Linking Water Quality and Quantity with Ecosystem Condition

Demonstration Project Training: 27 March 2012

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UNDP
Empowered lives.
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Catastrophic Impacts Tend to be Obvious…

Photo Credit: AP Photo/Charlie Riedel

Photo Credit: AP Photo/ Jeff Roberson

Image: William C Turnley 1990

Source: www.epa.gov

Most Impacts and Effects are More Subtle, Indirect, and/or Cumulative

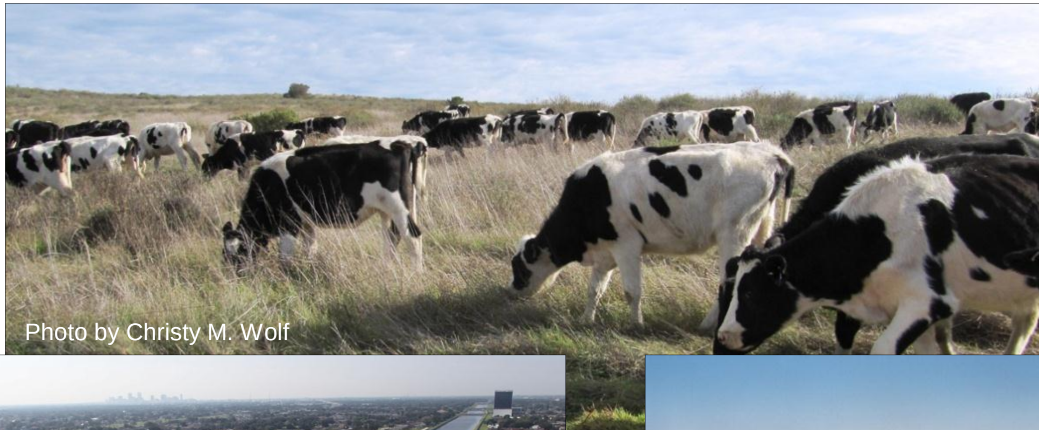


Photo by Christy M. Wolf

Photo Credit: www.vtwaterquality.org

source: Getty Images

rce: http://thisweekinnuclear.com

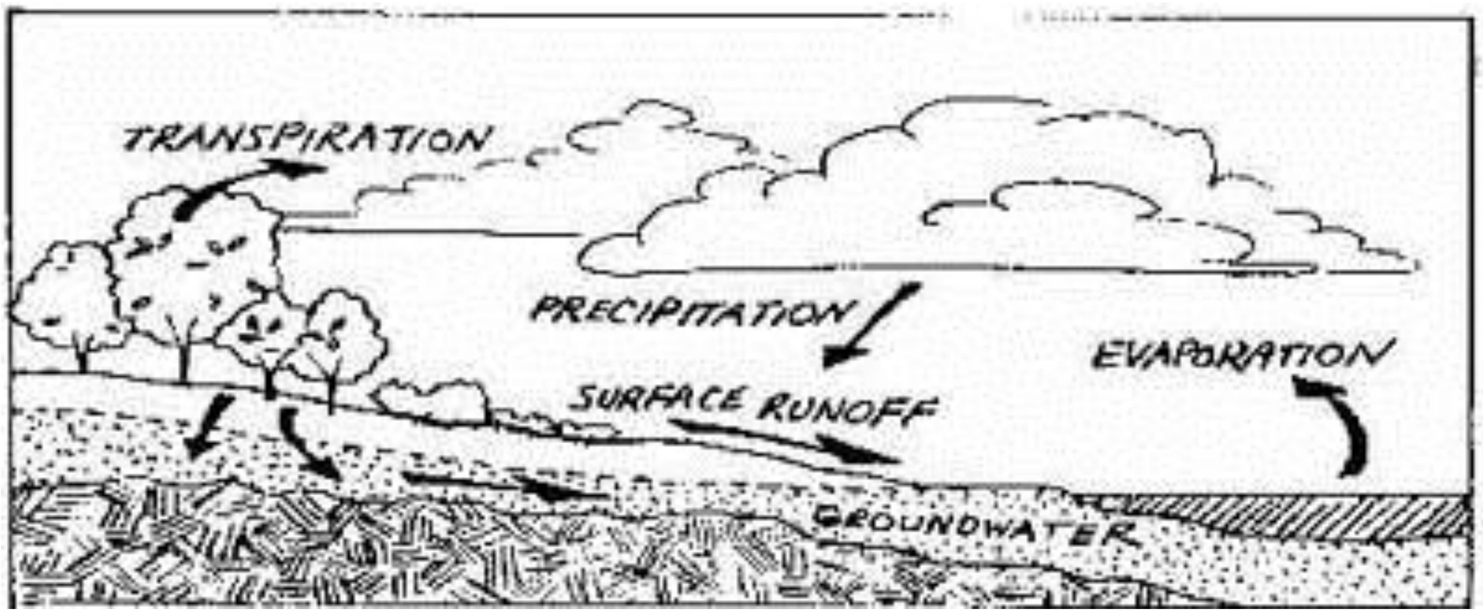
Wikipedia.org (author: Steven G. Johnson)

