A sensory system at the interface between urban stormwater runoff and salmon survival

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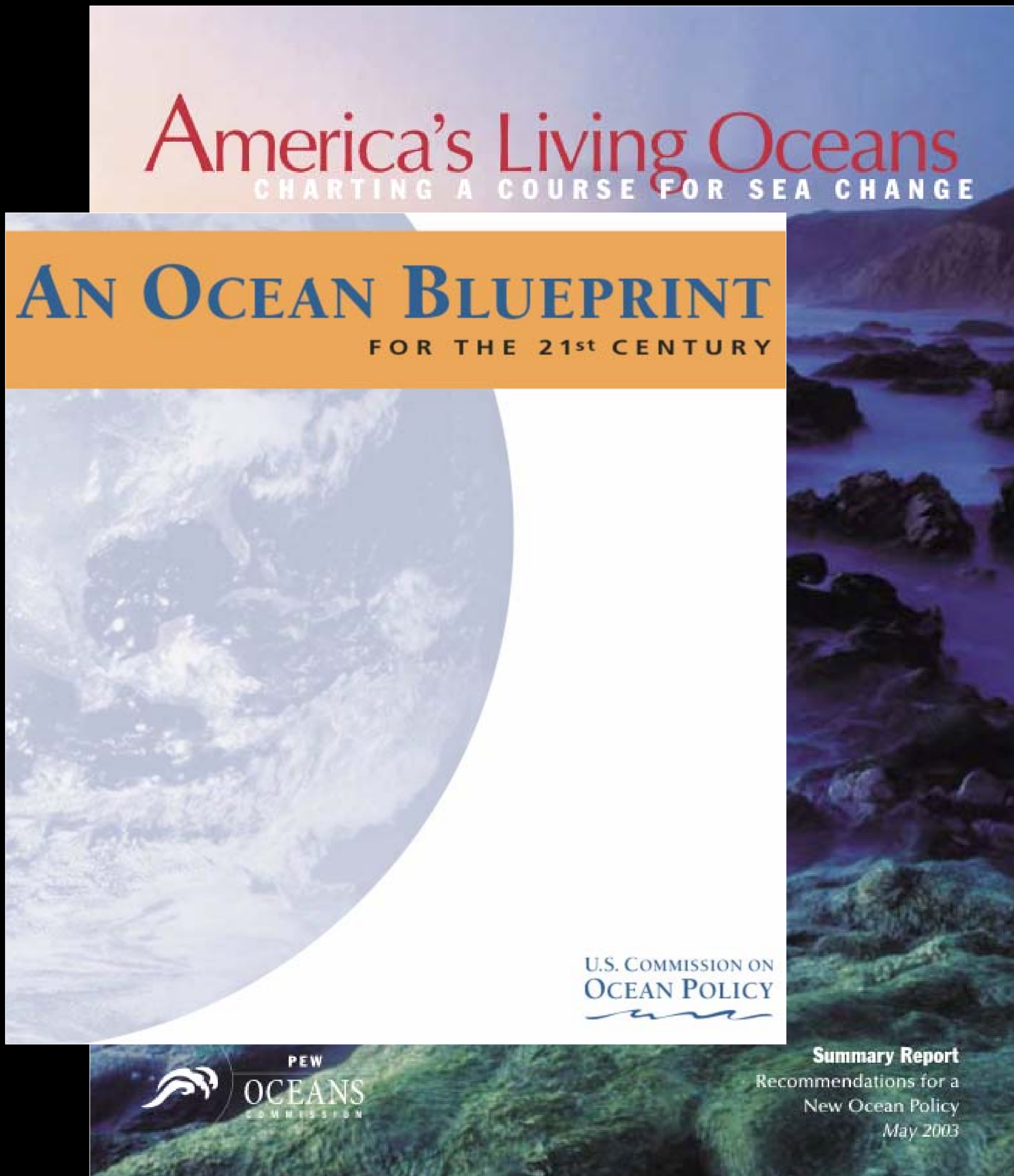
NWFSC
NORTHWEST FISHERIES SCIENCE CENTER

Major Threats to Our Oceans:



- Non-point source pollution
- Point source pollution
- Invasive species
- Aquaculture
- Coastal development
- Overfishing
- Habitat alteration
- Bycatch
- Climate change

REVIEW

Long-Term Ecosystem Response to the Exxon Valdez Oil Spill

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The ecosystem response to the 1989 spill of oil from the Exxon Valdez into Prince William Sound, Alaska, shows that current practices for assessing ecological risks of oil in the oceans and, by extension, other toxic sources should be changed. Previously, it was assumed that impacts to populations derive almost exclusively from acute mortality. However, in the Alaskan coastal ecosystem, unexpected persistence of toxic subsurface oil and chronic exposures, even at sublethal levels, have continued to affect wildlife. Delayed population reductions and cascades of indirect effects postponed recovery. Development of ecosystem-based toxicology is required to understand and ultimately predict chronic, delayed, and indirect long-term risks and impacts.

Before the Exxon Valdez oil spill, information available for constructing risk assessment models to predict ecologi-

Delays in recovery and emergence of long-term impacts are understood by bringing an ecosystem perspective to ecotoxicology

toxic hydrocarbons. Accordingly, mass mortalities of 1000 to 2800 sea otters (9) and unprecedented numbers of seabird deaths estimated at 250,000 (10) were documented during the days after the spill. An estimated 302 harbor seals, a short-haired marine mammal, were killed not by oiled pelage but likely from inhalation of toxic fumes leading to brain lesions, stress, and disorientation (2). Mass mortality also occurred among macroalgae and benthic invertebrates on oiled shores from a combination of chemical toxicity, smothering, and physical displacement from the habitat by pressurized wash-water applied after the spill (5, 7).

Table 1. Changing paradigms in oil ecotoxicology, moving from acute toxicity based on single species toward an ecosystem-based synthesis of short-term direct plus longer-term chronic, delayed, and indirect impacts.

Old paradigm	Emerging appreciation
Oil toxicity to fish	
Oil effects occur solely through short-term (~4 day) exposure to water-soluble fraction (1- to 2-ringed aromatics dominate) through acute narcosis mortality at parts per million concentrations.	Long-term exposure of fish embryos to weathered oil (3- to 5-ringed PAHs) at ppb concentrations has population consequences through indirect effects on growth, deformities, and behavior with long-term consequences on mortality and reproduction.

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rience high risk from floating oil (2, 6). Oiling of fur or feathers causes loss of insulating capacity and can lead to death from hypothermia, smothering, drowning, and ingestion of

shores where geomorphologic armoring by boulders and cobbles inhibited disturbance by waves (12). Some of this oil was similarly trapped under mussel beds providing an

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Editorial

Conservation Medicine

As the science of conservation biology matures, its practitioners increasingly find themselves exploring new and unfamiliar terrain. Many of us who were trained in the traditional organismal or field sciences—botany, zoology, ecology, genetics, and the like—now find ourselves dabbling in various human dimensions, learning about economics or becoming minor policy wonks. We have conversations with professionals from fields we never imagined we would have reason to discuss, and we even enjoy it. In fact, what it means to be a conservation biologist is evolving rapidly and broadening; certainly there are more practitioners of conservation biology today working in the social sciences, for example, than there were 15 years ago, when this society was just beginning

entific fields for the mutual benefit of humanity, wild species, and natural ecosystems.

I was surprised and pleased to learn that the attendees of this conference, most of whom specialize in human or animal medicine, were familiar with the Society for Conservation Biology (SCB), have great respect for the field, and are anxious to work with us in developing the field of conservation medicine. No salesmanship was necessary to convince others that conservation biologists have important perspectives to bring to the table and should be among the central players. I was impressed by the level and extent of knowledge of these medically oriented individuals of the concepts, data, and

