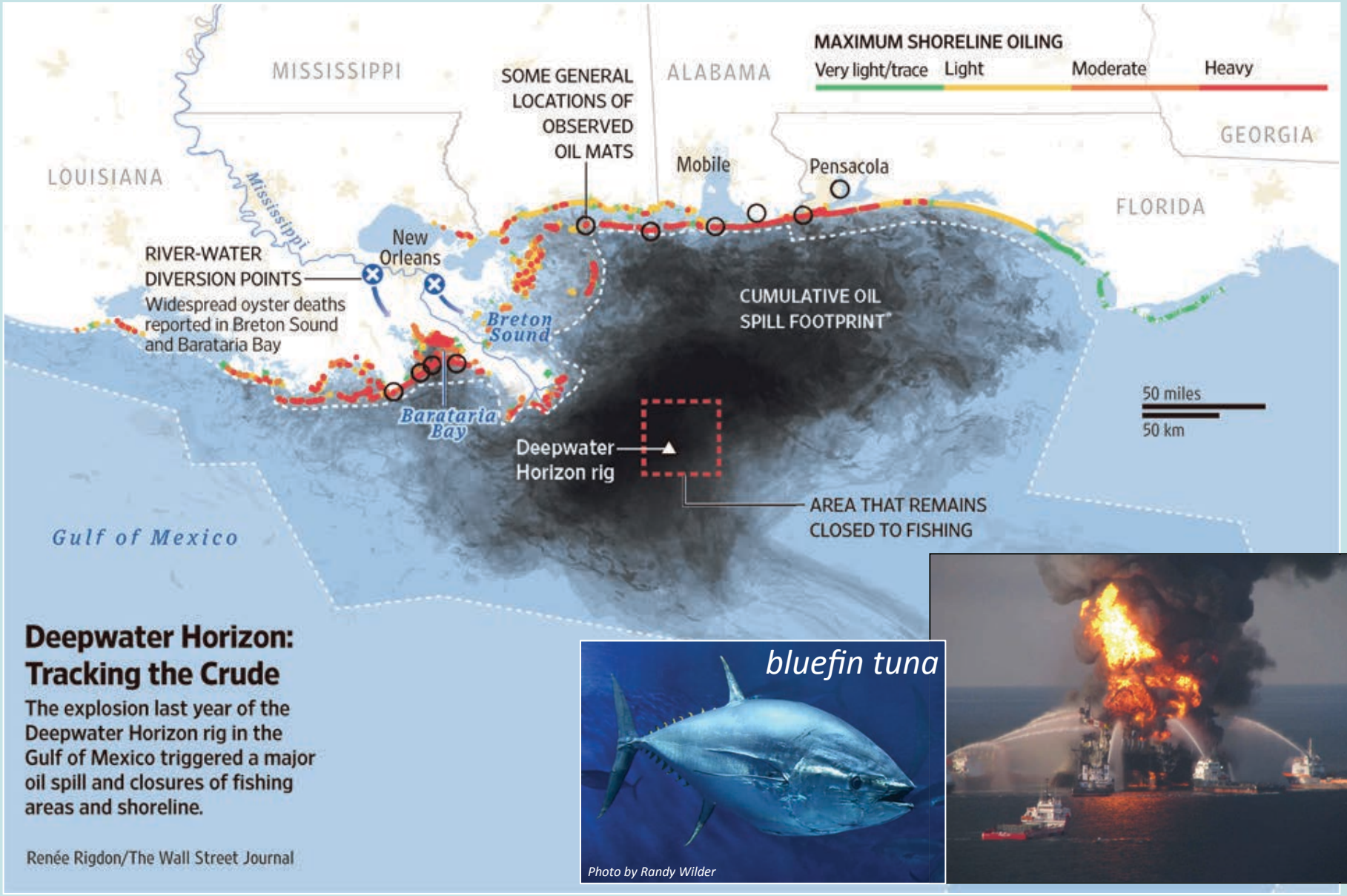
Nat Scholz and Jessica Lundin

NOAA Fisheries, Northwest Fisheries Science Center

USGS Oregon Water Science Center, 2016

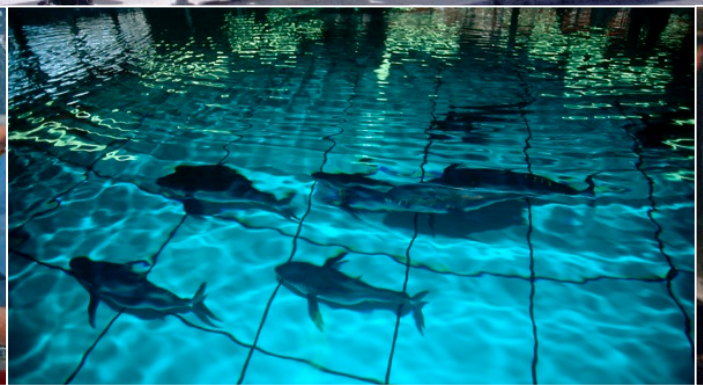
Photo by John McMillan

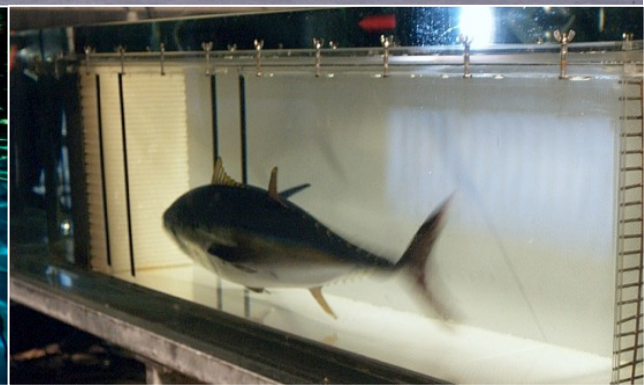
2010 *Deepwater Horizon* disaster

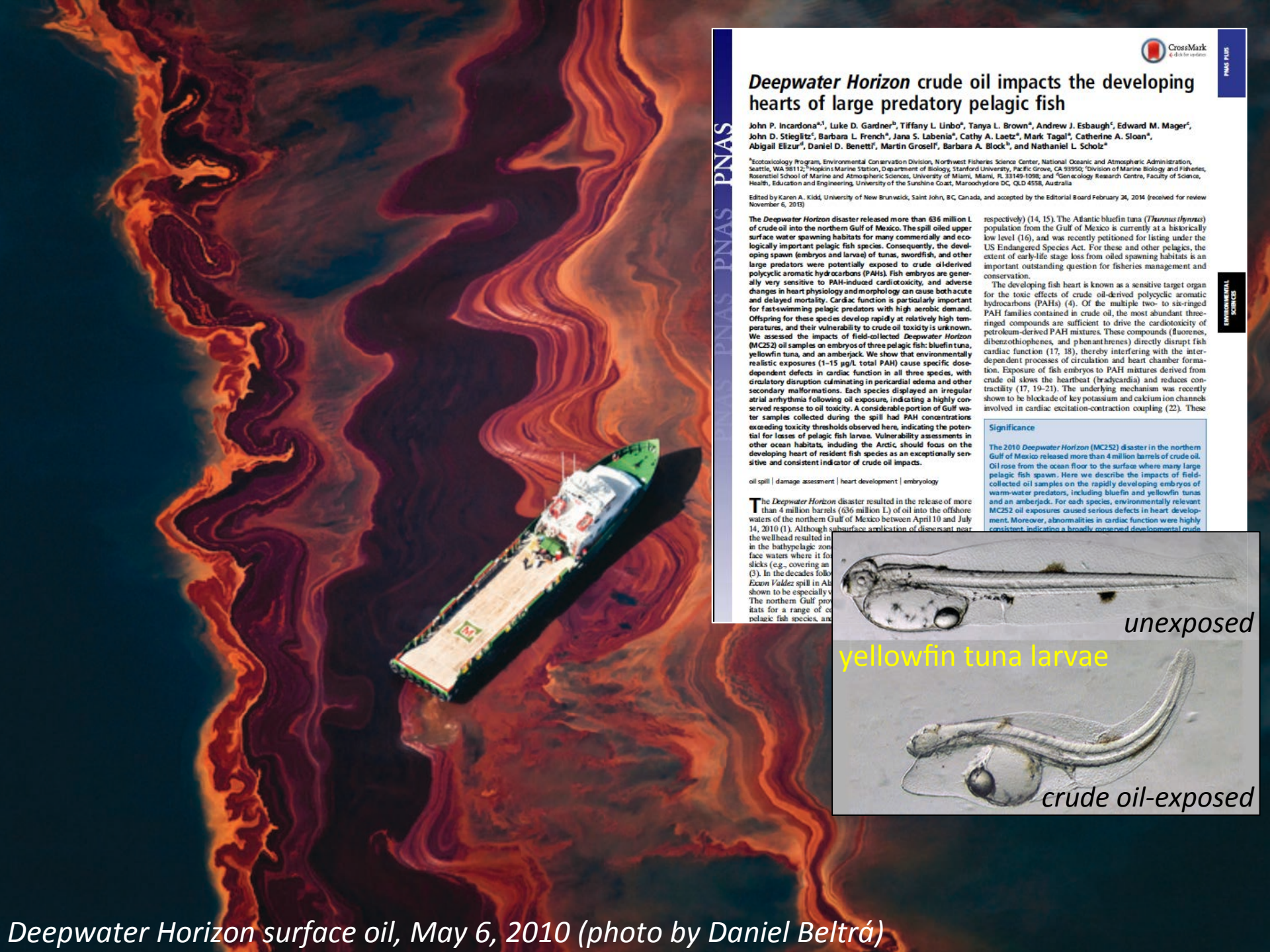


Tuna Research and Conservation Center

Stanford University and the Monterey Bay Aquarium







Deepwater Horizon crude oil impacts the developing hearts of large predatory pelagic fish

John P. Incardona[a,1], Luke D. Gardner[b], Tiffany L. Linbo[a], Tanya L. Brown[a], Andrew J. Esbaugh[c], Edward M. Mager[c], John D. Stieglitz[c], Barbara L. French[a], Jana S. Labenia[a], Cathy A. Laetz[a], Mark Tagal[a], Catherine A. Sloan[a], Abigail Elizur[d], Daniel D. Benetti[e], Martin Grosell[c], Barbara A. Block[b], and Nathaniel L. Scholz[a]