Source: Wikipedia.org (author Doron)

Source: http://science.nature.nps.gov

Wetlands are Part of a System

- Streams, rivers, and wetlands are part of a system
- Water moving cycle replenishes streams in the watershed
- System includes the *entire* watershed
  - Rainfall, groundwater recharge, runoff, evaporation
  - Land cover provides shade, nutrients, erosion control, buffering

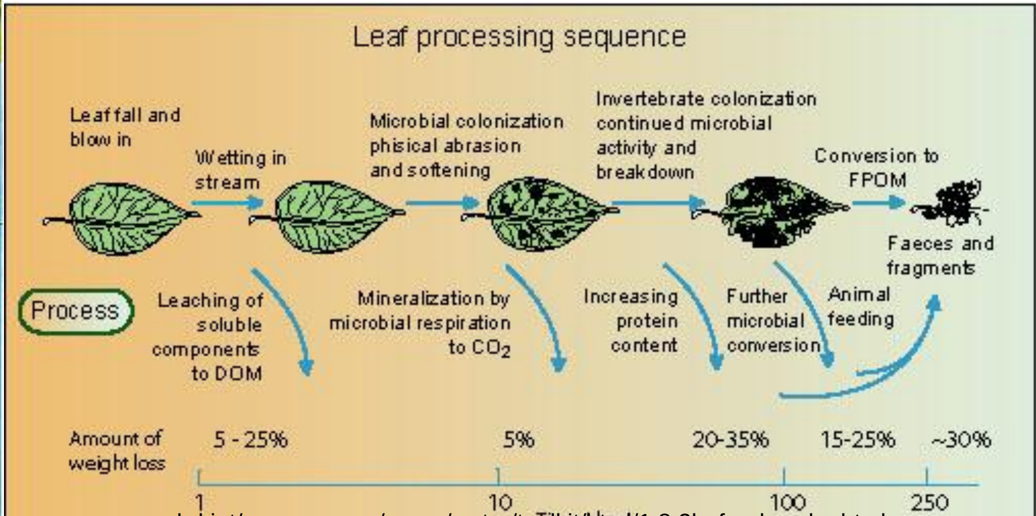


Source: http://water.epa.gov/type/rsl/monitoring/vms21.cfm

Wetlands are Part of a System

Source: http://www.goldridge08.com/

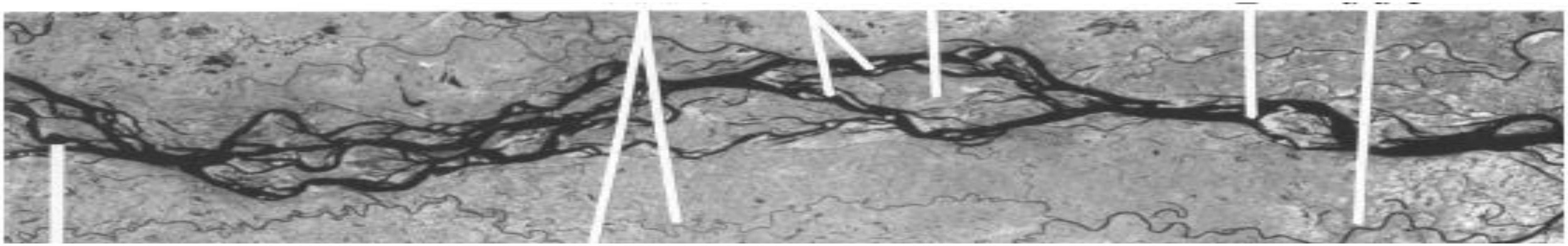
- Food webs create interdependence
- Energy base influences other trophic levels