Diversity

Conservation and Toxicology: Integrating the Disciplines*

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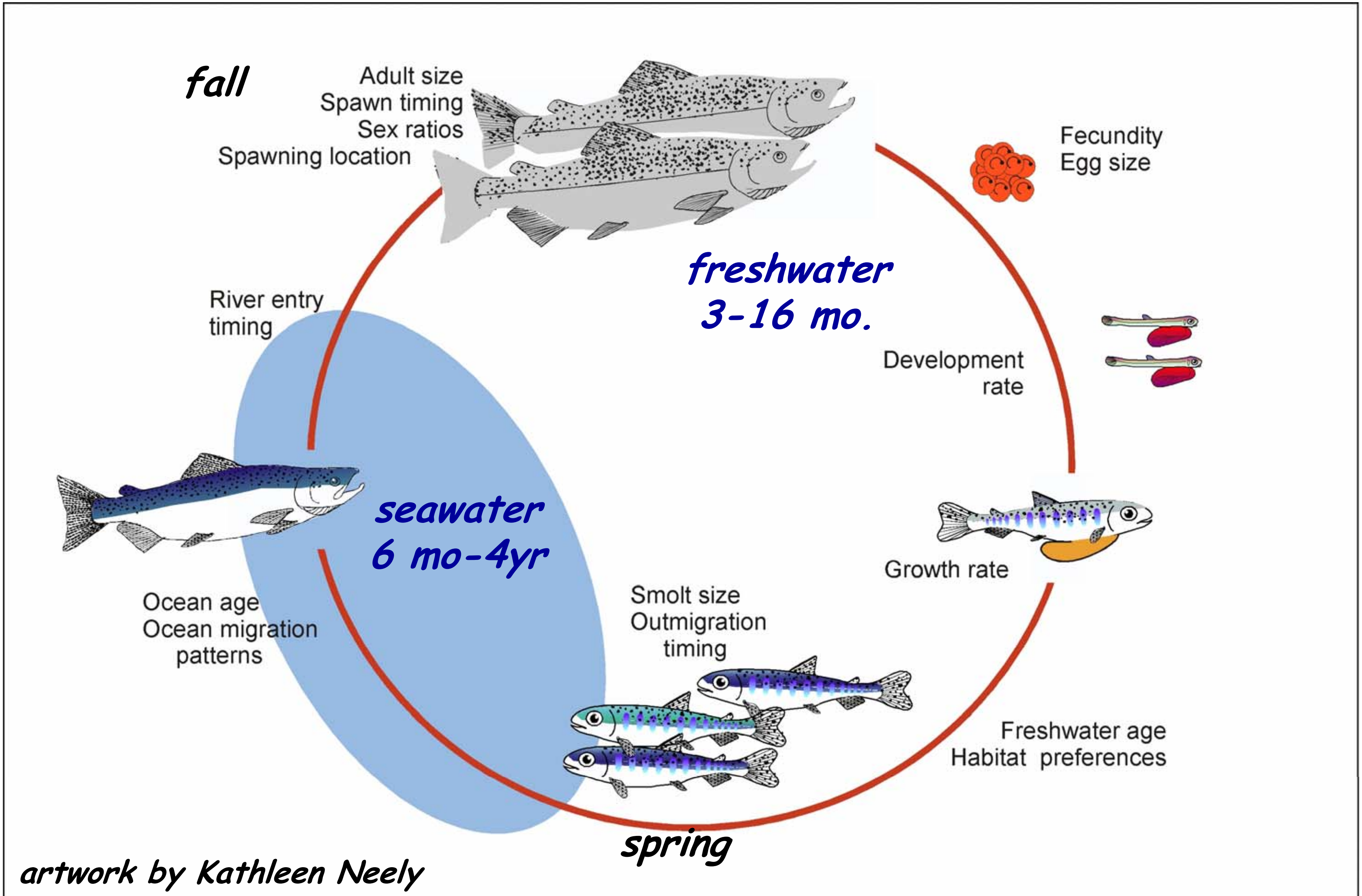
Global warming, ultraviolet radiation, and acid rain are large-scale environmental problems that concern conservation biologists. They are caused, to varying degrees, by human-generated pollution and consequently are also

tion Biology, only 8 articles of 394 (2%) discussed pollutant-related environmental damage. Likewise, only 56 articles of 560 (10%) in *Environmental Toxicology and Chemistry* discussed conservation issues relating to the

Pacific Salmon Life Cycle



Twenty six salmon and steelhead population segments, or Evolutionarily Significant Units (ESUs), are currently listed as either threatened or endangered under the U.S. Endangered Species Act (ESA).

ESA-listed species include:

- coho (*Oncorhynchus kisutch*)
- chinook (*O. tshawytscha*)
- chum (*O. keta*)
- sockeye (*O. nerka*)
- steelhead (*O. mykiss*)

Factors leading to the decline of salmon and steelhead…

Habitat loss or degradation

Invasive species

Pollution

Population growth (human)

Overharvest

adapted from E.O. Wilson, SETAC, 2004

Relevant Federal statutes (water quality)

Chemical-centric:

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

Clean Water Act (CWA)

Species-centric:

Endangered Species Act (ESA)

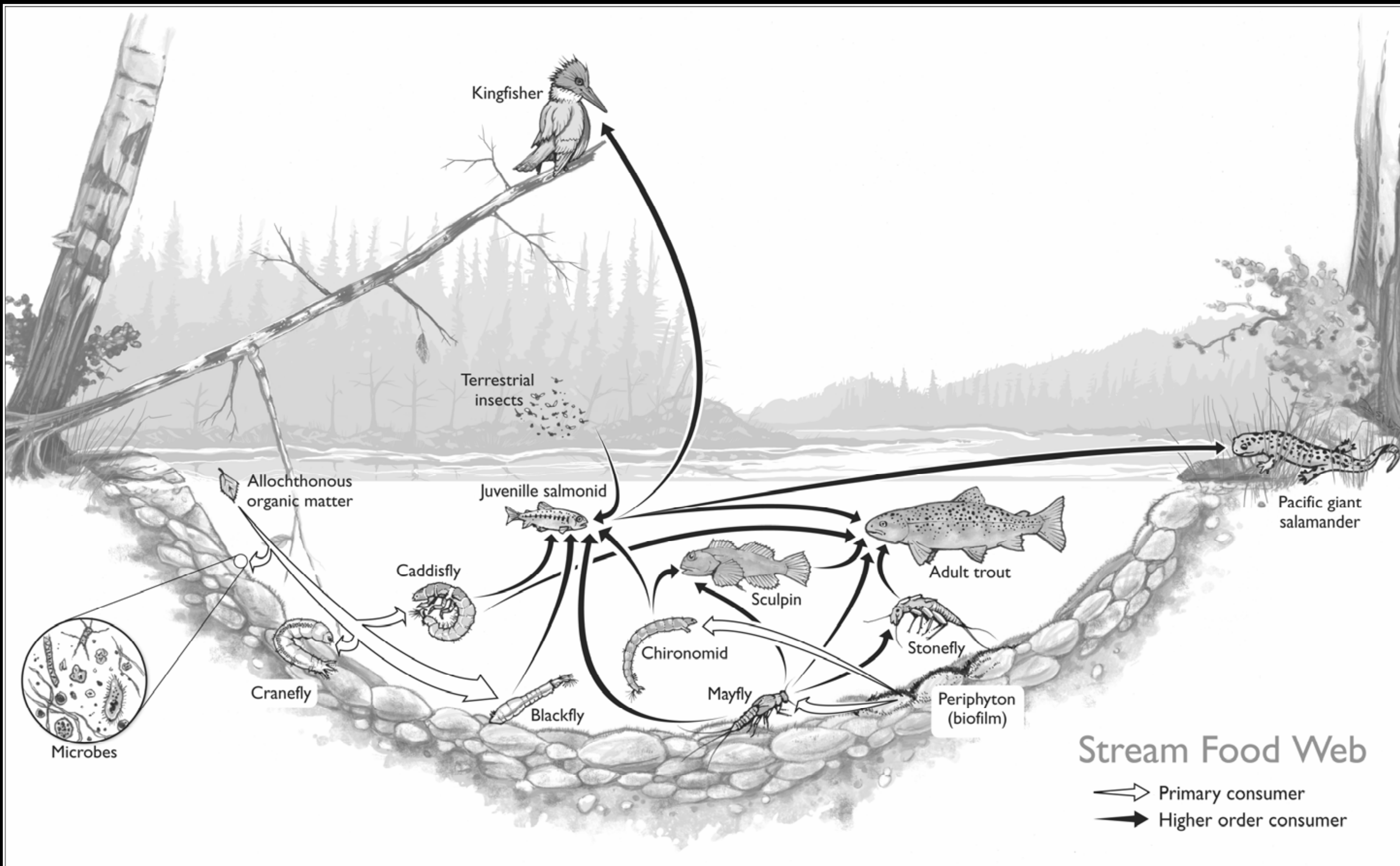
Magnuson-Stevens Act (Essential Fish Habitat; EFH)

Key considerations under ESA

- Impacts on salmon **Habitat**
- Impacts on salmon **Health**

Salmon in their natural laboratory exposure habitat

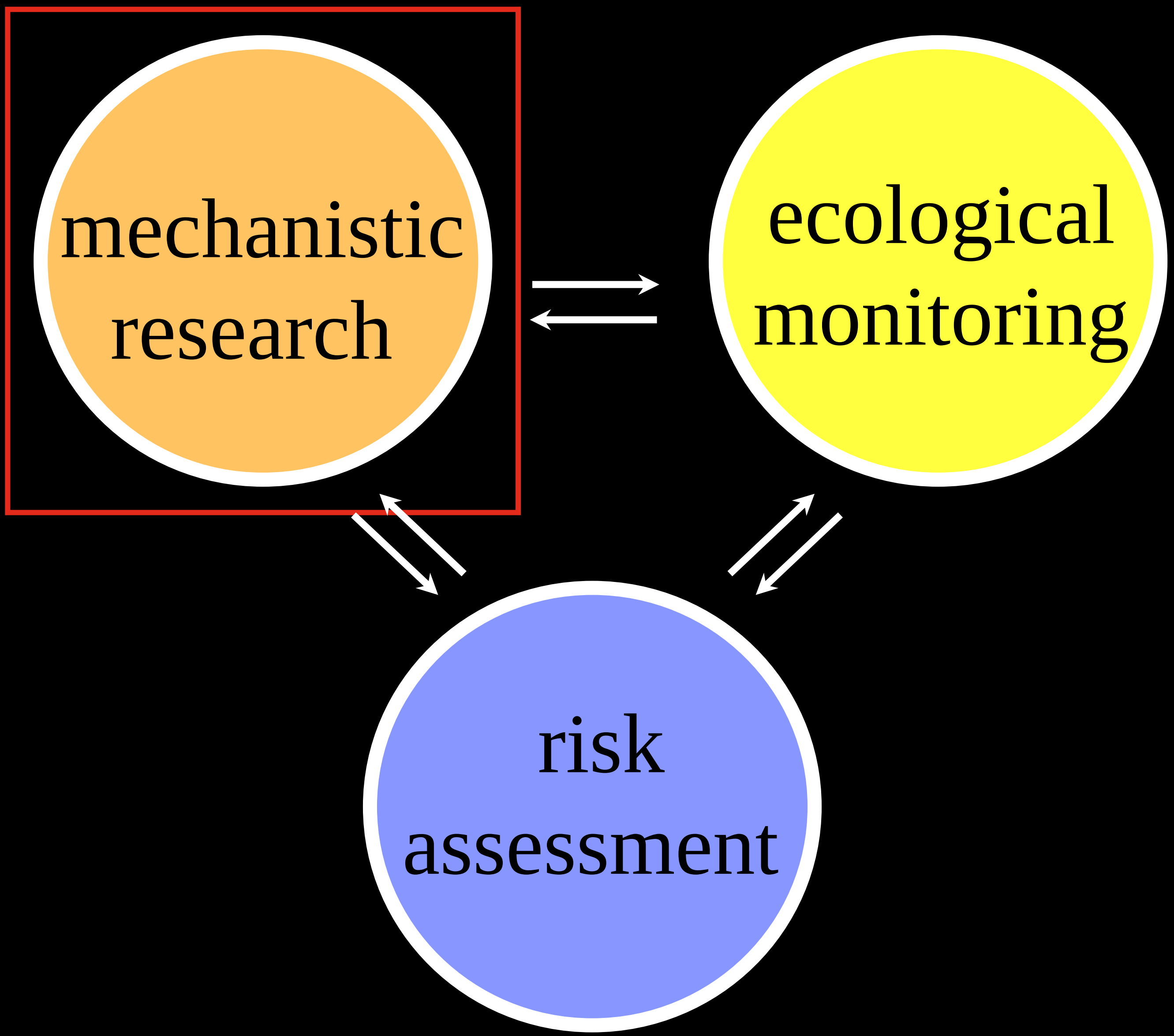
Salmon habitat - aquatic community structure



