Toward More Effectively Applying Ecotoxicology to Help Us Formulate Water Quality Regulations and Policy

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Contaminants: Sources, fates, transport and impacts

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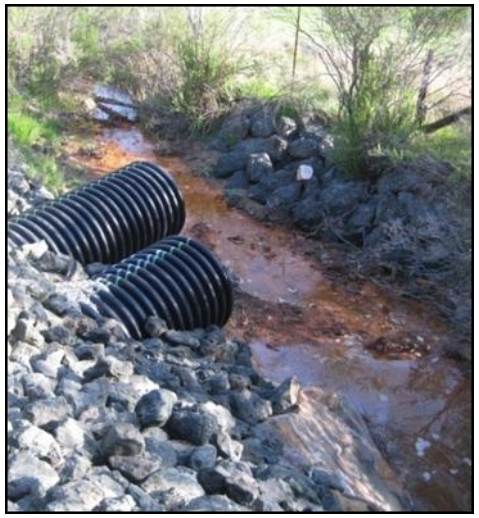
Serious problems in the Salish Sea

- Salmonids, orcas and other ESA- listed species NOT recovering despite our best efforts at limiting fishing, protecting wild stocks, protecting/restoring habitat
- Ecotoxicity is playing a big role; McCarthy *et al*. (2008; American Fisheries Soc Symp 64: 7-27) summarizes investigations on the effects of pesticides, PHC/PAHs, and various metals in stormwater runoff on fish and fisheries
- Continuing body burdens of legacy pollutants via bioaccumulation in orcas, fish, and other marine biota; need to ask the “so what” question



Serious problems……

- We haven't begun to solve the problem that our entire regulatory framework is based on individual toxicants rather than complex mixtures potentially causing longer-term exposures
- Research demonstrates that water quality can impact aquatic life differently during various life history stages
- Effectiveness in restoring critical habitat may be limited when water quality not comparably restored

Current example: Pre-spawn mortality in urban coho salmon

- Well-documented but unexplained pre-spawn mortality identified by NOAA NWFSC McCarthy *et al*. (2008; American Fisheries Soc Symp 64: 7) in adult female coho in Puget Sound streams; acutely sensitive to toxic urban stormwater runoff
- Sophisticated sublethal ecotoxicology research helping to identify metals, pesticides, and other constituents as possible causal agents within complex contaminant mixtures


Photograph by S. McCarthy, NOAA Fisheries

- While contaminant concentrations in stormwater may be present below toxicity thresholds, spawning adults are undergoing profound physiological changes (e.g. transitioning from marine to freshwater life stage) which further sensitizes them to individual toxicants or to complex environmental mixtures

A bit of context on stormwater inputs

- Stormwater runoff and septic tank discharges two of most common forms of nonpoint pollution to Salish Sea
- Have moved beyond “point source discharge” issues because we are generally treating municipal wastewater discharges via NPDES program
- *Complex contaminant mixtures:* US Commission on Ocean Policy (2004) found that multiple stressors a reason that regulatory agencies have experienced difficulties in addressing nonpoint pollution; stormwater and bed sediments are intertwined and both are characterized by complex mixtures
- TMDLs (also required by CWA) represent an advance over conventional thinking, as they are designed to regulate nonpoint mass loadings of individual constituents on watershed-wide basis (but still not well adapted to complex mixtures)
- Source control (e.g. LID) urgently needed to curtail inputs and prevent recontamination of remediated urban harbors & waterways

What we know or thought we knew about copper

- Copper a perfect example; ubiquitous, especially in brake pad linings, and we thought we had it figured out; dissolved copper (the toxic form) in stormwater is a key example of a common constituent potentially wreaking ecological havoc

- Washington, as elsewhere, has established AWQC, sediment management standards, and other well-defined guidelines in effect for decades
- The basic acute and chronic toxicological mechanisms, especially at high concentrations, are well established, but longer-term and sublethal exposures less well defined
- It is now apparent that we have been *under*-regulating copper in stormwater based on our new understanding of its toxicity (subject to controversy)

New developments in copper ecotoxicology

- NOAA NWFSC has conducted extensive research on the salmon olfactory nervous system, found to be an important target for dissolved-phase copper, a ubiquitous component of stormwater
- Juvenile fish rely on chemical signals to imprint on their natal streams, avoid predation, navigate during migration, locate prey, and eventually synchronize spawning
- When exposed to very common environmental concentrations of copper ranging from 1 to 20 µg/L (ppb), olfactory neurons consistently shown to be unresponsive in a dose-dependent manner

Copper: new developments (cont'd)