source: www.cbd.int/programmes/areas/water/toolkit/html/1.8.2b_food_webs.html

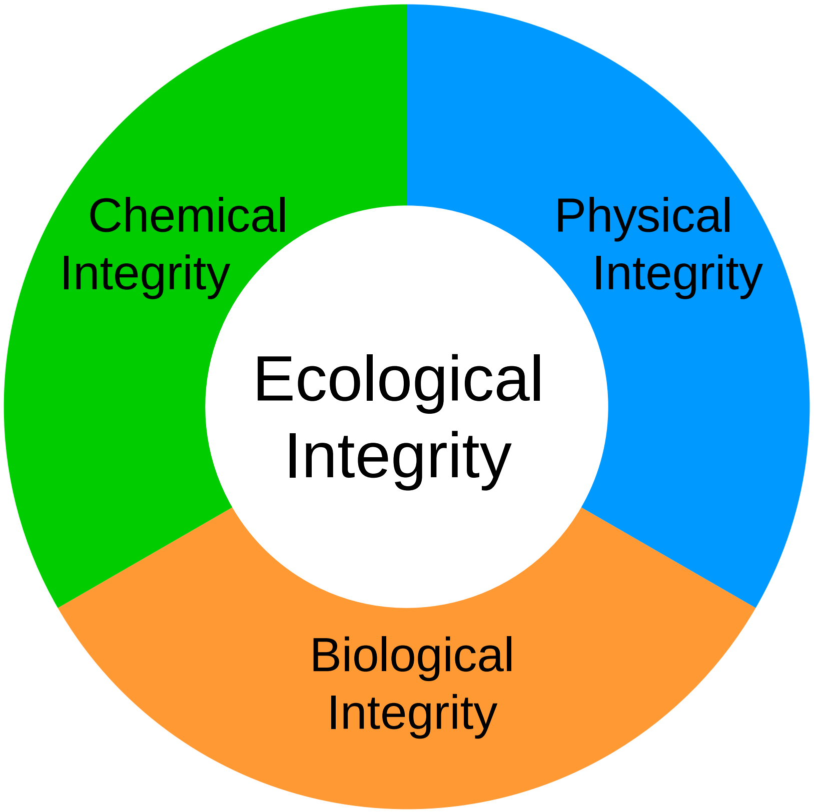
Wetlands are Part of a System

- Unimpaired rivers are naturally very dynamic and complex
  - Daily, seasonal, annual patterns of water discharge
  - Fluctuations in temperature, chemistry
  - Substrate composition varies; heterogeneous microhabitats
  - River flooding and meandering replenishes nutrients
  - Sediment erosion, transport, deposition
- These cycles, especially the lateral interactions between channel and floodplain, are critical to holistic understanding of natural river ecosystems and potential effects of alterations

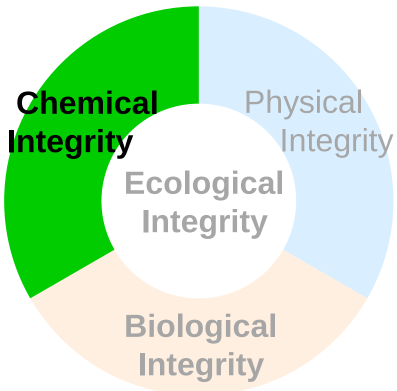


Ecological Integrity

- Especially significant in context of whole system
- Ecological Integrity is combination of chemical, physical and biological integrity
- Degradation of one or more of these components will affect health of whole system

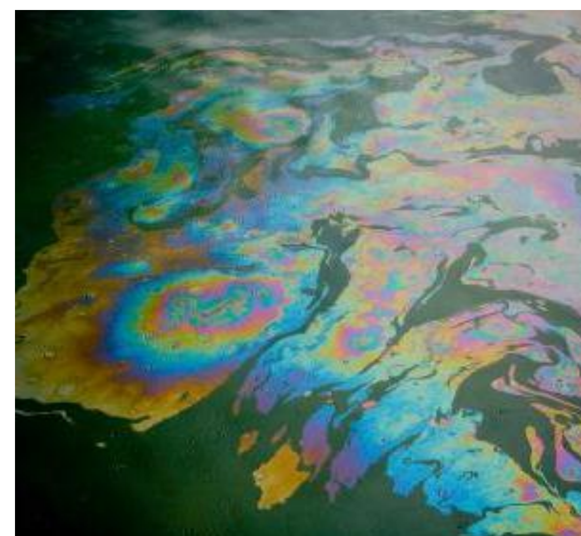


Chemical Integrity



- Organic and inorganic chemical components of the water and include:
  - Dissolved oxygen
  - Turbidity
  - Dissolved solids
  - Nitrogen
  - Phosphorous
  - Other Nutrients
  - pH
  - Salinity
  - Bacteria