Salmon-centric toxicological endpoints of potential concern

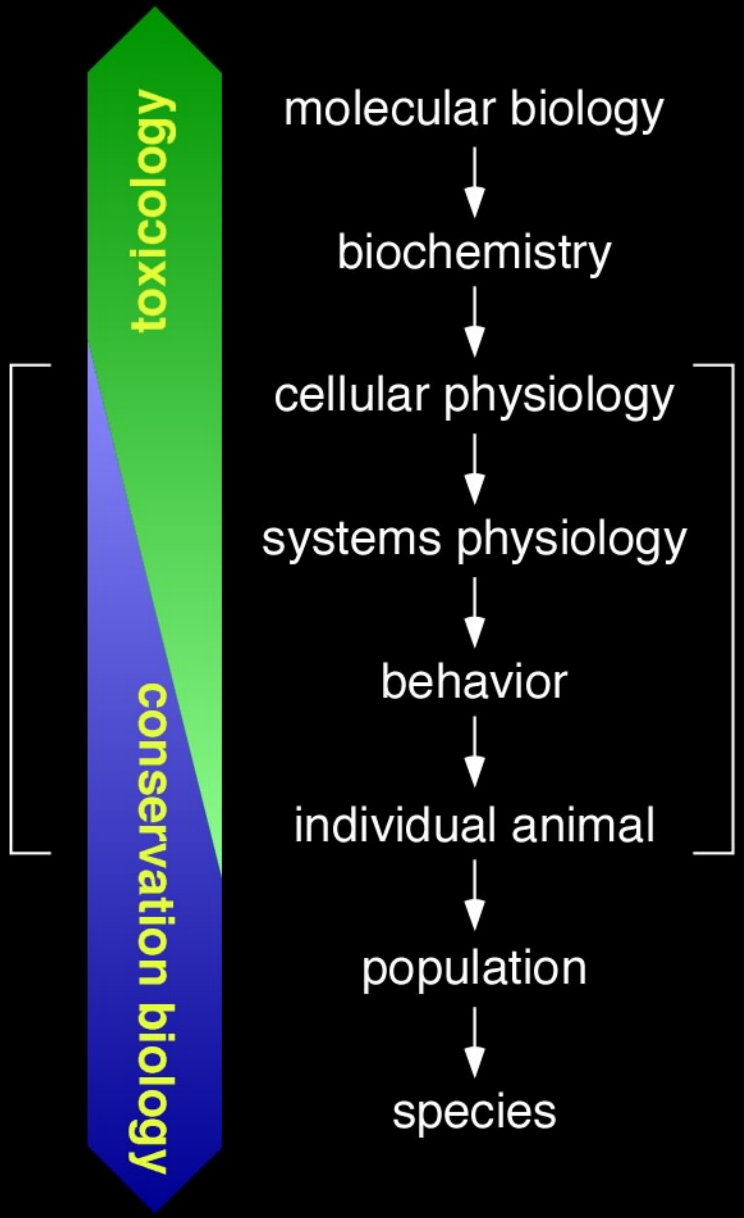
Assessment Endpoints	Assessment Measures
Juvenile growth	Foraging behavior
	Growth rate
	Condition index
Reproduction	Courtship behavior
	Number of eggs produced
	Fertilization success
Early development	Gastrulation
	Organogenesis
	Hatching success
Smoltification	Anion exchange (i.e. gill Na^+/K^+ ATPase activity)
	Blood hormone (i.e. thyroxin)
	Salinity tolerance
Disease-induced mortality	Immunocompetence
	Pathogen prevalence in tissues
	Histopathology
Predation-induced mortality	Predator detection
	Shelter use
	Schooling or shoaling behavior
Migration or distribution	Use of juvenile rearing habitats
	Adult homing behavior
	Selection of spawning sites

The Ecotoxicology and Environmental Fish Health Program at NWFSC



Evaluating the impacts of pollution on fish health

The importance of inter-relationships between scales of biological complexity



Urban growth and impervious surfaces =

non-point source pollution

Seattle Post-Intelligencer

50¢

A HEARST NEWSPAPER

KING, PIERCE, SNOHOMISH, ISLAND,
KITSAP & THURSTON COUNTIES

TUESDAY, AUGUST 16, 2005

DRIVEN TO POLLUTE

Cars replacing industry as Sound's worst foe

increasing, and it's prob-
with people driving."
t from a car's tailpipe into
sically two ways: Either
d until they fall directly
r they land on the ground
by rain into the Sound or

ndings mirror those of re-
wide with the U.S. Geo-

POLLUTION, A6

INSIDE

Identifying the top pollutants in Puget Sound – and a list of what you can do to help

SEE A6

Seattle Post-Intelligencer
April 5, 2003

POLLUTE: King County tests runoff into lake from 520 bridge

FROM B1

The tests appear to be the first on local bridges since the early 1980s. They show that some of the 10 metallic pollutants in the runoff exceed water-quality standards but are diluted to safer levels after entering the lake.

Pollution comes from a variety of sources on the 115,000 vehicles that cross the 520 bridge on an average day, including oil, grease and transmission fluid.

Even well-maintained vehicles pollute to some degree through brake pads, which grind off tiny amounts of metals with each use.

King County officials are doing more tests on 520's runoff and hope they will be representative of pollution on other limited-access highways, said Dean Wilson of the county Department of Natural Resources.

Formally known as the Gov. Albert D. Rosellini Evergreen Point Bridge, the structure was built in the early 1960s. Little thought was given to pollution flowing off the road.

At the time, Lake Washington was severely polluted by sewage discharges and in the early years of a cleanup. By comparison, road runoff mattered little.

Now, though, the lake meets water quality standards, meaning it's considered fit for swimming and fishing.

WHAT'S IN 520 BRIDGE RUNOFF

Polluted water that violates Washington's **acute standards** can harm or kill aquatic life in a single exposure. If it violates the **chronic standards**, the water harms aquatic life with repeated exposure.

Metals in Lake Washington
In parts per billion

NICKEL
.37
Acute: 577; Chronic: 64*

COPPER
1.75
Acute: 6.26; Chronic: 4.58*

ZINC
1.76
Acute: 48.6; Chronic: 42.5*

LEAD
.184
Acute: 20; Chronic: .78*

MERCURY (parts per trillion)
1.26
Acute: 2,100 Chronic: 12*

Several heavy metals were found in water washing off the Evergreen Point Bridge. The highest levels of the metals corresponded to the period of highest traffic volume.

Metals washing off 520 bridge
In parts per billion

	Low volume	Medium	High
NICKEL	2.57	6.74	7.71
COPPER	34.2	53.8	58.5
ZINC	52.7	144	158
LEAD	6.07	12.1	15.1
MERCURY (parts per trillion)	5.23	8.51	11.7