[a]Ecotoxicology Program, Environmental Conservation Division, Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA 98112; [b]Hopkins Marine Station, Department of Biology, Stanford University, Pacific Grove, CA 93950; [c]Division of Marine Biology and Fisheries, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, FL 33149-1098; and [d]Genecology Research Centre, Faculty of Science, Health, Education and Engineering, University of the Sunshine Coast, Maroochydore DC, QLD 4558, Australia

Edited by Karen A. Kidd, University of New Brunswick, Saint John, BC, Canada, and accepted by the Editorial Board February 24, 2014 (received for review November 6, 2013)

The *Deepwater Horizon* disaster released more than 636 million L of crude oil into the northern Gulf of Mexico. The spill oiled upper surface water spawning habitats for many commercially and ecologically important pelagic fish species. Consequently, the developing spawn (embryos and larvae) of tunas, swordfish, and other large predators were potentially exposed to crude oil-derived polycyclic aromatic hydrocarbons (PAHs). Fish embryos are generally very sensitive to PAH-induced cardiotoxicity, and adverse changes in heart physiology and morphology can cause both acute and delayed mortality. Cardiac function is particularly important for fast-swimming pelagic predators with high aerobic demand. Offspring for these species develop rapidly at relatively high temperatures, and their vulnerability to crude oil toxicity is unknown. We assessed the impacts of field-collected *Deepwater Horizon* (MC252) oil samples on embryos of three pelagic fish: bluefin tuna, yellowfin tuna, and an amberjack. We show that environmentally realistic exposures (1–15 μg/L total PAH) cause specific dose-dependent defects in cardiac function in all three species, with circulatory disruption culminating in pericardial edema and other secondary malformations. Each species displayed an irregular atrial arrhythmia following oil exposure, indicating a highly conserved response to oil toxicity. A considerable portion of Gulf water samples collected during the spill had PAH concentrations exceeding toxicity thresholds observed here, indicating the potential for losses of pelagic fish larvae. Vulnerability assessments in other ocean habitats, including the Arctic, should focus on the developing heart of resident fish species as an exceptionally sensitive and consistent indicator of crude oil impacts.

oil spill | damage assessment | heart development | embryology

The *Deepwater Horizon* disaster resulted in the release of more than 4 million barrels (636 million L) of oil into the offshore waters of the northern Gulf of Mexico between April 10 and July 14, 2010 (1). Although subsurface application of dispersant near the wellhead resulted in
in the bathypelagic zon
face waters where it fo
slicks (e.g., covering an
(3). In the decades follo
Exxon Valdez spill in Al
shown to be especially v
The northern Gulf pro
itats for a range of c
pelagic fish species, an
respectively) (14, 15). The Atlantic bluefin tuna (*Thunnus thynnus*) population from the Gulf of Mexico is currently at a historically low level (16), and was recently petitioned for listing under the US Endangered Species Act. For these and other pelagics, the extent of early-life stage loss from oiled spawning habitats is an important outstanding question for fisheries management and conservation.

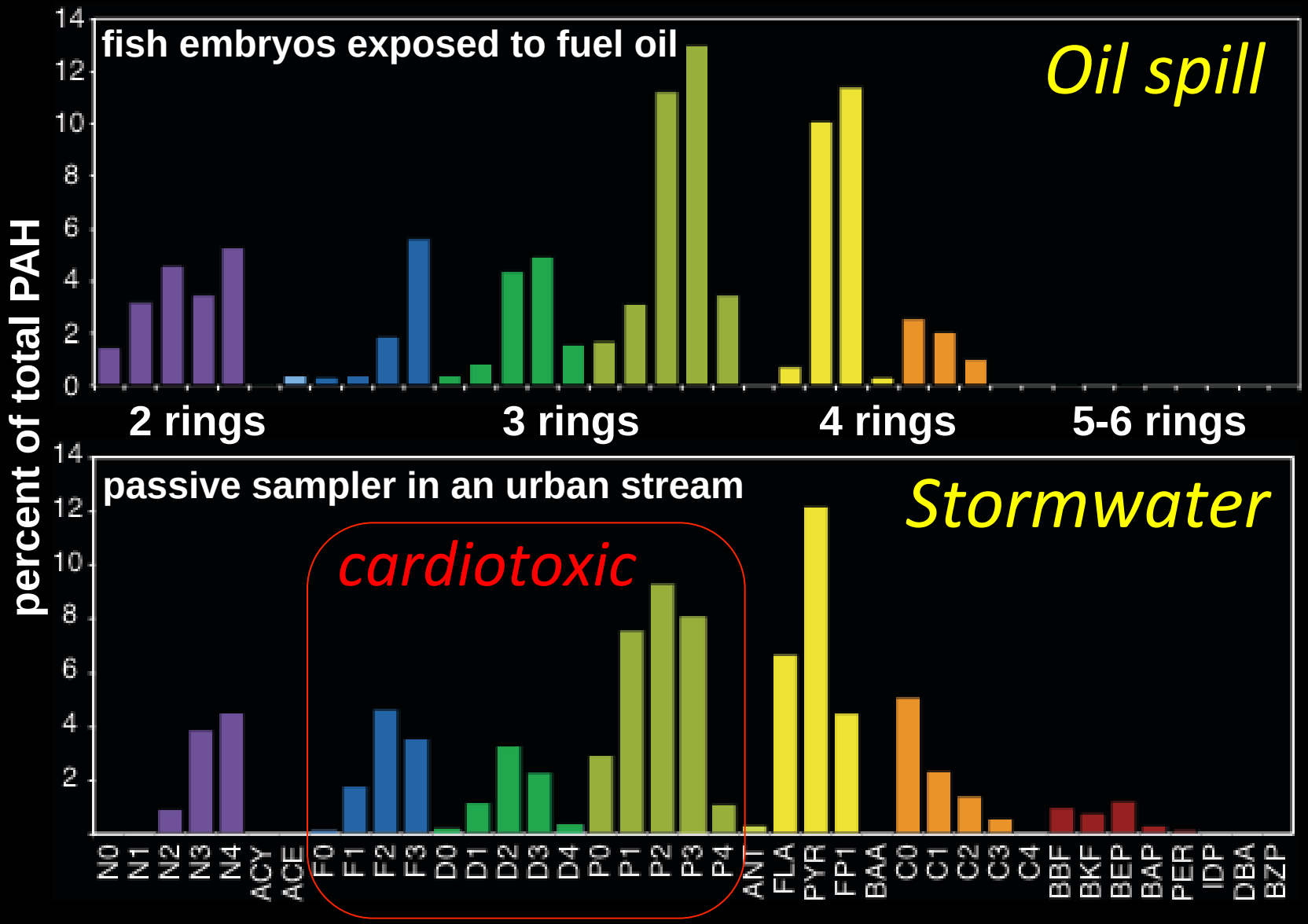
The developing fish heart is known as a sensitive target organ for the toxic effects of crude oil-derived polycyclic aromatic hydrocarbons (PAHs) (4). Of the multiple two- to six-ringed PAH families contained in crude oil, the most abundant three-ringed compounds are sufficient to drive the cardiotoxicity of petroleum-derived PAH mixtures. These compounds (fluorenes, dibenzothiophenes, and phenanthrenes) directly disrupt fish cardiac function (17, 18), thereby interfering with the inter-dependent processes of circulation and heart chamber formation. Exposure of fish embryos to PAH mixtures derived from crude oil slows the heartbeat (bradycardia) and reduces contractility (17, 19–21). The underlying mechanism was recently shown to be blockade of key potassium and calcium ion channels involved in cardiac excitation-contraction coupling (22). These

Significance

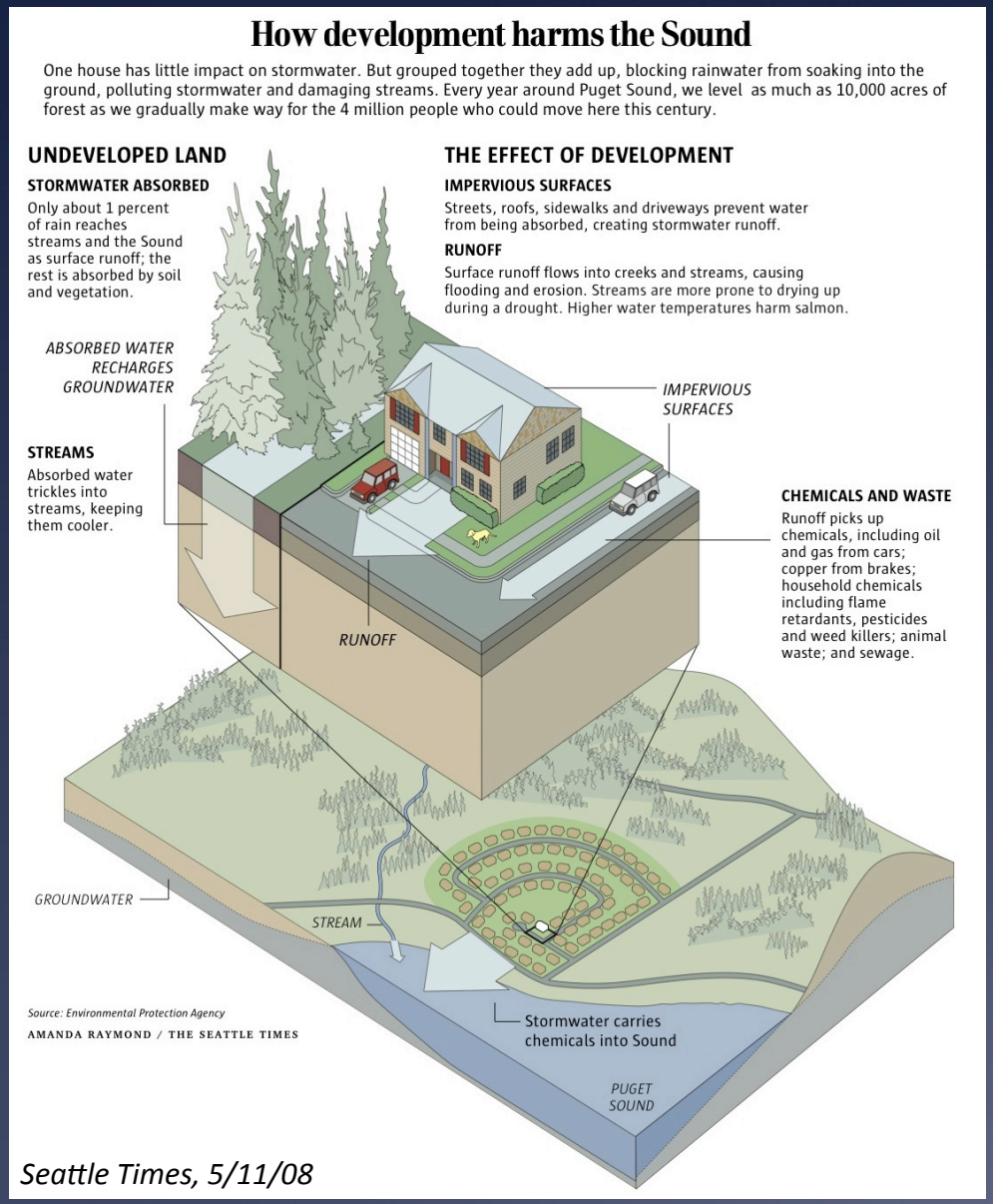
The 2010 *Deepwater Horizon* (MC252) disaster in the northern Gulf of Mexico released more than 4 million barrels of crude oil. Oil rose from the ocean floor to the surface where many large pelagic fish spawn. Here we describe the impacts of field-collected oil samples on the rapidly developing embryos of warm-water predators, including bluefin and yellowfin tunas and an amberjack. For each species, environmentally relevant MC252 oil exposures caused serious defects in heart development. Moreover, abnormalities in cardiac function were highly consistent, indicating a broadly conserved developmental crude