- Stressors affecting Chemical Integrity include:
  - Excess nutrients/organic loading (fertilizers, sewage)
  - Sedimentation/burial (dirt, minerals, sand, silt)
  - Excess of harmful pathogens (bacteria, viruses)
  - Toxins (pesticides, oil, hazardous waste, pharmaceuticals, heavy metals)
  - Pollutants in general (acid rain, air pollution)



(photo source: http://www.phongpo.com)

Obvious Impaired Chemical Integrity: "The River that Caught Fire"

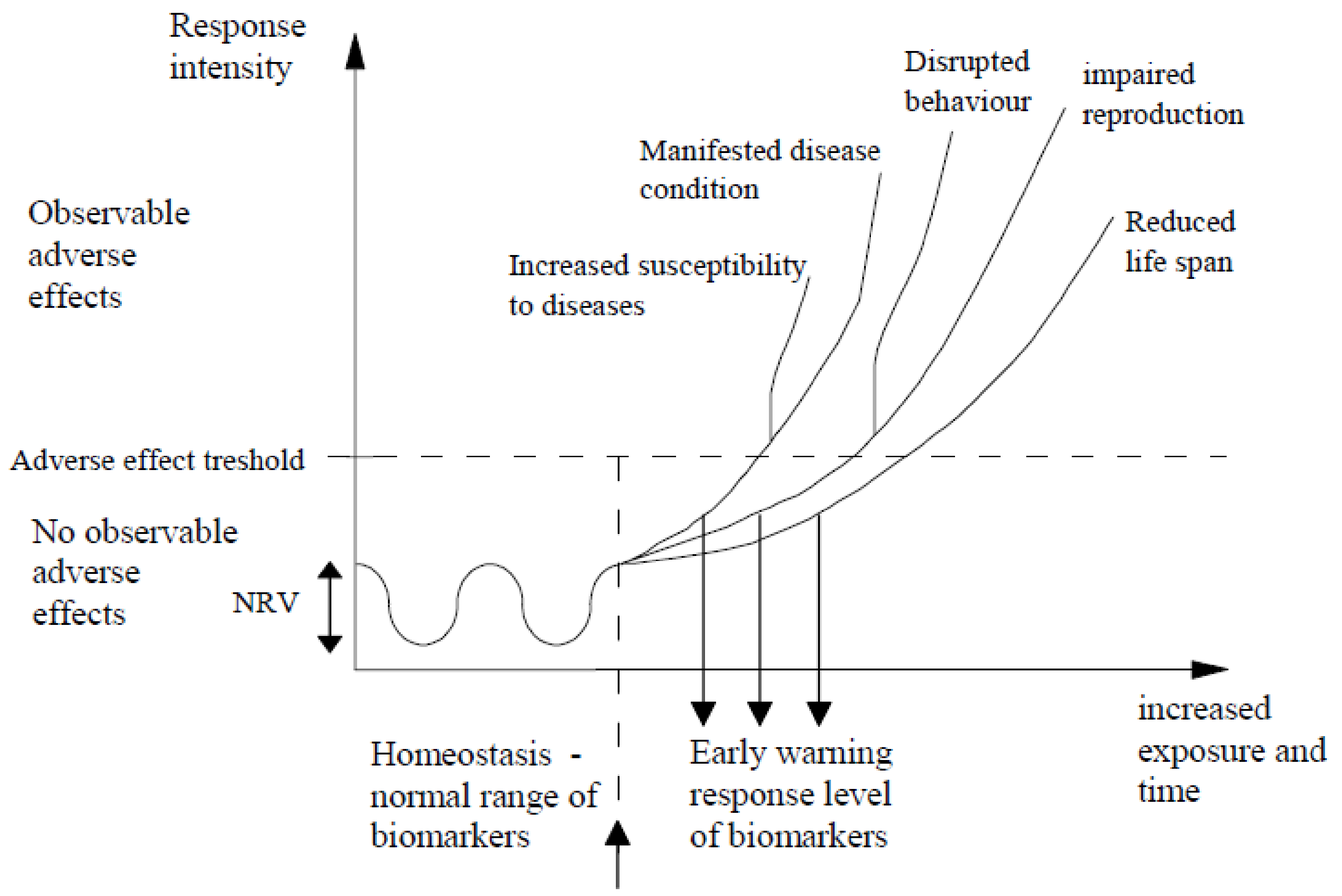
- Cuyahoga River 1969
- Contaminated with oily waste from waterfront industries
- Burning rivers in industrialized areas were common in late 19th and early 20th centuries.