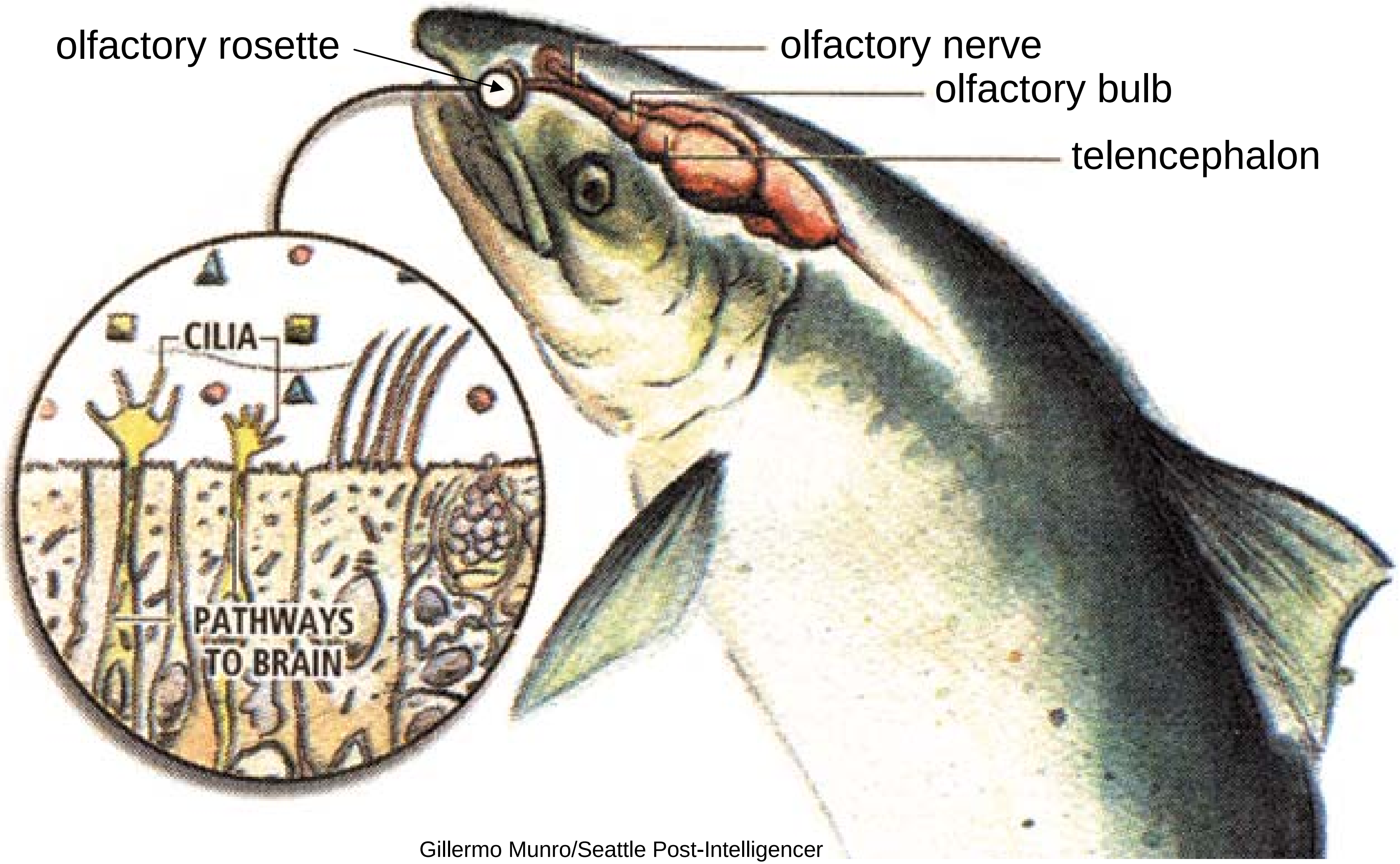
*Some standards vary according to water hardness. Standards used here apply in fresh water at a hardness of 34.6

Source: Puget Soundkeeper Alliance, Frontier Geosciences
SEATTLE POST-INTELLIGENCER

Copper (traffic volume):

- 34.2 µg/L (low)
- 53.8 µg/L (medium)
- 58.5 µg/L (high)

The salmon olfactory nervous system

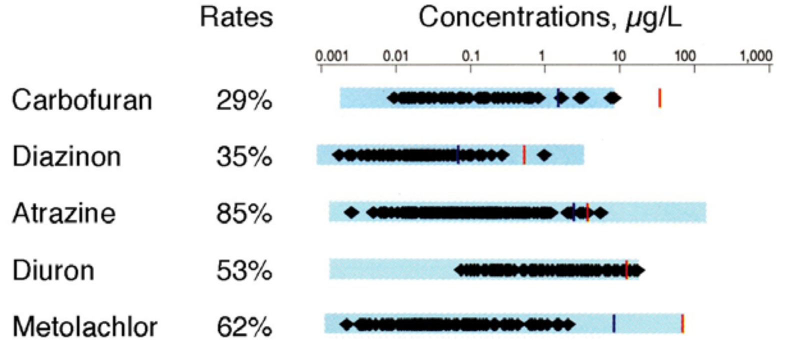


Gillermo Munro/Seattle Post-Intelligencer

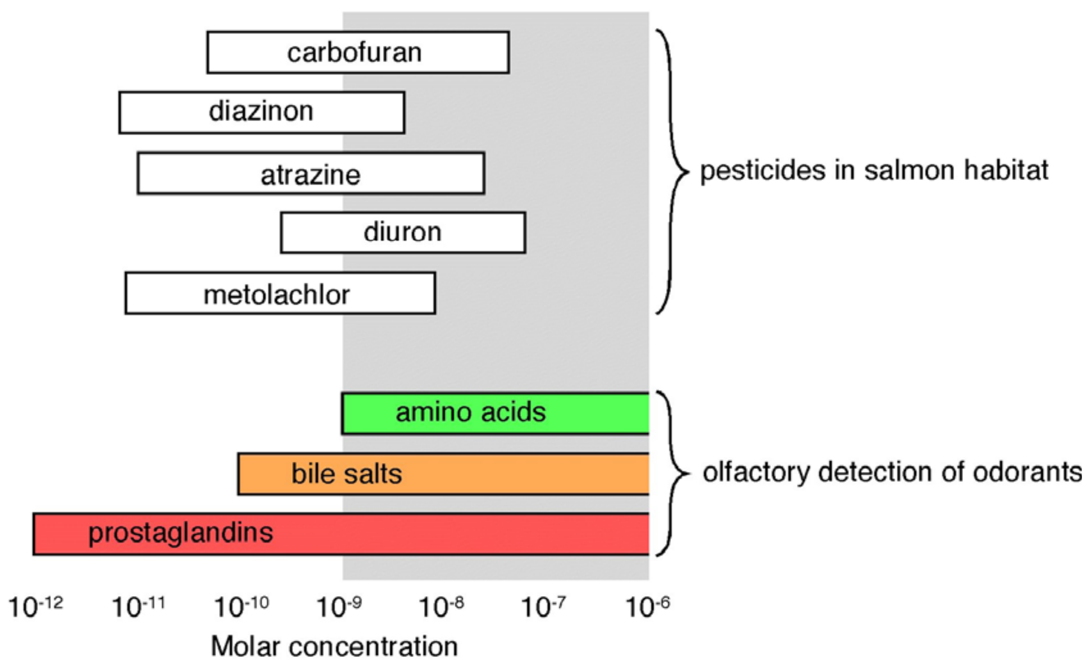
Why focus on the salmon nose?

- The nose is directly exposed to pollutants.
- Receptor neurons are very sensitive.
- Basic biology is well understood.
- Neurophysiological recordings are straightforward.
- Olfaction is linked to survival and reproduction.
- Olfaction guides imprinting and homing behaviors.