Deepwater Horizon surface oil, May 6, 2010 (photo by Daniel Beltrá)

Polycyclic aromatic hydrocarbons (PAHs): common patterns from oil spills and stormwater



The environmental health impacts of toxic runoff



Seattle Times, 5/11/08

- What are they?
- How can they be effectively minimized?
- Are ongoing efforts to reduce impacts working?

Underwater video of an urban stormwater outfall

West Seattle diving footage by Laura James (www.tox-ick.org)

Montlake Cut, Seattle, November 19th 2012

The stormwater pollution you see…

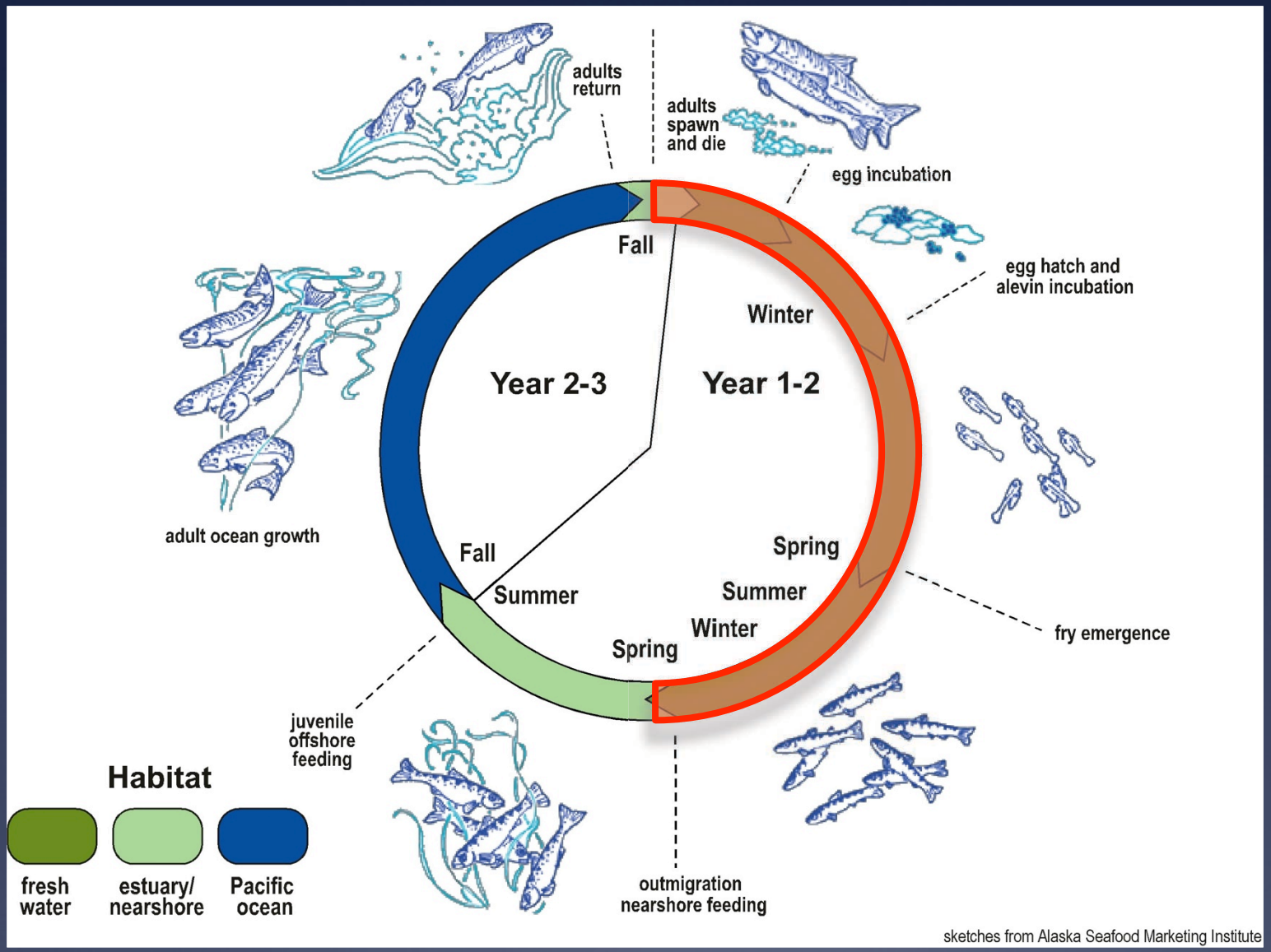
Photo by Blake Feist, NOAA Fisheries

Montlake Cut, Seattle, November 19th 2012


Last month
(1/21/16)
Photo by Blake Feist, NOAA Fisheries

A focus on freshwater coho salmon life stages

Higher Risk of Stormwater Impacts



Symptomatic adult coho spawner

Pipers Creek, Seattle, Fall 2000

Coho spawner mortality is widespread and recurrent (60-90% of total fall runs)

Longfellow Creek 2003

Des Moines Creek 2004

Longfellow Creek 2005

Longfellow Creek 2012

A common suite of symptoms across years

Longfellow Creek 2002

Longfellow Creek 2005

Longfellow Creek 2012

Coho prespawn mortality study #1: *forensic investigation*

Major findings:

- Adult spawners are consistently dying each fall
- The phenomenon is widespread in urban watersheds
- Mortality rates are typically high (60-90% of total run)
- Toxic urban runoff appears to be causal

OPEN ACCESS Freely available online (2011, 6(8):e28013) PLoS one

Recurrent Die-Offs of Adult Coho Salmon Returning to Spawn in Puget Sound Lowland Urban Streams

Nathaniel L. Scholz[1]*, Mark S. Myers[1], Sarah G. McCarthy[2], Jana S. Labenia[1], Jenifer K. McIntyre[1], Gina M. Ylitalo[1], Linda D. Rhodes[1], Cathy A. Laetz[1], Carla M. Stehr[1], Barbara L. French[1], Bill McMillan[3], Dean Wilson[2], Laura Reed[4], Katherine D. Lynch[4], Steve Damm[5], Jay W. Davis[5], Tracy K. Collier[1]

1 Northwest Fisheries Science Center, NOAA Fisheries, Seattle, Washington, United States of America, **2** Department of Natural Resources and Parks, King County, Seattle, Washington, United States of America, **3** Wild Fish Conservancy, Duvall, Washington, United States of America, **4** Seattle Public Utilities, City of Seattle, Seattle, Washington, United States of America, **5** Washington Fish and Wildlife Office, U.S. Fish and Wildlife Service, Lacey, Washington, United States of America

Coho prespawn mortality study #2: *population-scale implications*

Major findings:

- Models predict rapid local extinctions at spawner mortality rates observed in Seattle-area streams
- Mortality may drag down coho abundance in non-urban watersheds as a consequence of straying

Integrated Environmental Assessment and Management — Volume 7, Number 4—pp. 648–656

Estimating the Future Decline of Wild Coho Salmon Populations Resulting from Early Spawner Die-Offs in Urbanizing Watersheds of the Pacific Northwest, USA

Julann A Spromberg† and Nathaniel L Scholz†*

†National Oceanic and Atmospheric Administration (NOAA) Fisheries, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA

(2011, 7:648)