source: http://ohiohistorycentral.org


Source: http://www.cleveland.com

"The lower Cuyahoga has no visible life, not even low forms such as leeches and sludge worms that usually thrive on wastes." *-- The Federal Water Pollution Control Administration*

Subtle Impaired Chemical Integrity:
Effect of Pollutant Exposure/Dose Over Time



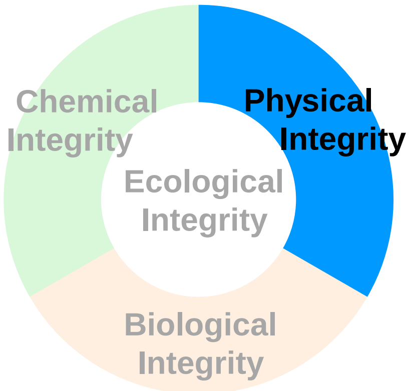
Source: RF-Akvamiljø, www.rf.no

Example of Effects from Changes in Water Chemistry

- Dissolved oxygen (DO) = critical water quality parameter for aerobic organisms
- Nutrient loading (N or P) leads to eutrophication
  - Algae blooms
  - Blocks out light
  - Algae and other plants die
  - Decomposing organisms deplete O_2
  - Creating hypoxic or anoxic conditions

Photo source: http://anniekatec.blogspot.com

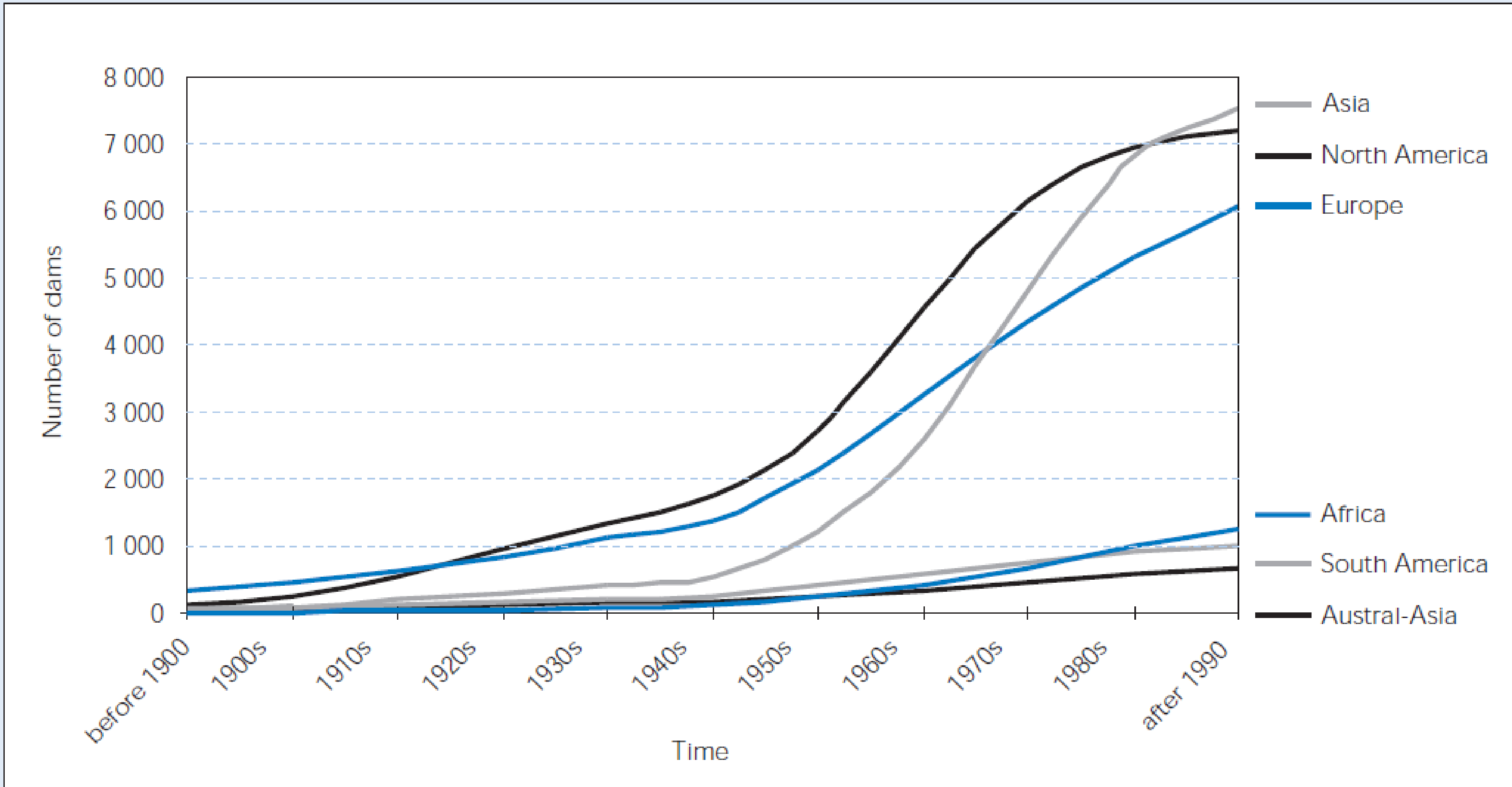
Physical Integrity



- Physical integrity includes geomorphology (streambank, floodplains, channel depth), hydrology, and habitat structure.
- Examples of impacts that may physically affect rivers and streams
  - Dredging or filling
  - Erosion, runoff
  - Thermal alteration
  - Flow alterations
  - Channelization
  - Impoundments
  - Habitat removal/frag.
  - Impervious surfaces

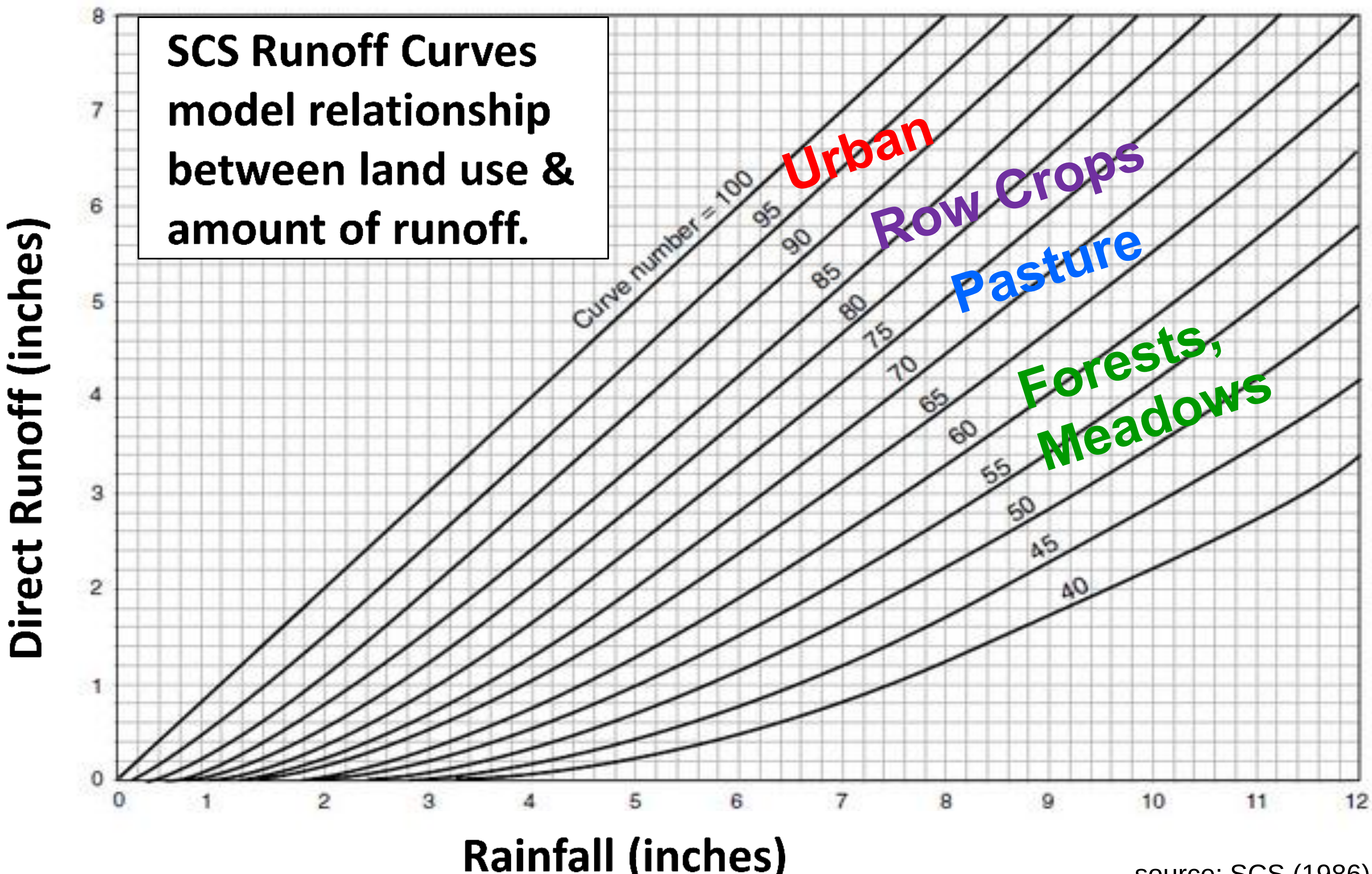
photo: http://you-are-here.com/location/la_river.html