Surface water pesticide detections in the Willamette Basin

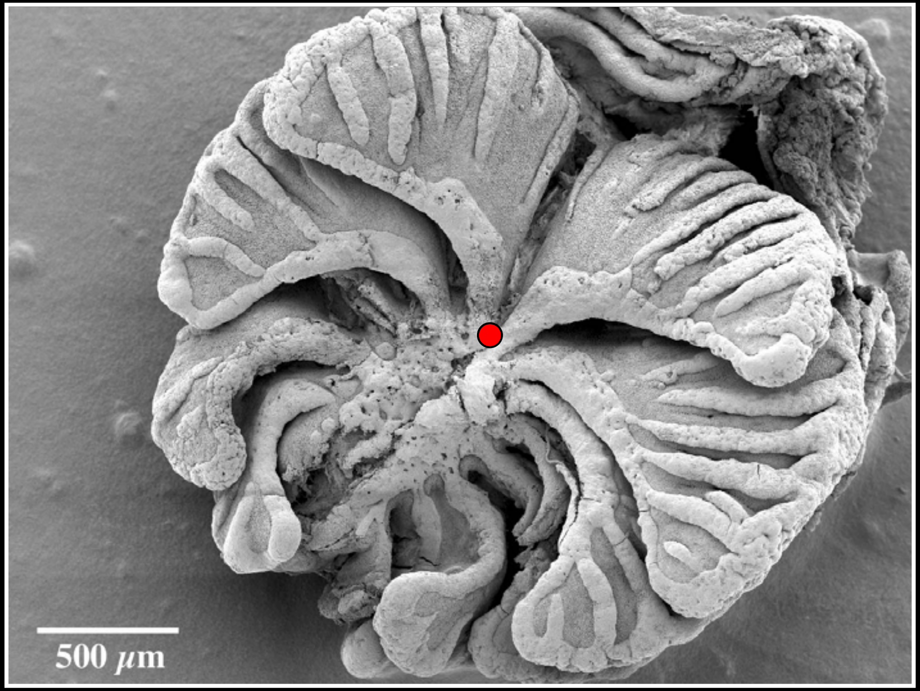


from USGS Circular 1161

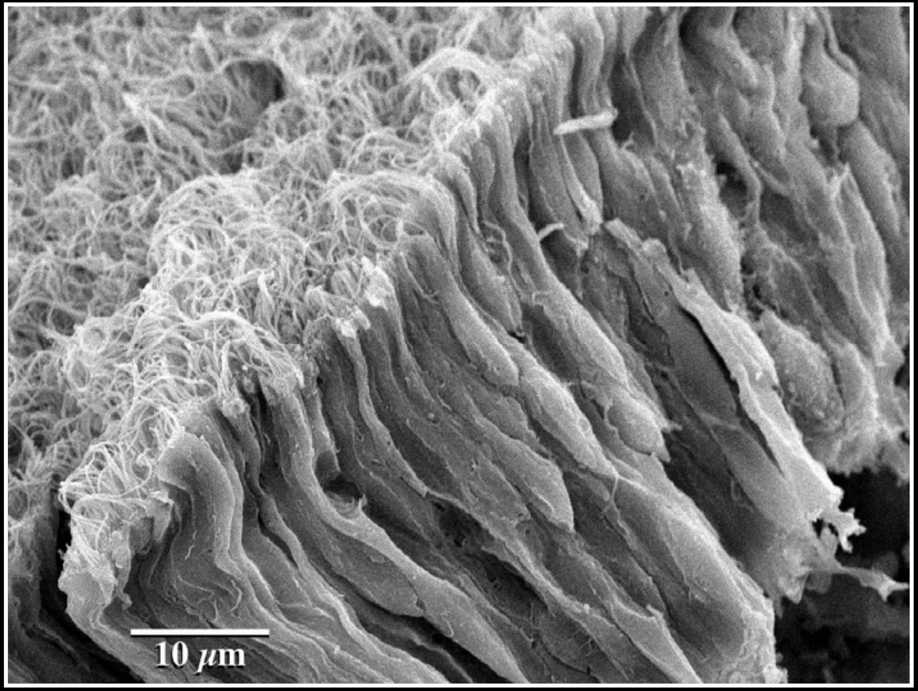


The olfactory organ (rosette) of coho salmon

Age 0



Age 1+

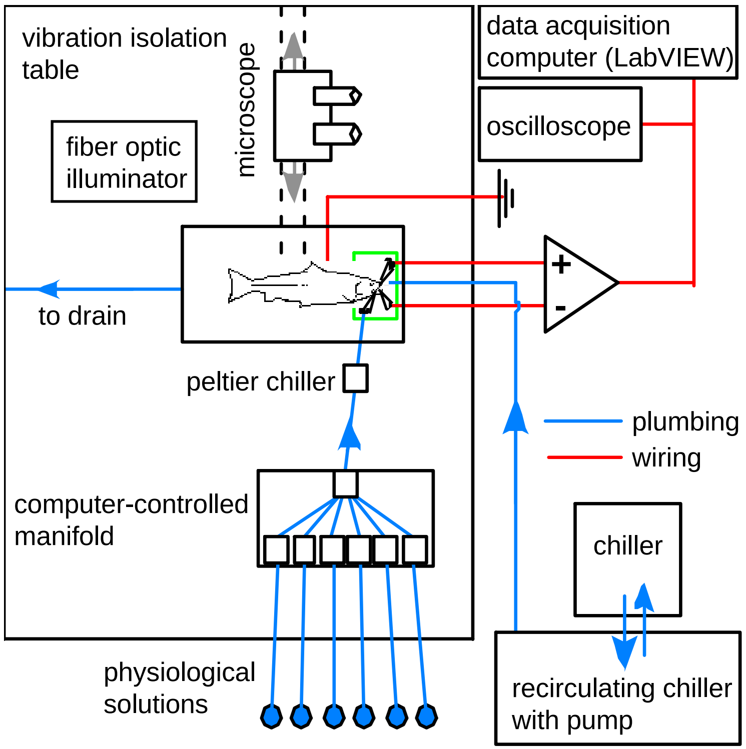


Scanning electron micrographs by Carla Stehr, NOAA Fisheries

● = electrode location for neurophysiological field potential recordings

In vivo olfactory recordings

A



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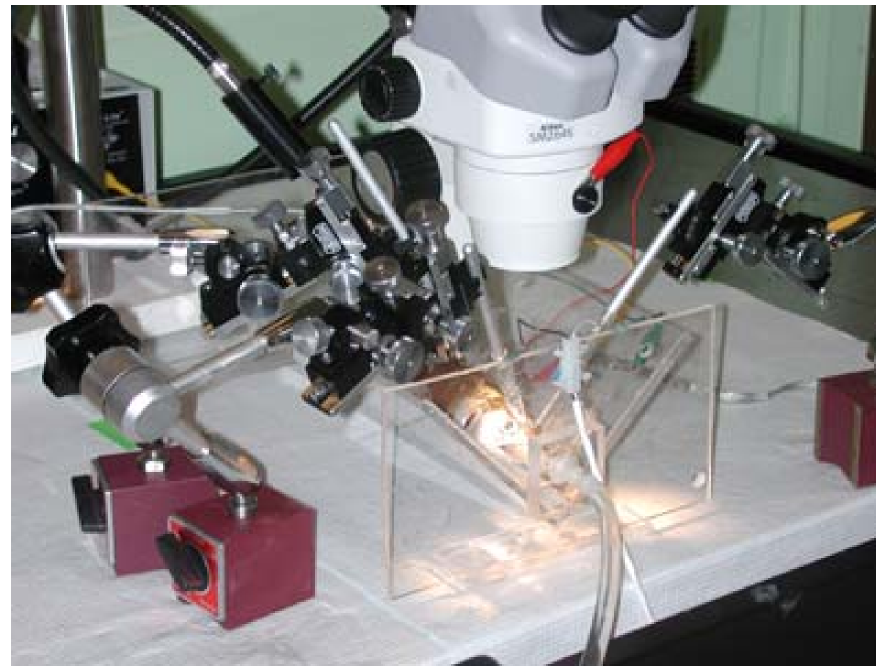
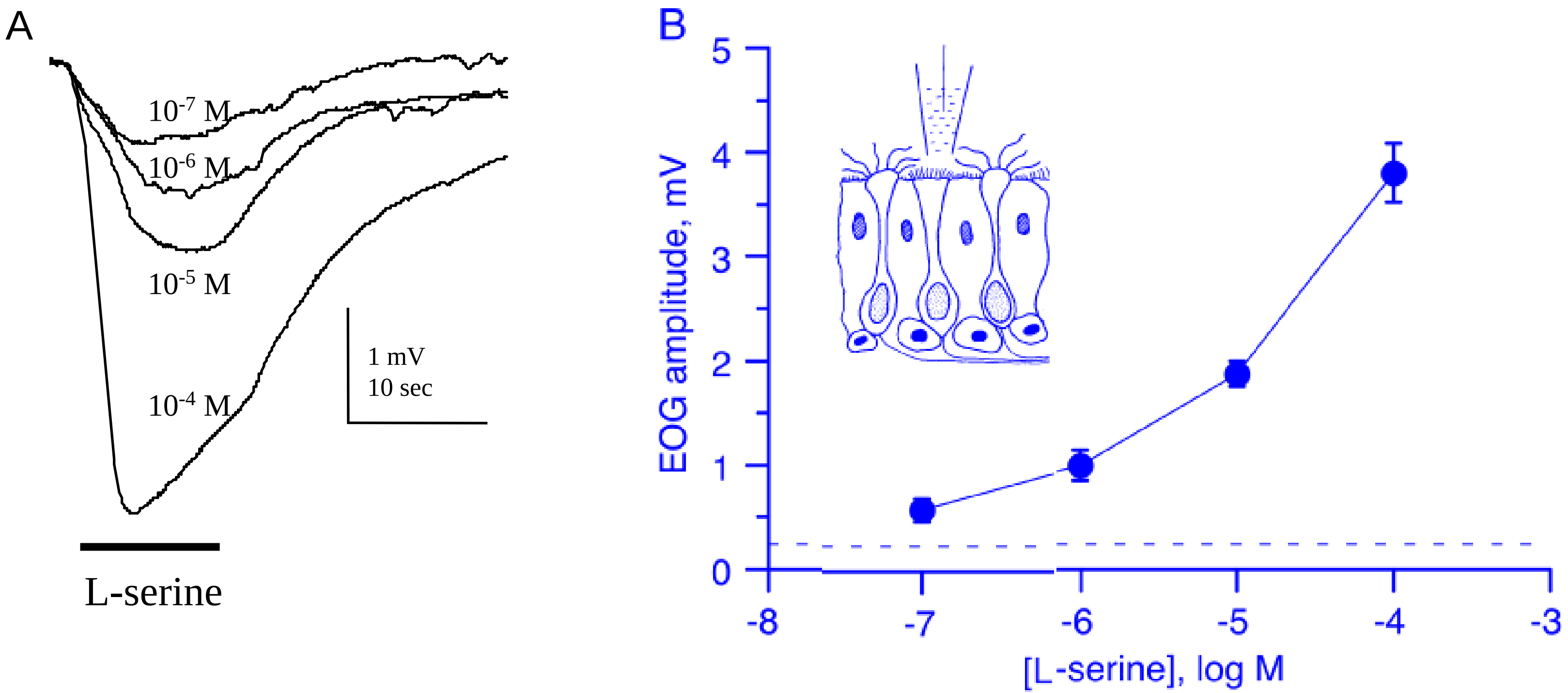
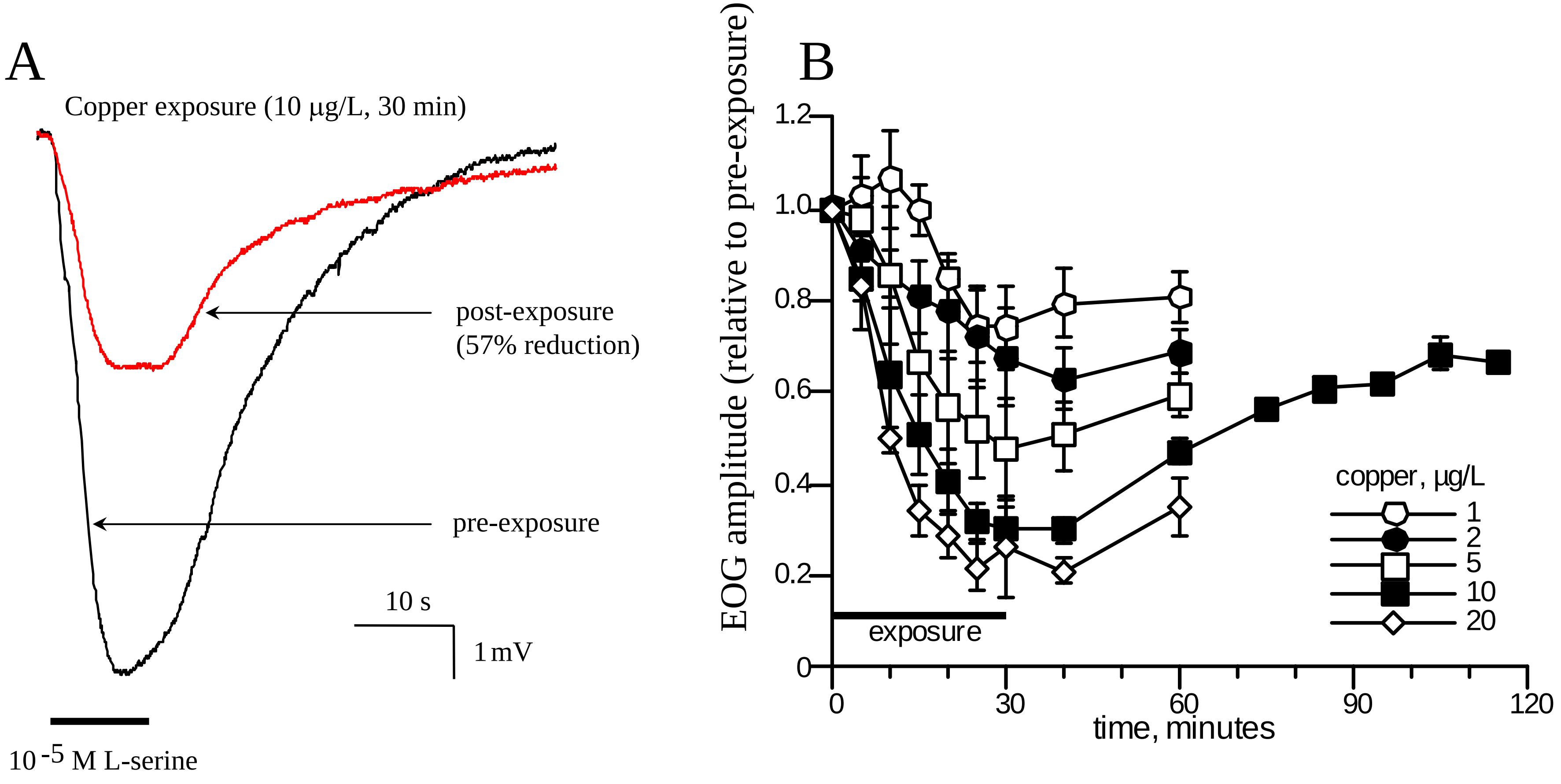