Model output summary

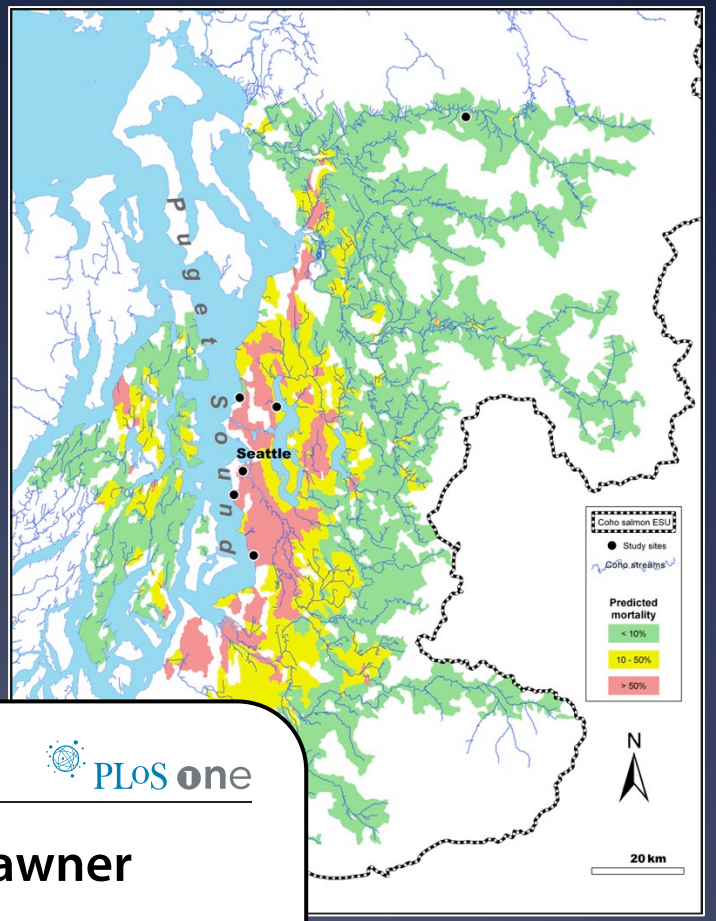
Predictive value for coho mortality

Datalayer	Variable	AICc weight	Model averaged coefficient	Unconditional SE
Impervious	Impervious surfaces	0.7158	16.8425	14.5376
Roadways	Local roads	0.5647	-15.6199	68.3331
Property type	Commercial	0.5107	7.9375	8.2616
Land cover	Dense urban	0.3865	-7.7776	16.1614
Property type	Apartments & condominiums	0.2409	-9.5330	31.1917
Roadways	Heavily used roads	0.2019	5.3445	31.5073
Land cover	Forest	0.1163	-0.7793	6.2249
Land cover	Light to medium urban	0.1149	0.3250	2.9751
Land cover	Grass, shrubs & crops	0.0993	0.1664	5.4517
Property type	Residential	0.0975	0.0738	16.8920
Property type	Industrial	0.0547	-0.2475	4.7008
Property type	Parks & open space	0.0000	0.0000	0.0000

Coho prespawn mortality study #3: *predictive modeling based on land use*

Major findings:

- Spawner mortality rates correlate closely with land cover (% impervious, roads, etc.)
- Coho are likely to be impacted across large geographic areas



OPEN ACCESS Freely available online

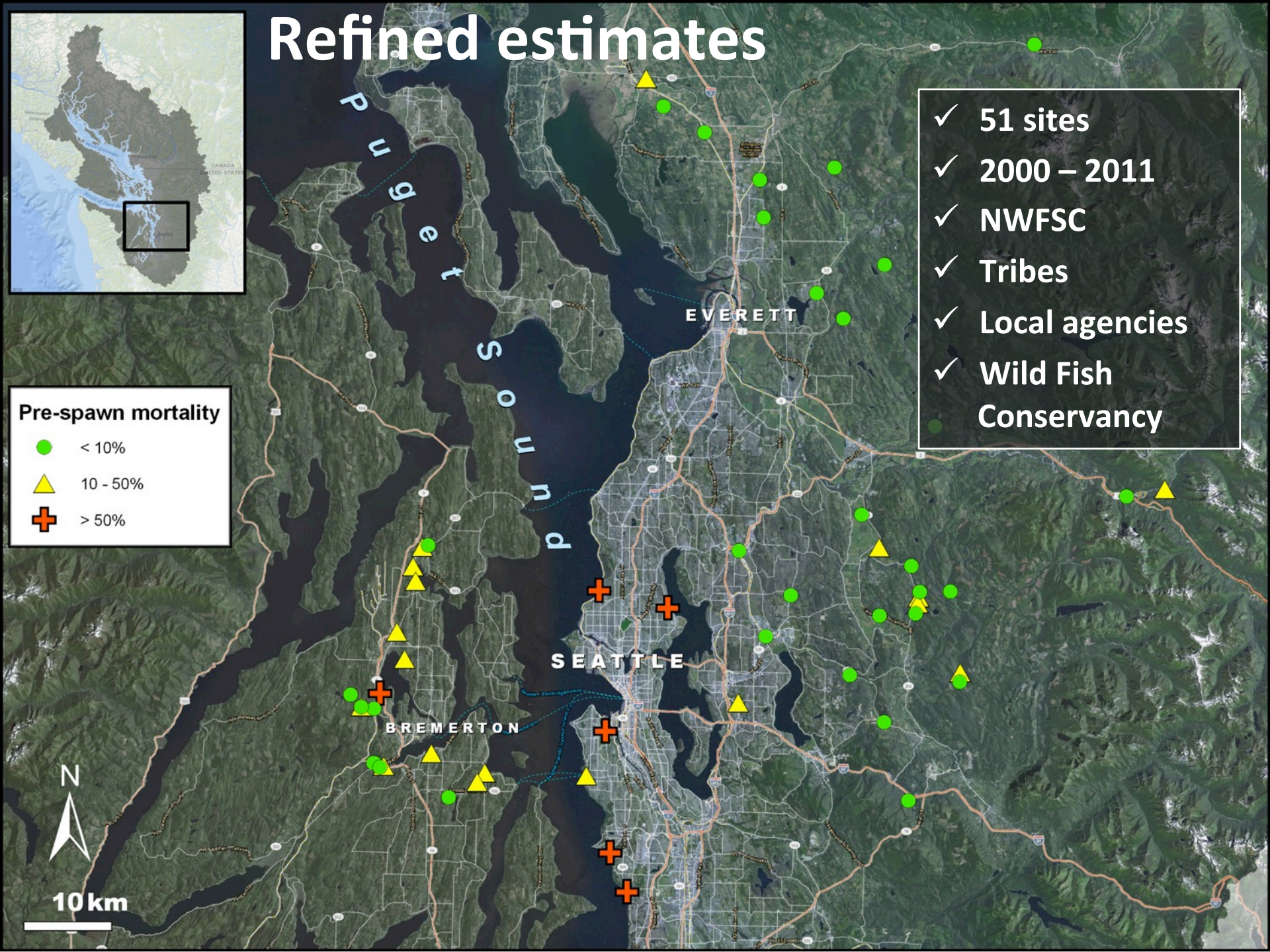
(2011, 6(8):e23424)

PLoS one

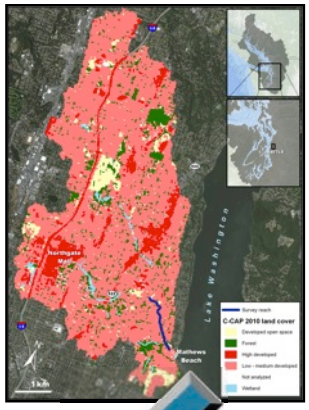
Landscape Ecotoxicology of Coho Salmon Spawner Mortality in Urban Streams

Blake E. Feist[1]*, Eric R. Buhle[1], Paul Arnold[2], Jay W. Davis[2], Nathaniel L. Scholz[1]

1 Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington, United States of America, **2** Washington Fish and Wildlife Office, United States Fish and Wildlife Service, Lacey, Washington, United States of America

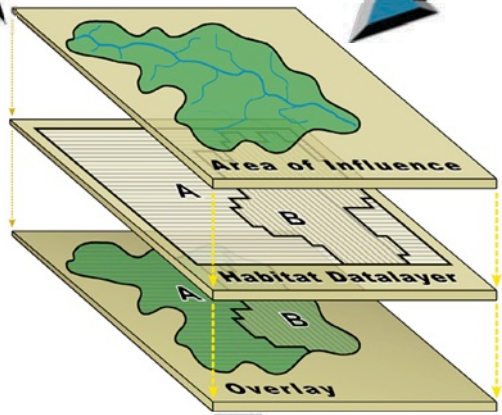

Refined estimates
Puget Sound
EVERETT
SEATTLE
BREMERTON
Pre-spawn mortality
< 10%
10 - 50%
> 50%
✓ 51 sites
✓ 2000 – 2011
✓ NWFSC
✓ Tribes
✓ Local agencies
✓ Wild Fish Conservancy
N
10 km

Model Overview

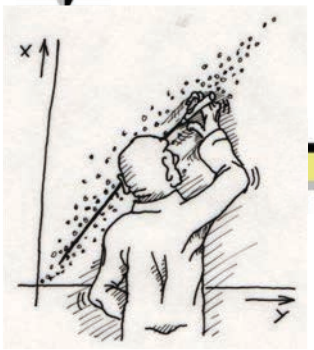


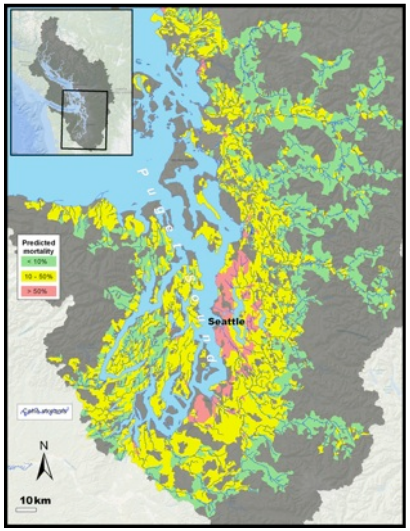
Landscape Data

Spatial Analyses



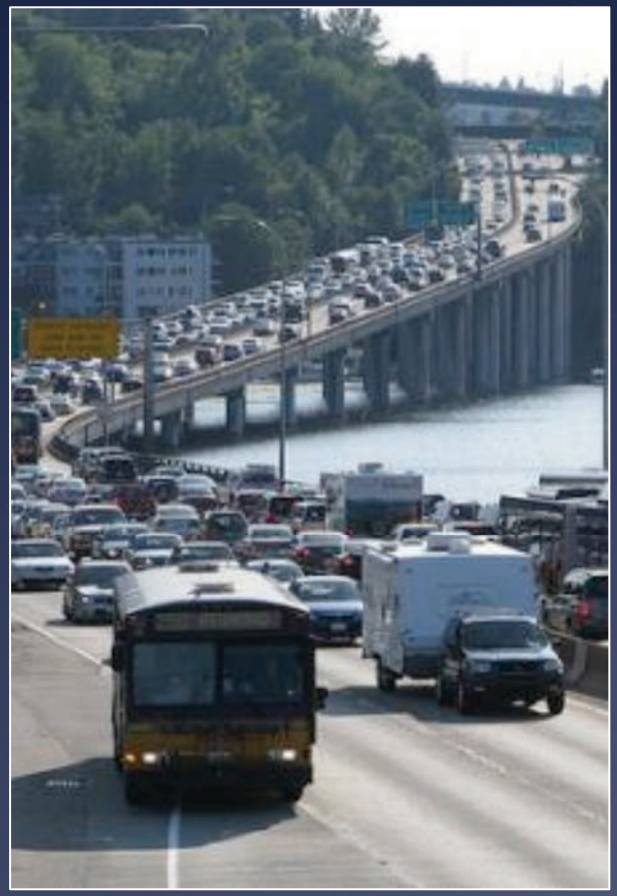
Statistical Analyses





- Correlated Variables
- Predictive Model of Spawner Mortality

Fall 2011-14: Key Question



Is exposure to urban runoff sufficient to cause coho pre-spawn mortality?