- Hecht *et al.* (2007: NOAA TM NMFS-NWFSC-83) used dose-response sublethal neurobehavioral toxicity data to derive a range of "benchmark" concentrations of 0.59 to 2.1 µg/L, an unenforceable but highly toxicologically relevant guideline in stormwater which is more than tenfold lower than current acute or chronic freshwater AWQC
- Because copper is a general inhibitor of chemoreception in salmon, may interfere with any or all behaviors that require a normally functioning olfactory system; damage could be more pervasive than we realize
- While copper exposures may not kill fish outright, sensory deprivation in salmon and steelhead could increase mortality rates over time to juveniles due to inability to avoid predation (a behavioral endpoint during freshwater rearing (e.g. McIntyre *et al.* Environ Sci Technol, in press)

Silver “lining”: a success story

- Concrete example of how ecotoxicology research can help to support appropriate legislation; the first 100% copper-free ceramic brake pad signed into law by WA State legislature in March 2010, the first state to do so

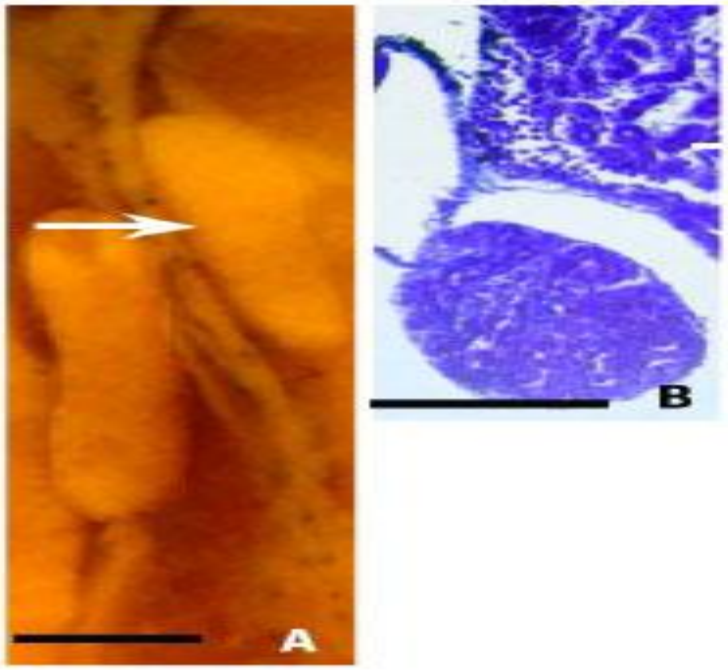
- In 2009, California authored SB 346 based on similar research, requiring that the use of copper in brake pads be reduced to no more than 5% by 2021

Other disturbing ecotoxicological findings

- Sandahl *et al.* (2004; Can J of Fish & Aquatic Sci 61:404) reported sublethal neurotoxicity in juvenile coho salmon exposed to multiple toxicants, including copper as well as two common OP pesticides (chlorpyrifos , esfenvalerate)
- Recent studies of herring and salmon in oil spills (e.g. Exxon Valdez) have disclosed troubling effects of PAH on the developing fish heart
- Sophisticated ecotoxicological research using zebrafish (Glickman and Yelon 2002: Seminar in Cell and Development Biology 13(6): 507; Incardona et al., 2004: Toxicol & Appl Pharmacol 196(2): 191-205) and other species has demonstrated that the fish heart is a primary target of low molecular weight PAH toxicity at low concentrations; both embryos and larvae appear highly sensitive
- Scholz *et al. (*2006; ET&C 25(5): 1200-1207) reports that mixtures of common insecticides produce synergistic neurotoxicity and mortality in juvenile salmon; implications for threatened Pacific salmon in Salish Sea

Disturbing ecotoxicological research with national-international implications

- Hayes *et al.* (2003: Env Health Perspectives 111(4): 1-8) reporting widespread endocrine disruption from atrazine; world's most widespread herbicide
- Effects on leopard frogs and toads clearly documented up to 100x below EPA AWQC
- 0.1 ppb of atrazine causes testicular oogenesis (hermaphroditism) in multiple species



Inescapable conclusion:

- Current advanced ecotoxicology research is showing us that we may be *under*-regulating certain contaminants and contaminant mixtures

Bioaccumulation from sediments

- Some of the historically most disturbing ecotoxicity worldwide concerns bioaccumulation of DDT, PCBs, mercury, and dioxins; links in legacy pollutants established between bioaccumulation and toxicity in several notorious cases; need to apply these lessons to the Salish Sea (we don't want a repeat of these cases)
- Because effects associated with bioaccumulation may be tricky to demonstrate, bioaccumulation is frequently overlooked or oversimplified in dredging and remediation projects
- Lack of guidance requires reliance on cumbersome, inconsistent site-specific bioassays, ecorisk assessment, and sediment quality guidelines; disagreement among state and federal agencies on how to regulate