Odor-evoked extracellular field potentials (coho)



Sublethal copper neurotoxicity in juvenile coho (30 min exposures)



Baldwin. et al., 2003, *Environ. Toxicol. Chem.* 22:2266
Sandahl et al., 2004, *Can. J. Fish. Aquat. Sci.* 61:404

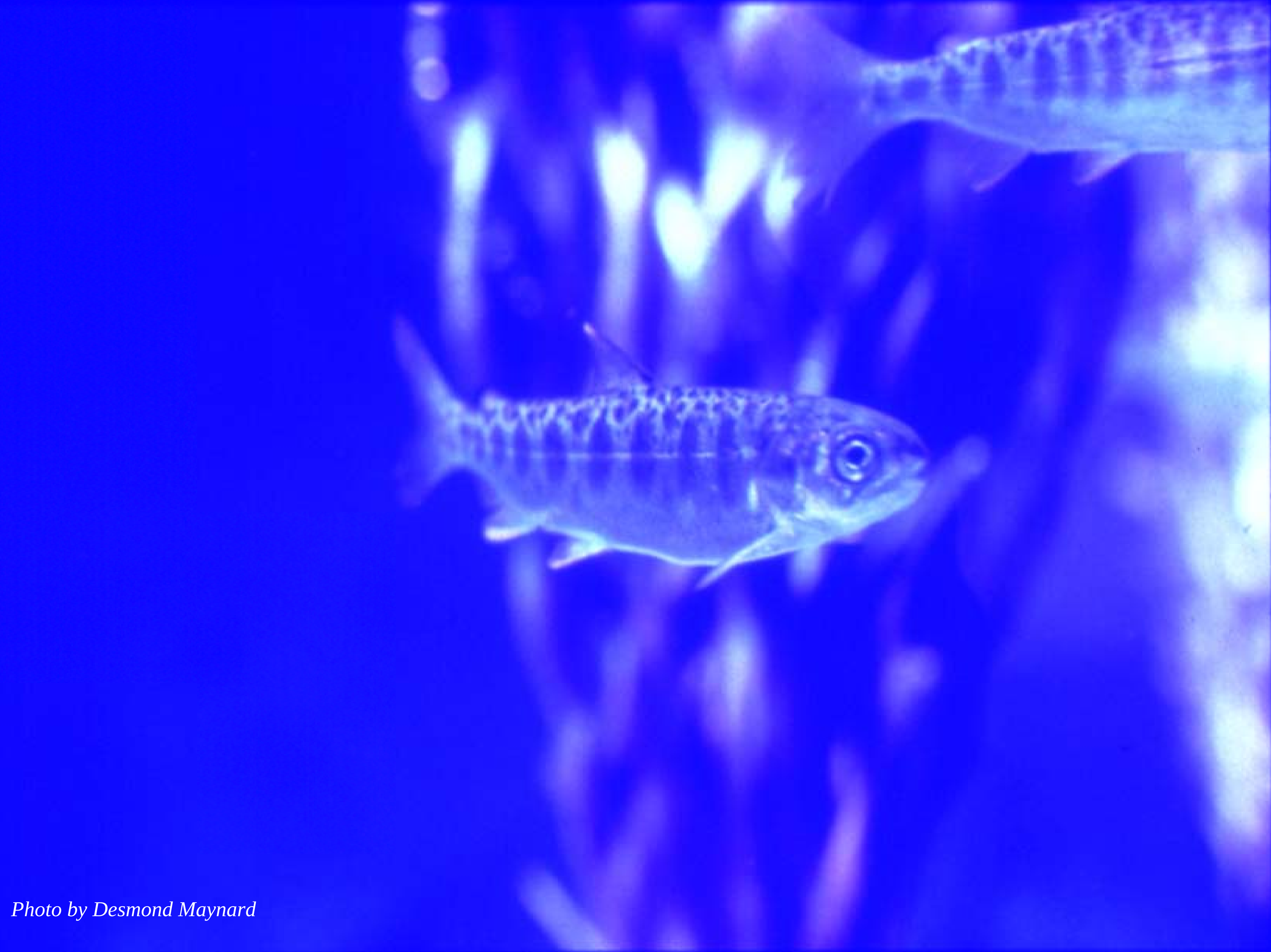
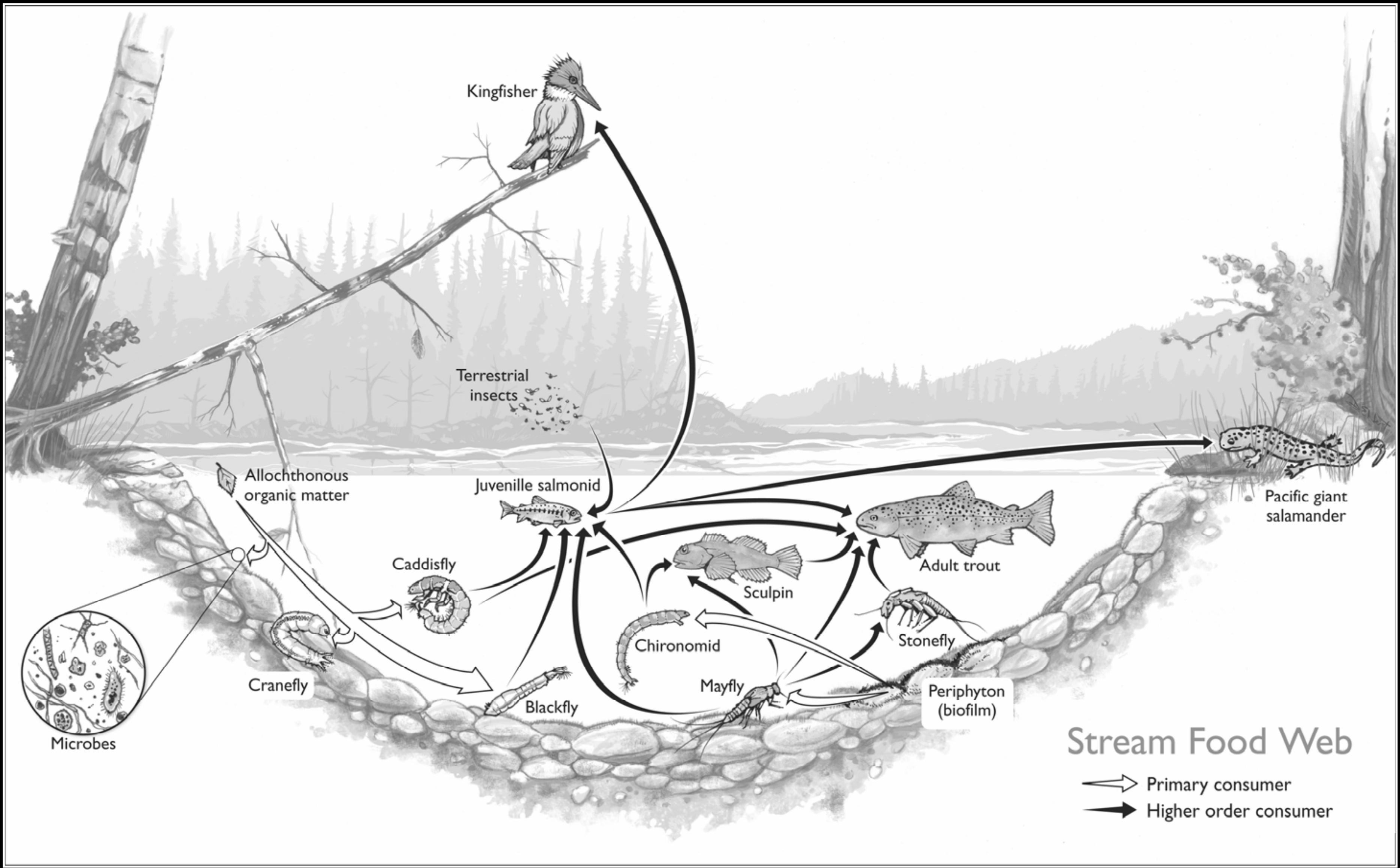