Numbers of Dams Constructed by in World in Last 100 Years



Source: ICOLD, 1998. Note: Information excludes the time-trend of dams in China (as cited in World Commission on Dams, 2000)

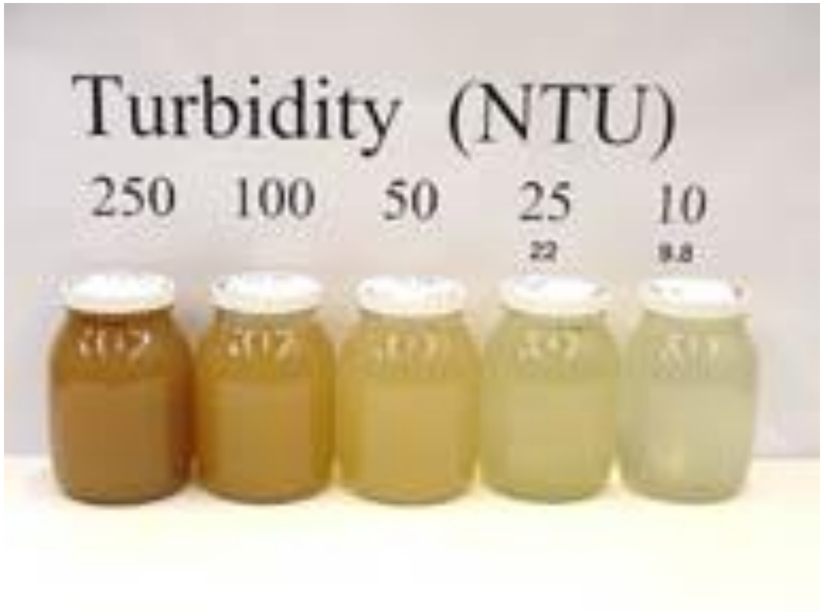
Chemical & Physical Integrity: Effects of Surrounding Land Use



source: SCS (1986)

Example of Effects from Changes in Water Turbidity

- High Turbidity reduces light availability (decreases photosynthesis and O_2 production)

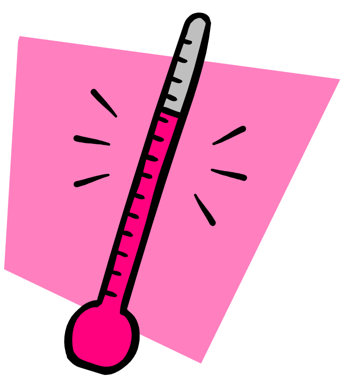


- Suspended solids can impact submerged aquatic vegetation, benthic organisms, and ability of juvenile fish to catch prey

Photo source: http://ecologyadventure2water.edublogs.org

Example of Effects from Changes in Water Temperature

- Elevated water temperatures reduce DO
- For each organism there is a thermal “death point”, and optimal temperature range for abundance
- Temperature influences enzyme reactions, hormonal control, digestion, osmoregulation
- Fish spawning and hatching of eggs are geared towards annual temperature changes
- Many toxic substances exhibit increased toxicity at elevated temperatures
- Loss of riparian habitat (shade source) exacerbates problem



Example of Effects from Changes in Flow Modification

- Change in volume/velocity of water flow can affect habitat structure (loss of scouring, loss of sandbars)
- Reduced or increased sedimentation
- Aquatic macroinvertebrates shift in community composition after human-induced water withdrawals

- Reduced water volume and velocity can affect fish migrations
- Loss of sinuosity. High degree of sinuosity provides diverse habitat (e.g., riffles), and stream is better able to handle surges (e.g., more protected from erosion)

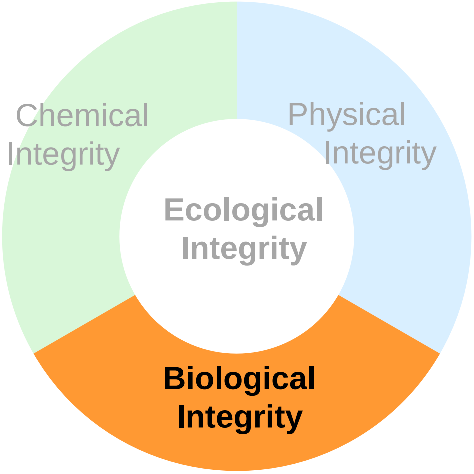
Example of Effects from Changes in Riparian Vegetation