Grover's Creek facility, Suquamish Tribe

Metal and PAH exposures (2011)

Spawners exposed to environmentally-relevant mixtures…

PAHs:

Water accommodated fraction (crude oil)

e.g., Phenanthrene (0.240 µg/L)

Pyrene (0.365 µg/L)

Fluoranthene (0.365 µg/L)

Metals:

Cadmium (0.3 µg/L)

Copper (7.0 µg/L)

Lead (1.0 µg/L)

Nickel (2.0 µg/L)

Zinc (9.0 µg/L)

… showed no significant increase in mortality!

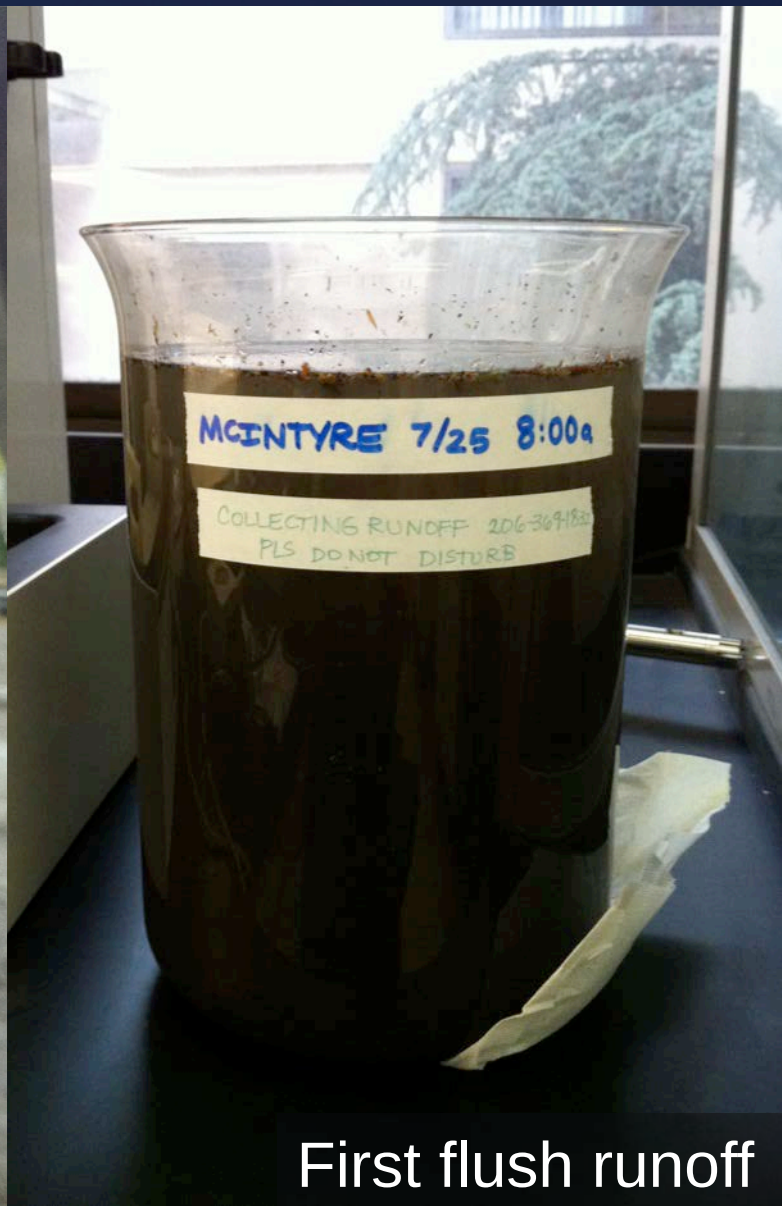
Runoff from a high-density urban arterial (highway, downtown Seattle)

SR 520, Seattle

Collect runoff, characterize baseline toxicity

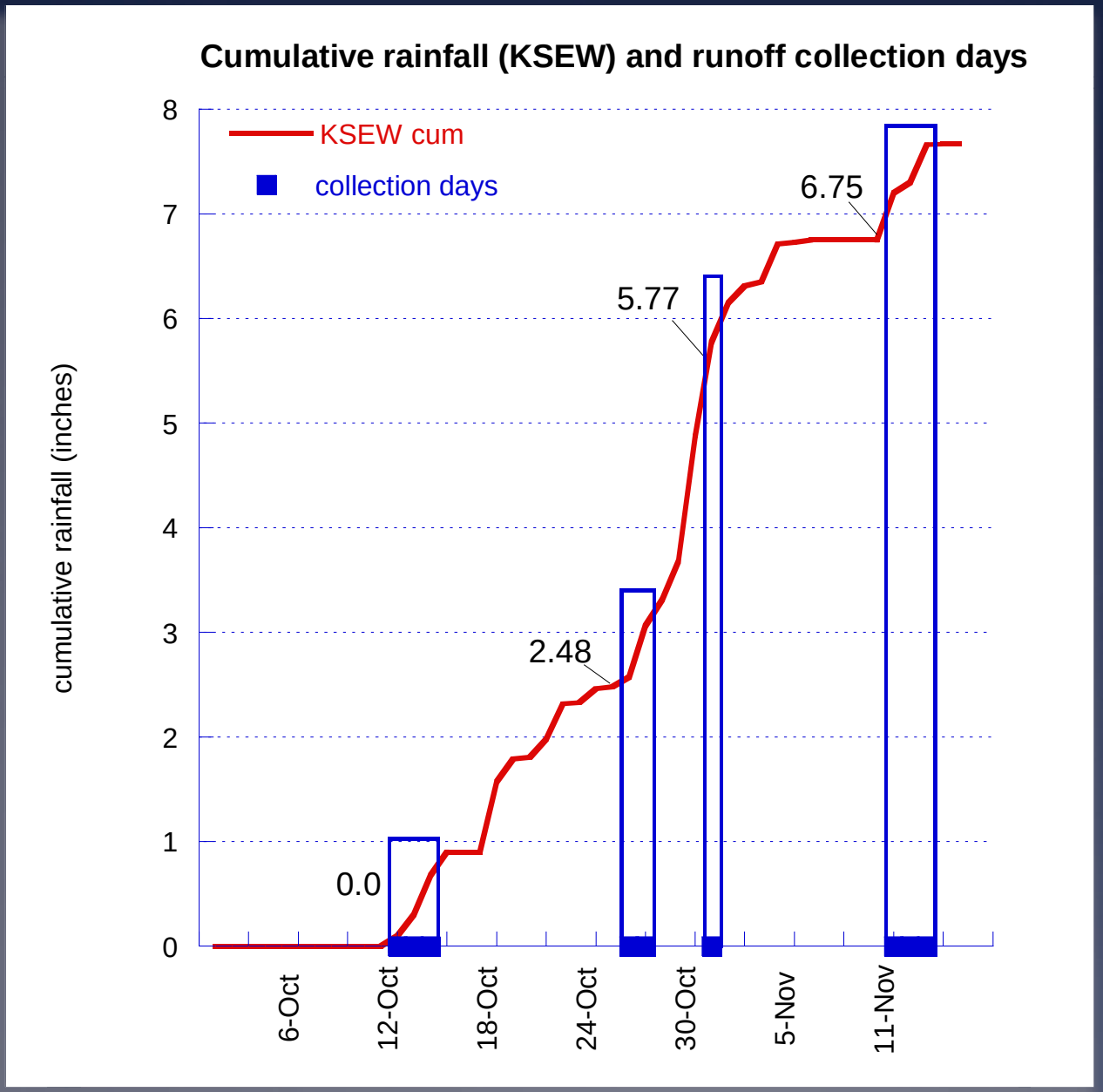
Project lead: Jenifer McIntyre, postdoc, Washington State University

Downspout from highway



First flush runoff

Stormwater runoff collections (fall, 2012)



Exposing adult coho spawners to stormwater under controlled experimental conditions