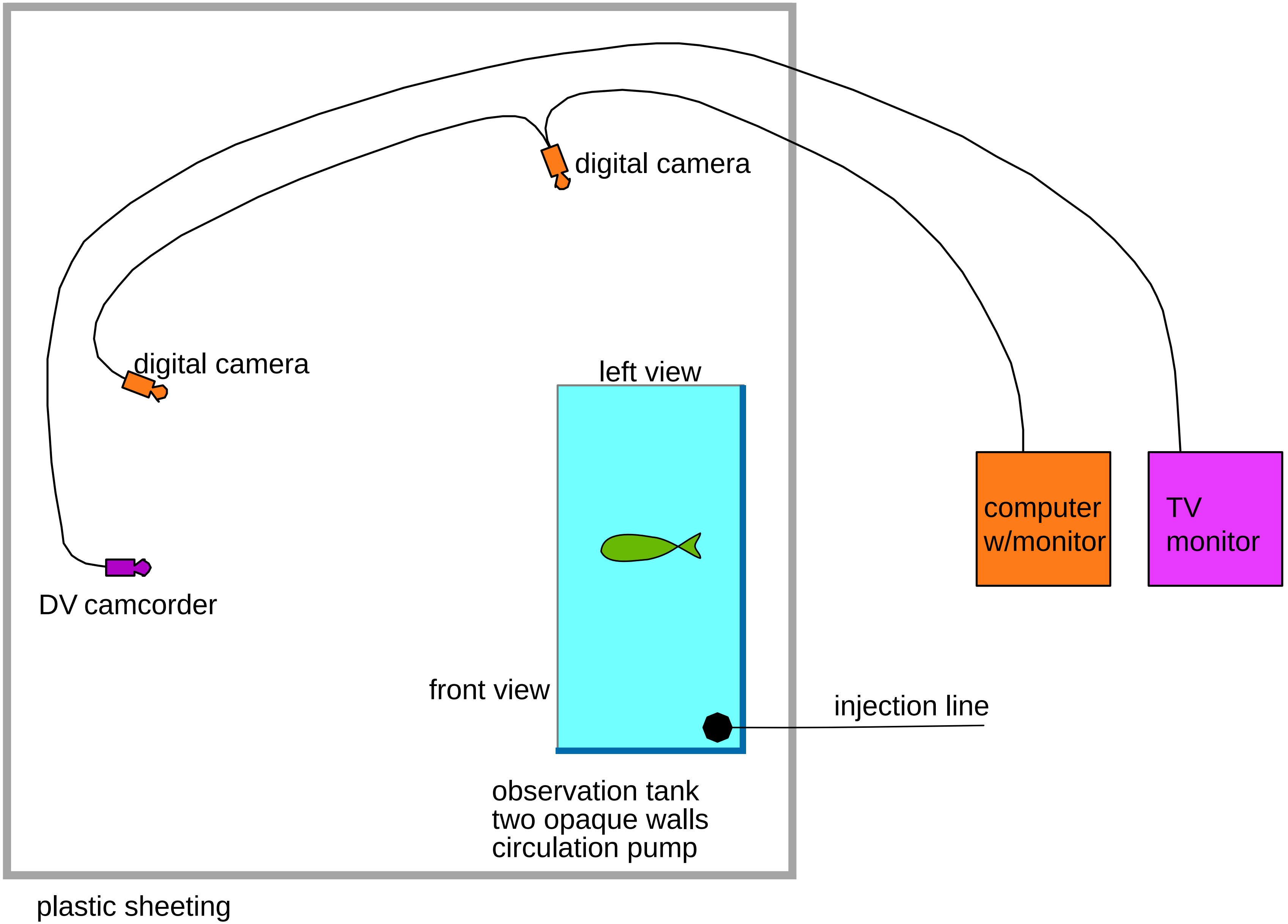
Photo by Desmond Maynard


Photo by David Sillasen

Salmon habitat - aquatic community structure



Computer-aided analysis of juvenile coho behaviors

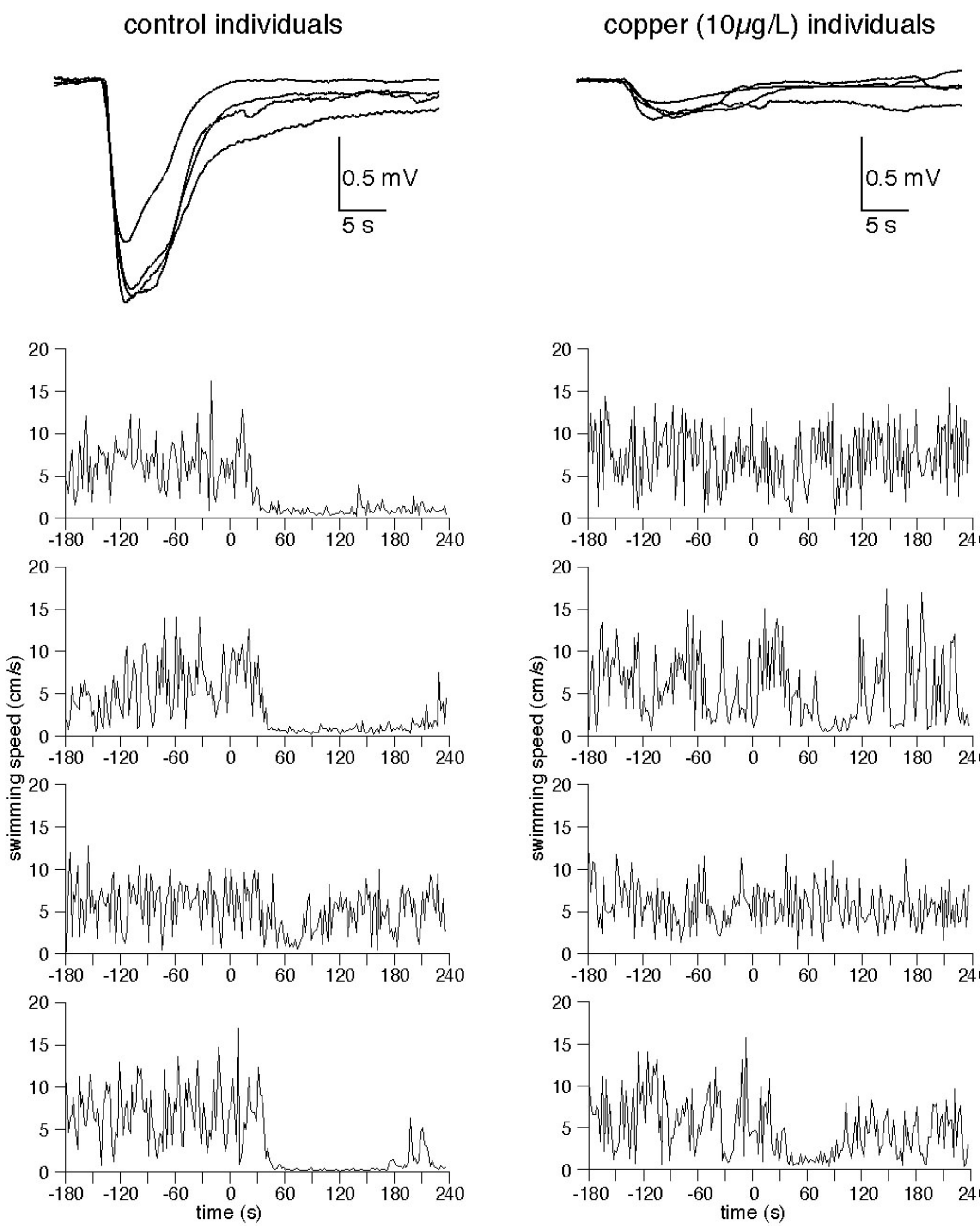


0 ppb
copper

Left Side Vie

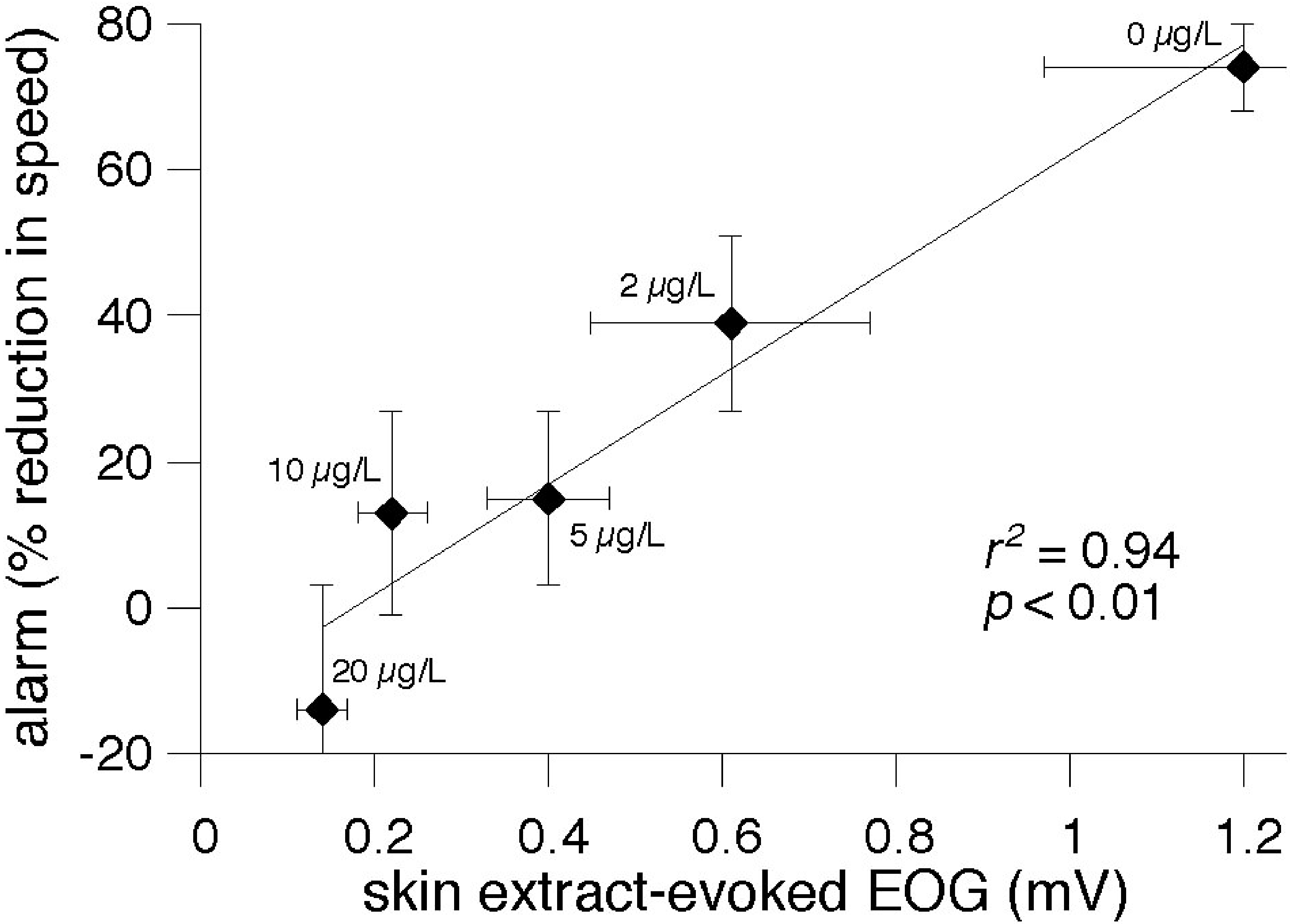
Front View

10 ppb
copper



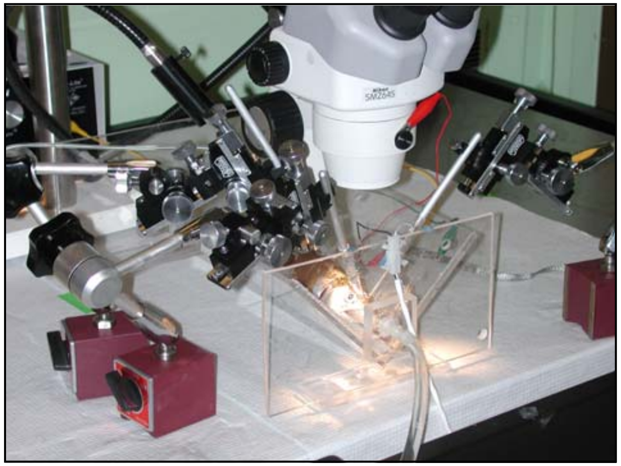
control individuals
copper (10μg/L) individuals
0.5 mV
5 s
0.5 mV
5 s
swimming speed (cm/s)
swimming speed (cm/s)
20
15
10
5
0
-180
-120
-60
0
60
120
180
240
time (s)
time (s)

Relative impacts of dissolved copper on juvenile coho olfactory neurophysiology and predator-avoidance behavior



Task 1 - Direct *in vivo* measures of neurotoxicity in the salmon olfactory system.