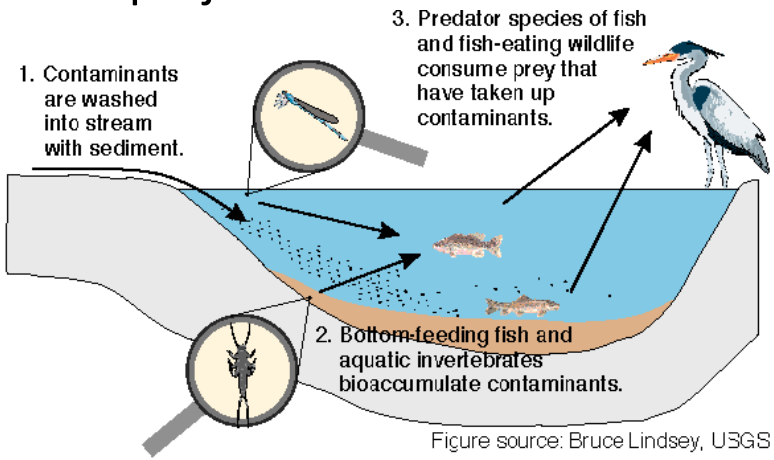


Figure source: Bruce Lindsey, USGS

Bioaccumulation (continued)

- Major driver in Tribal , First Nation, and subsistence fisheries in Salish Sea
- Growing body of dredging-related toxicology research (e.g. from USACE Engineering Research & Development Center; ERDC) addressing the "so-what" question by investigating effects through direct sampling, laboratory/mesocosm studies, & mathematical modeling (e.g. Bridges *et al.* 1996: Misc Paper D-96-1, US Waterways Experiment Station)
- ERDC is developing major bioaccumulation-effects database (Environmental Residue Effects Database), which should help to improve our decision-making and standardize rule-making for bioaccumulatives; much needed development to bring our understanding of bioaccumulation "up to speed" with toxicity
- Unlike "conventional" toxicity, bioaccumulation often affords the luxury of considering a single contaminant at a time; easier to "tease out" an individual toxicant

Critical habitat restoration

- Push for ecological restoration of critical habitat in Puget Sound and Lower Columbia River in particular
- Recent designation of Puget Sound to national prominence has attracted Congressional funding and designation of PS Partnership

- Presence of bioaccumulatives in dredged sediment limits dredge placement options; no beach nourishment allowed; attempt to eliminate CWA NPDES mixing zones when present
- “Restored” habitat doesn’t guarantee viability; need to pay special attention to water and sediment quality

Ideas for righting the ship: forcing us to think outside the regulatory "box"

- NMFS/NWFSC has been an effective leader in producing ecotoxicological research emphasizing ESA listed-species and habitat protection in the Puget Sound; have issued numerous white papers and recommended toxicity-based sediment/WQ guidelines for metals and organics (not always attainable)
- When ecotoxicological research discloses new findings regarding the response of aquatic life to environmental toxicants, we need to implement rigorous peer review and provide reviewers with means to formulate regulations ; need to tighten the gap between research and policy
- The full array of validated techniques and endpoints (e.g. sublethal toxicity, behavioral endpoints, endocrine disruption, immunosuppression) have not been adequately integrated into our environmental policy-making process

Other ideas

- Need to do a much better job of using our understanding of ESA-listed species sensitive life history stages & critical habitats to set toxicologically meaningful (yet attainable) regulations
- On bioaccumulation, we should integrate ERDC's national dredging research on *effects* from bioaccumulatives (e.g. ERED) into stormwater and sediment regulations, which should help foster better interagency agreement
- While most contaminants in stormwater may be present at or below concentrations known to cause toxicity, we need to more carefully test sensitive life stages and characterize complex environmental mixtures

More still……

- Complex contaminant mixtures pose a huge problem because the overwhelming body of our regulatory process (e.g. from USEPA) is based on our understanding of individual constituents, which occur only rarely
- Conventional ecorisk assessments may be fatally flawed, as they don't address:
  - delayed or indirect effects
  - sensitive life history stages
  - interaction of complex environmental mixtures
  - holistic view of ecosystem-wide impacts
- Should conceptually restructure ecorisk assessments to incorporate a higher degree of ecological representation
- "New" generations of contaminants need to be addressed (USEPA 70's vintage "priority pollutant" list is becoming obsolete); must also consider contaminant interaction to characterize true toxicity

Questions?

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