Exposures following sequential rainfall events in 2012-14

clean well water

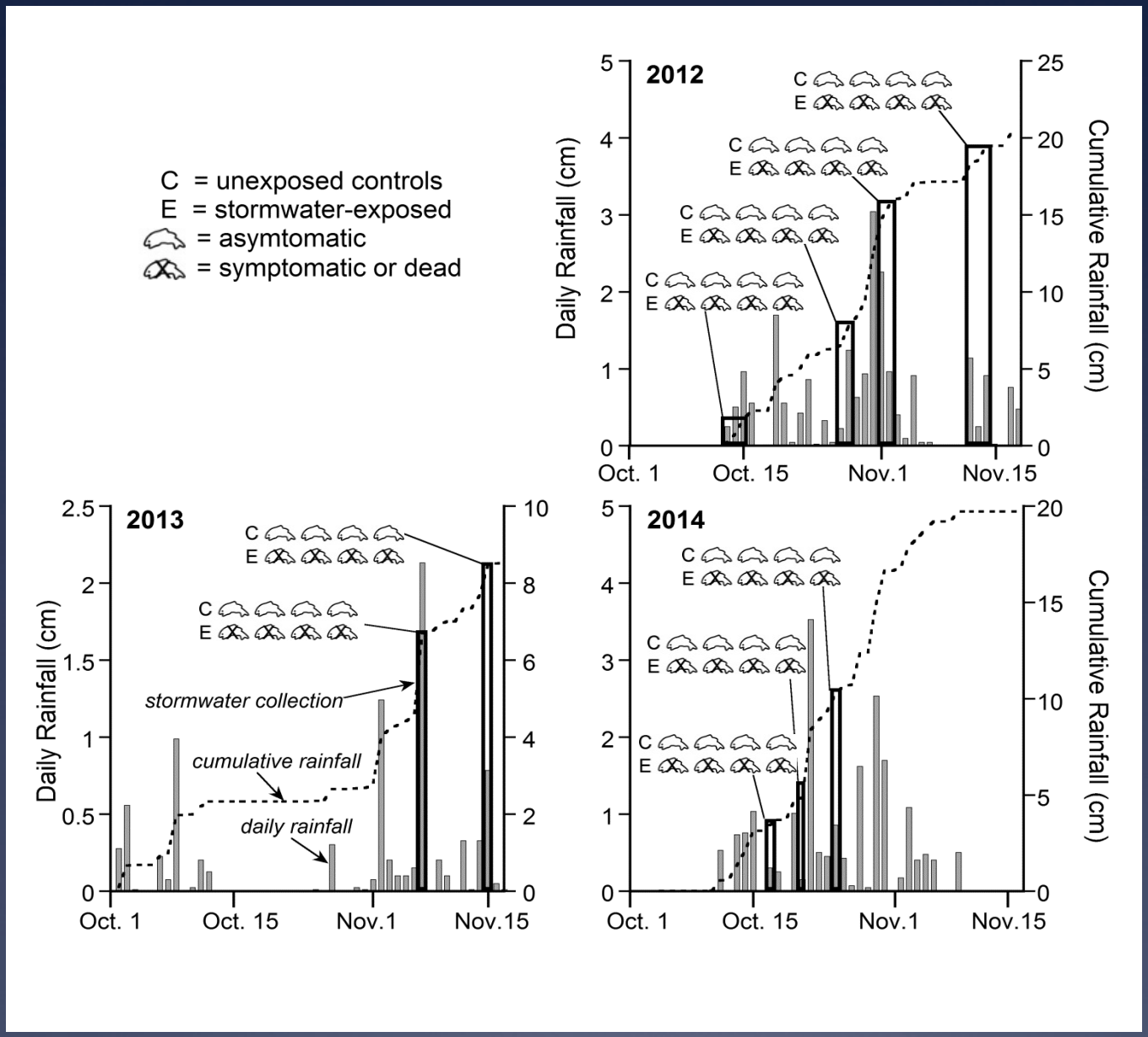
collected stormwater

Exposure to urban runoff is sufficient to cause adult coho pre-spawner mortality

unexposed (3.5 hrs)

stormwater-exposed (3.5 hr)

November 11th, 2012

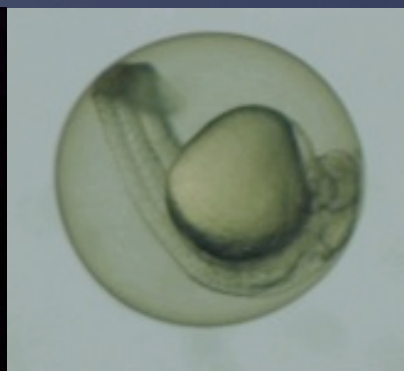

C = unexposed controls
E = stormwater-exposed
= asymtomatic
= symptomatic or dead
2012
2013
2014
Daily Rainfall (cm)
Cumulative Rainfall (cm)
stormwater collection
cumulative rainfall
daily rainfall
Oct. 1
Oct. 15
Nov.1
Nov.15

PSM: coho but not chum spawners?

Pipers Creek 2006

Urban stormwater runoff is toxic

- Multiple symptoms of toxicity in fish and invertebrates
- Acute lethality, reproductive impairment, cardiovascular toxicity



Evolving science, from…

"What's the problem?"

to

"What's the solution?"

Green Stormwater Infrastructure

Bioretention

Green roof

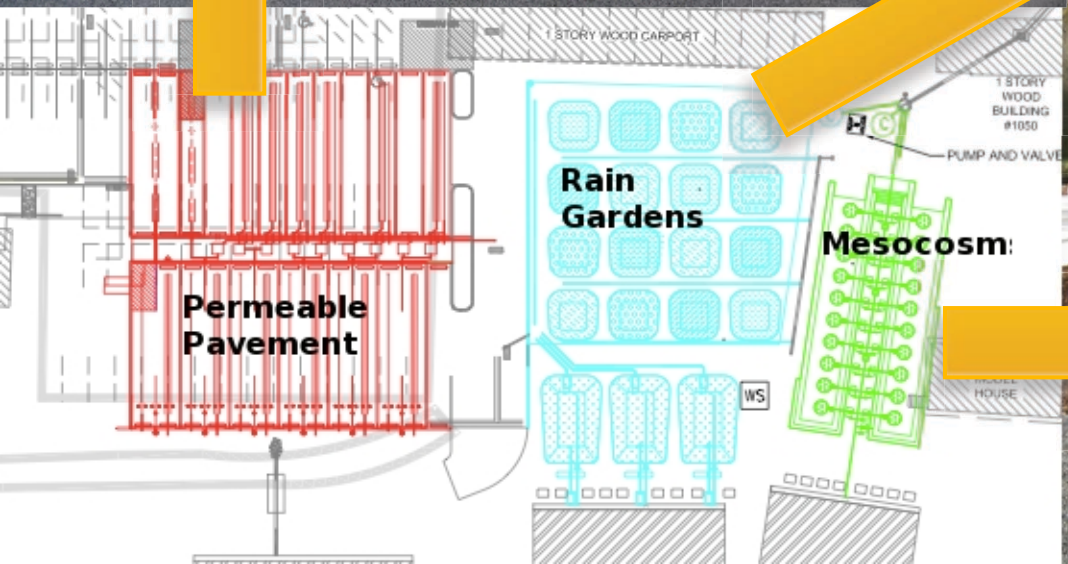
Pervious pavement

Emerging technologies for the built landscape may be less harmful to salmon and other aquatic animals

WSU Puyallup GSI Facility

Permeable Pavement

Rain Gardens

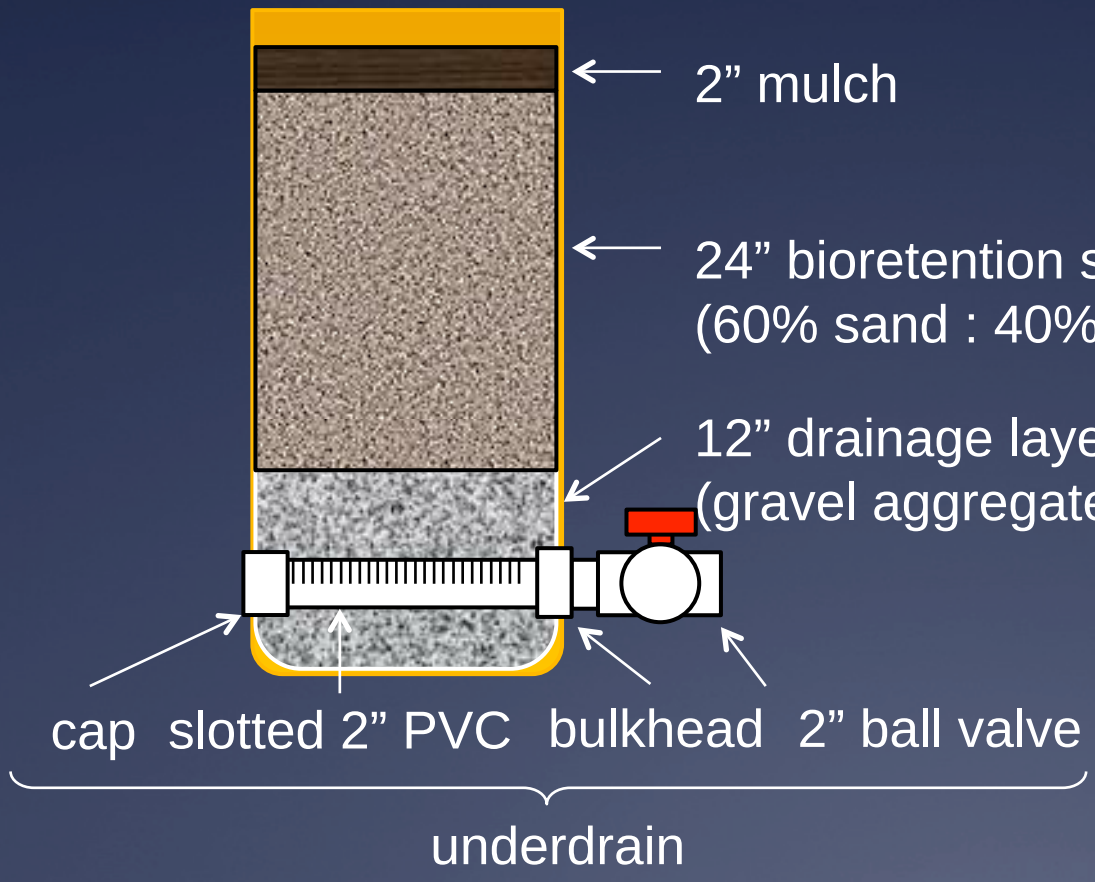


Mesocosms

WASHINGTON STATE UNIVERSITY

Bioretention Filtration System

Washington State Department of Ecology
Low Impact Development Technical Guidance Manual 2012



Biological Effectiveness of Bioretention

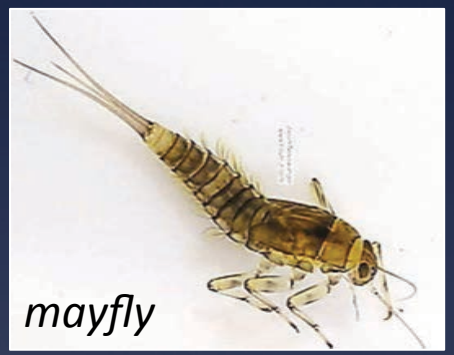
- 4 treatments
  - Untreated
  - Soil column
  - Soil + Plants
  - Lab control
- Daphnid survival & reproduction
- Zfish embryo survival & sublethal
- Mayfly survival
- Coho survival

Test with Target Organisms

Did bioretention filtration prevent toxicity?