- *Toxicity thresholds for dissolved copper*
- *Extent of neural injury and recovery*
- *Impacts on critical behaviors*

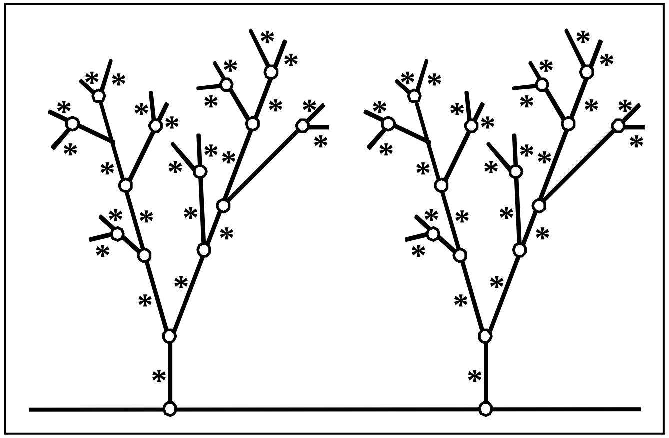


Task 2 - Quantifying the effects of copper on salmon survival and reproductive success.

- *Predator-induced mortality in juveniles*
- *Spawning behavior and fertilization success*

Task 3 - Modeling the impacts of copper on natural salmon populations.

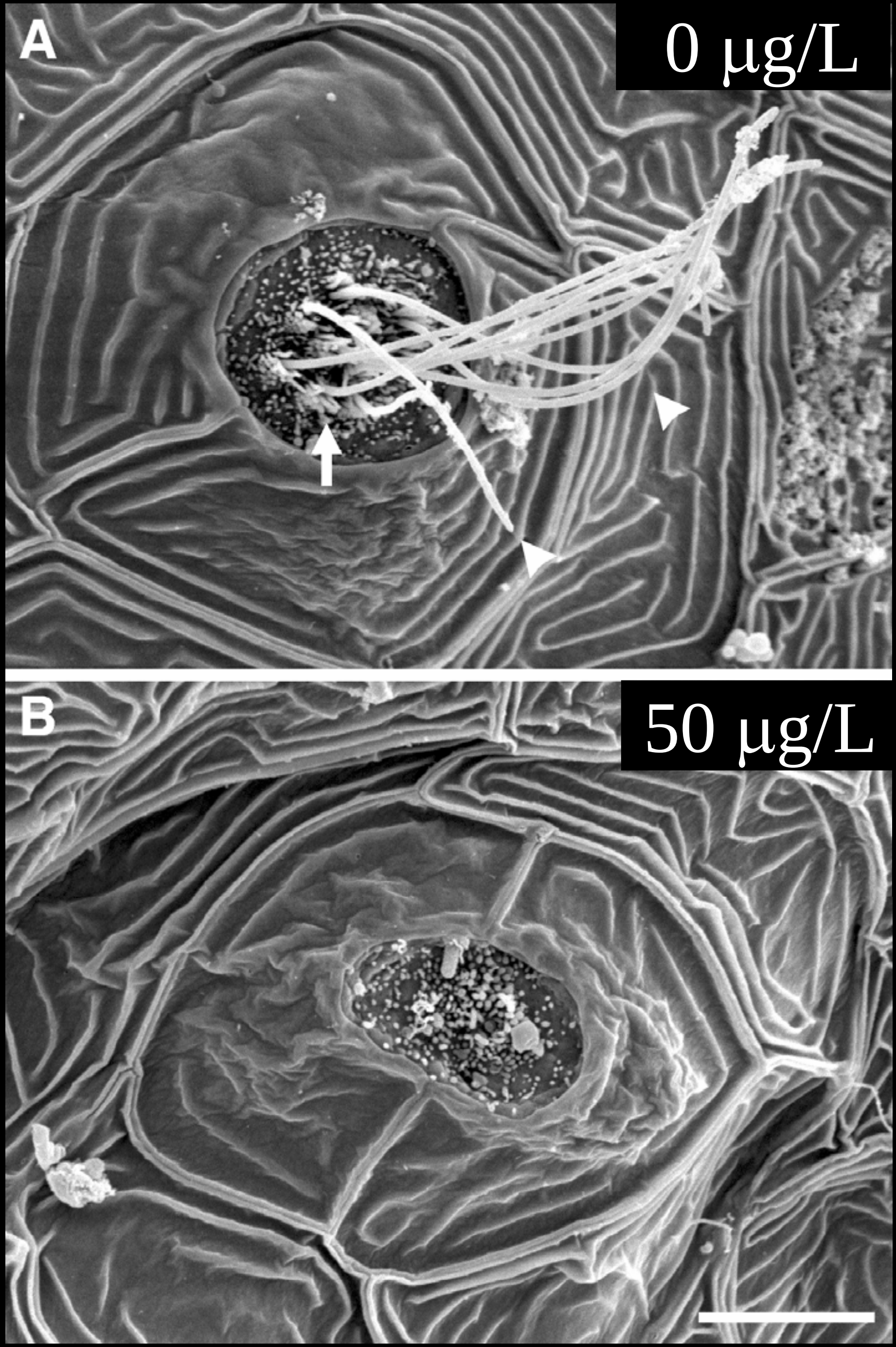
- *Homing and straying in wild and hatchery fish*
- *Limits on the productivity of wild populations*



Copper-induced loss of apical cilia from lateral line neurons

Arrows: stereocilia

Arrowheads: kinocilia



Linbo et al., 2006, *Environ. Toxicol. Chem*. 25:597

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