Survival of salmon and their prey before and after soil mesocosm treatment

Fall 2012



% MORTALITY

100%	85%	100%
0%	4%	0%

Result: toxicity largely eliminated

Science of the Total Environment 500–501 (2014) 173–180

Contents lists available at ScienceDirect

Science of the Total Environment

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

Zebrafish and clean water technology: Assessing soil bioretention as a protective treatment for toxic urban runoff

J.K. McIntyre [a,*], J.W. Davis [b], J.P. Incardona [c], J.D. Stark [a], B.F. Anulacion [c], N.L. Scholz [c]

[a] Washington State University Puyallup Research & Extension Center, 2606 W Pioneer Ave, Puyallup, WA 98371, USA
[b] U.S. Fish & Wildlife Service Washington Fish & Wildlife Office, 510 Desmond Dr. SE, Lacey, WA 98503, USA
[c] NOAA–NMFS Northwest Science Center, 2725 Montlake Blvd E, Seattle, WA 98112, USA

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Chemosphere

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

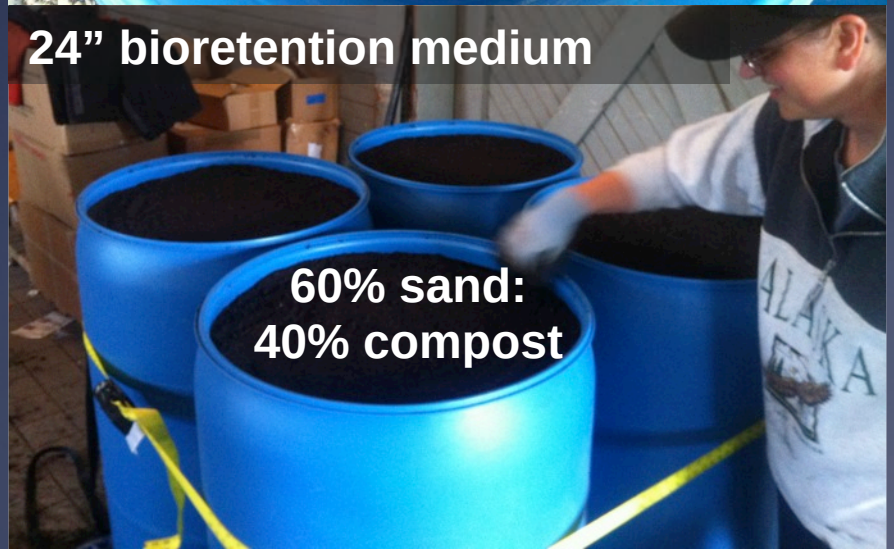
Soil bioretention protects juvenile salmon and their prey from the toxic impacts of urban stormwater runoff

J.K. McIntyre [a,*], J.W. Davis [b], C. Hinman [a], K.H. Macneale [c], B.F. Anulacion [c], N.L. Scholz [c], J.D. Stark [a]

[a] Washington State University, Puyallup Research and Extension Center, Puyallup, WA, USA
[b] U.S. Fish & Wildlife Service, Washington Fish and Wildlife Office, Lacey, WA, USA
[c] National Ocean and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, WA, USA

Can bioretention prevent impacts to coho embryos and spawners?

Constructing portable bioretention



Exposures and treatment at Suquamish Hatchery on Grover's Creek

Can bioretention prevent coho PSM?

Clean well water

100% Normal

Untreated runoff

100% Symptomatic

Treated runoff

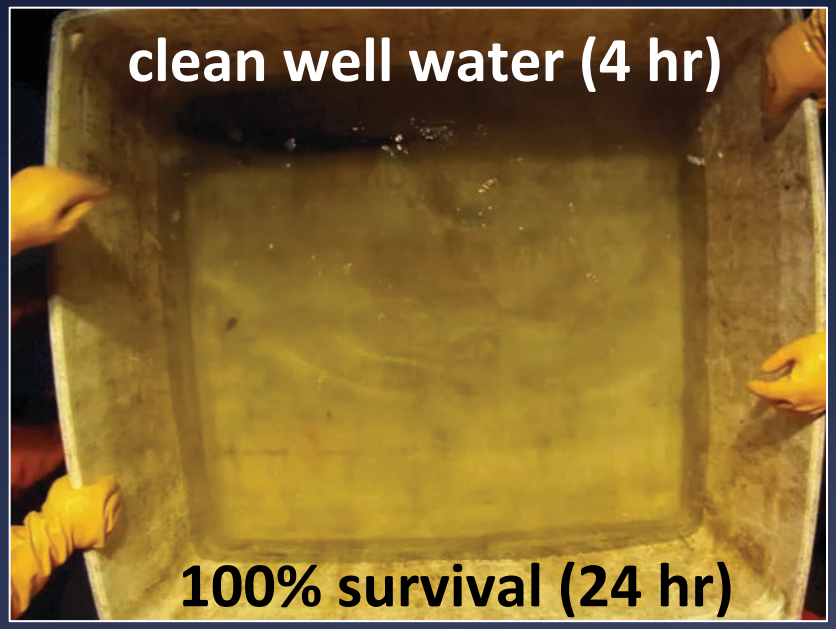
??????

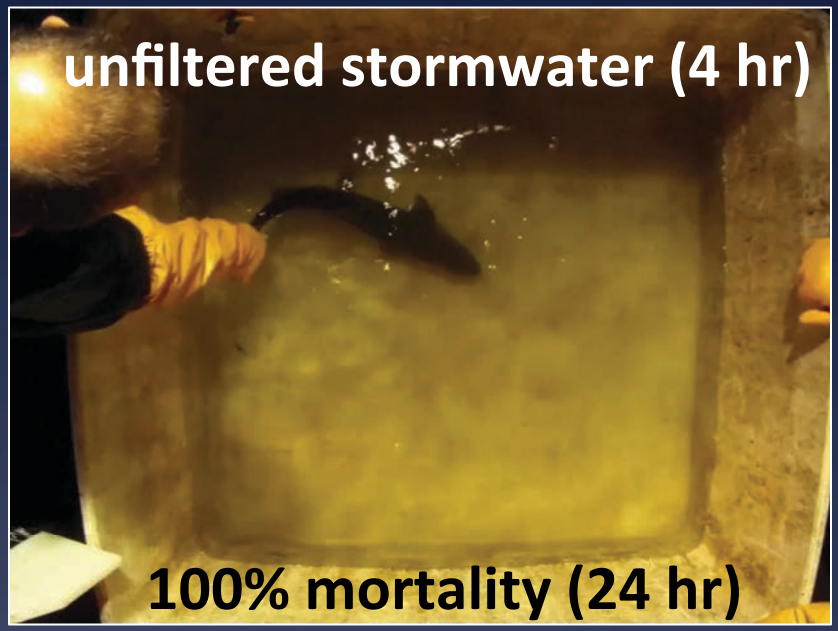
Stormwater Runoff Exposures 2013/14

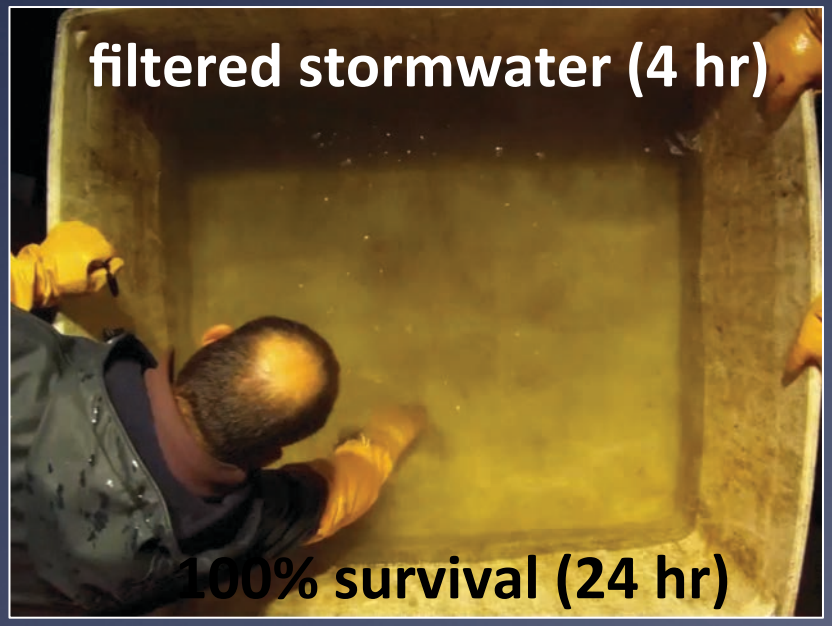
Study Year	Test Date	Exposure (hours)	Control Water	Untreated Runoff	Treated Runoff
2013	Nov 8	4	100 % Live	50% Dead; 50% Symptomatic	100% Live
2013	Nov 18	24	100% Live	100% Dead	100% Live
2014	Oct 20	24	100% Live	100% Dead	100% Live
2014	Oct 22	24	100% Live	100% Dead	100% Live
2014	Oct 27	24	100% Live	100% Dead	100% Live

- All fish exposed to Untreated Runoff were symptomatic or dead at <24 h
- All Control and Treated fish alive & asymptomatic at 24 h

Stormwater runoff exposures, 2013-14







Seven distinct storm events.
In all cases:

100% mortality (or symptomatic)
vs.
100% survival

Toxic road runoff kills adult coho salmon in hours, study finds

Originally published October 8, 2015 at 11:07 am *Updated October 9, 2015 at 6:25 am*

A three-year-old adult coho makes its way through the Issaquah Salmon Hatchery. (Mike Siegel / The Seattle Times)

A new study shows that stormwater runoff from urban roadways is so poisonous to coho salmon that it can kill adult fish in as little as 2½ hours.

Seattle Times
10/8/15

Journal of Applied Ecology

British Ecological Society

Journal of Applied Ecology 2015

doi: 10.1111/1365-2664.12534

Coho salmon spawner mortality in western US urban watersheds: bioinfiltration prevents lethal storm water impacts

Julann A. Spromberg[1], David H. Baldwin[2], Steven E. Damm[3], Jenifer K. McIntyre[4], Michael Huff[5], Catherine A. Sloan[2], Bernadita F. Anulacion[2], Jay W. Davis[3] and Nathaniel L. Scholz[2]*

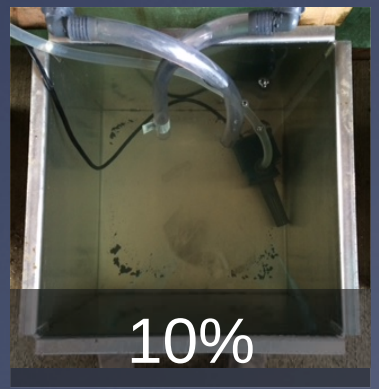
[1]Ocean Associates, Under Contract to Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112, USA; [2]Environmental and Fisheries Science Division, Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112, USA; [3]U.S. Fish and Wildlife Service, Washington Fish and Wildlife Office, 510 Desmond Dr. S.E., Lacey, WA 98503, USA; [4]Puyallup Research and Extension Center, Washington State University, 2606 W. Pioneer Ave., Puyallup, WA 98371, USA; and [5]Suquamish Tribe, PO Box 498, 18490, Suquamish Way, Suquamish, WA 98392, USA

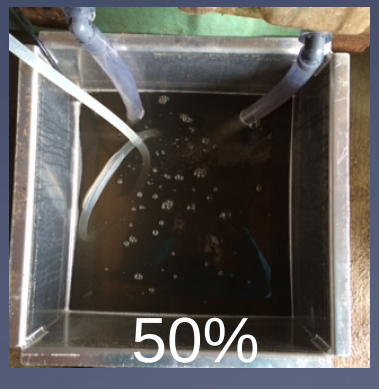
Coho embryolarval studies – Fall 2014 & 2015

Episodic exposure of coho embryos

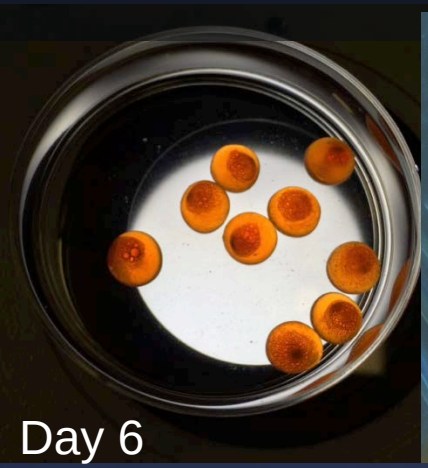
1 stack / treatment
7 trays / stack
9 cups / tray
130 eggs / cup

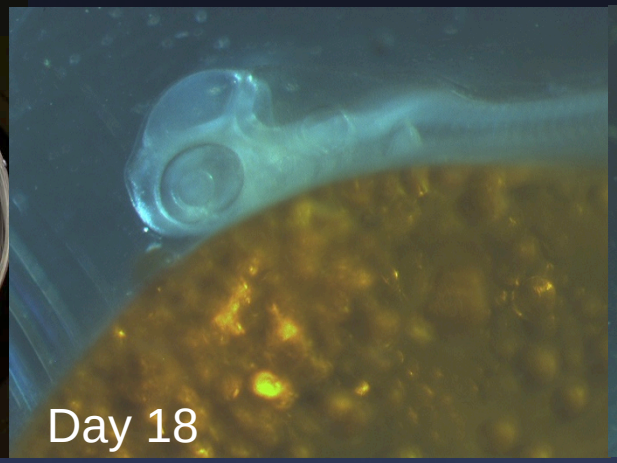
5 treatments
Background: Flowing clean water
Exposures: 24 h recirculated runoff

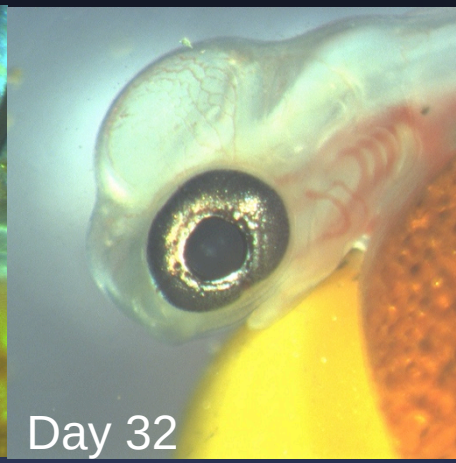


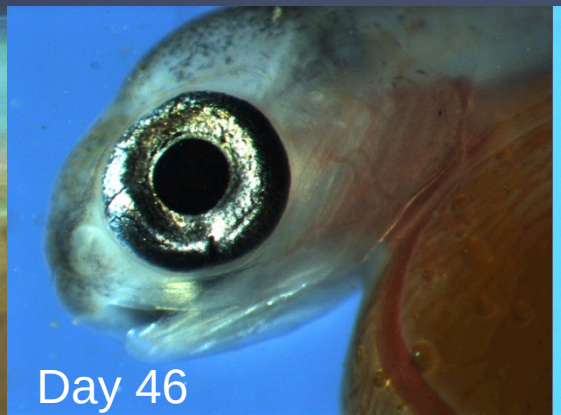


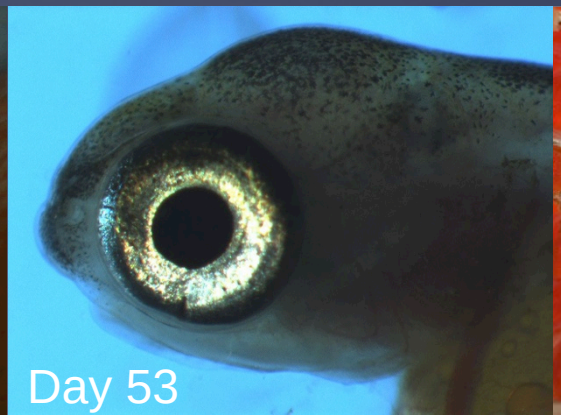
Episodic exposure of coho embryos



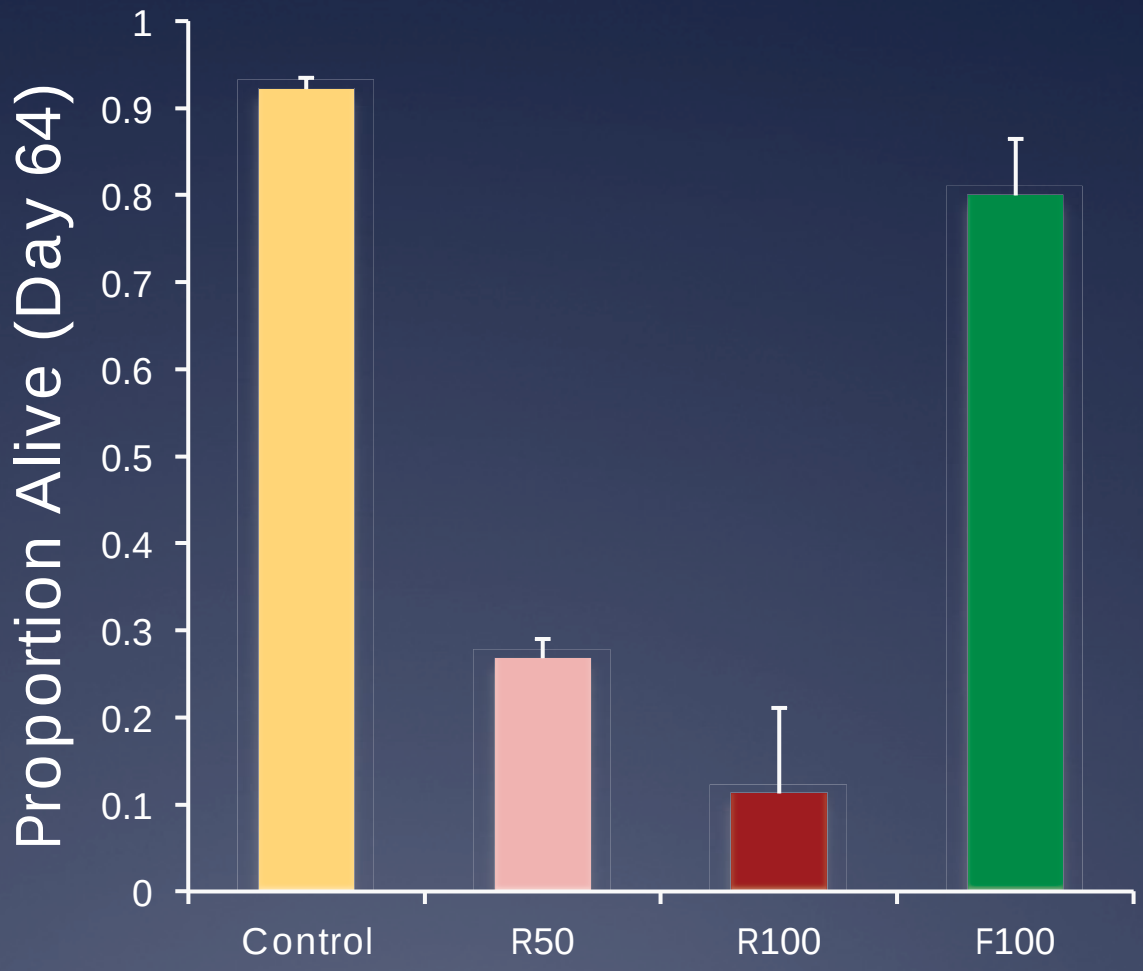








Bioinfiltration reverses larval lethality



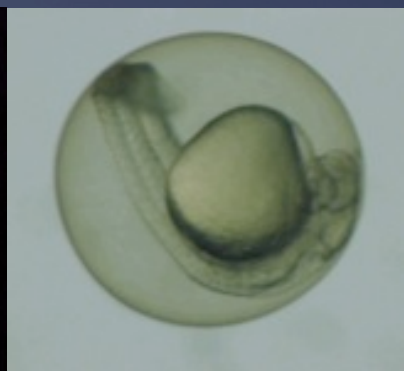
Unpublished data as of January…

Green Stormwater Effectiveness Summary

- Soil bioretention can prevent acute toxicity of highway runoff
  - Invertebrates
  - Developing fish
  - Juvenile and adult salmon

- Outstanding research questions:
  - Performance longevity
  - Effective sizing
  - Optimal media



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