Loss or Degradation of Riparian Vegetation

- Loss of Terrestrial Habitat
- Loss of Energy Source
- Loss of Stream Shade
- Alters Water Quality and Quantity

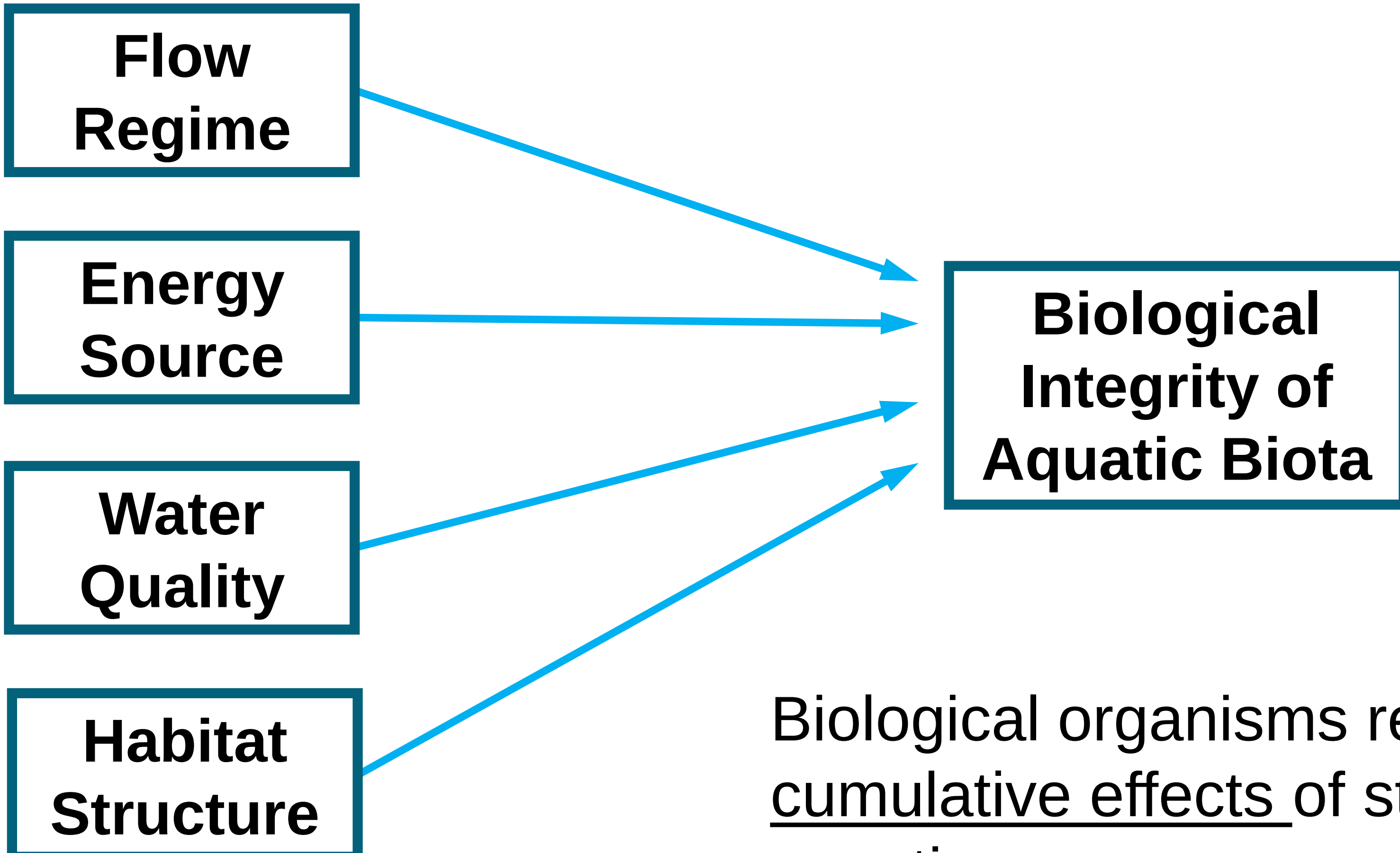
Photo by: Michael Field, SDNHM

Biological Integrity



Biological Integrity = "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981)

Biological Integrity

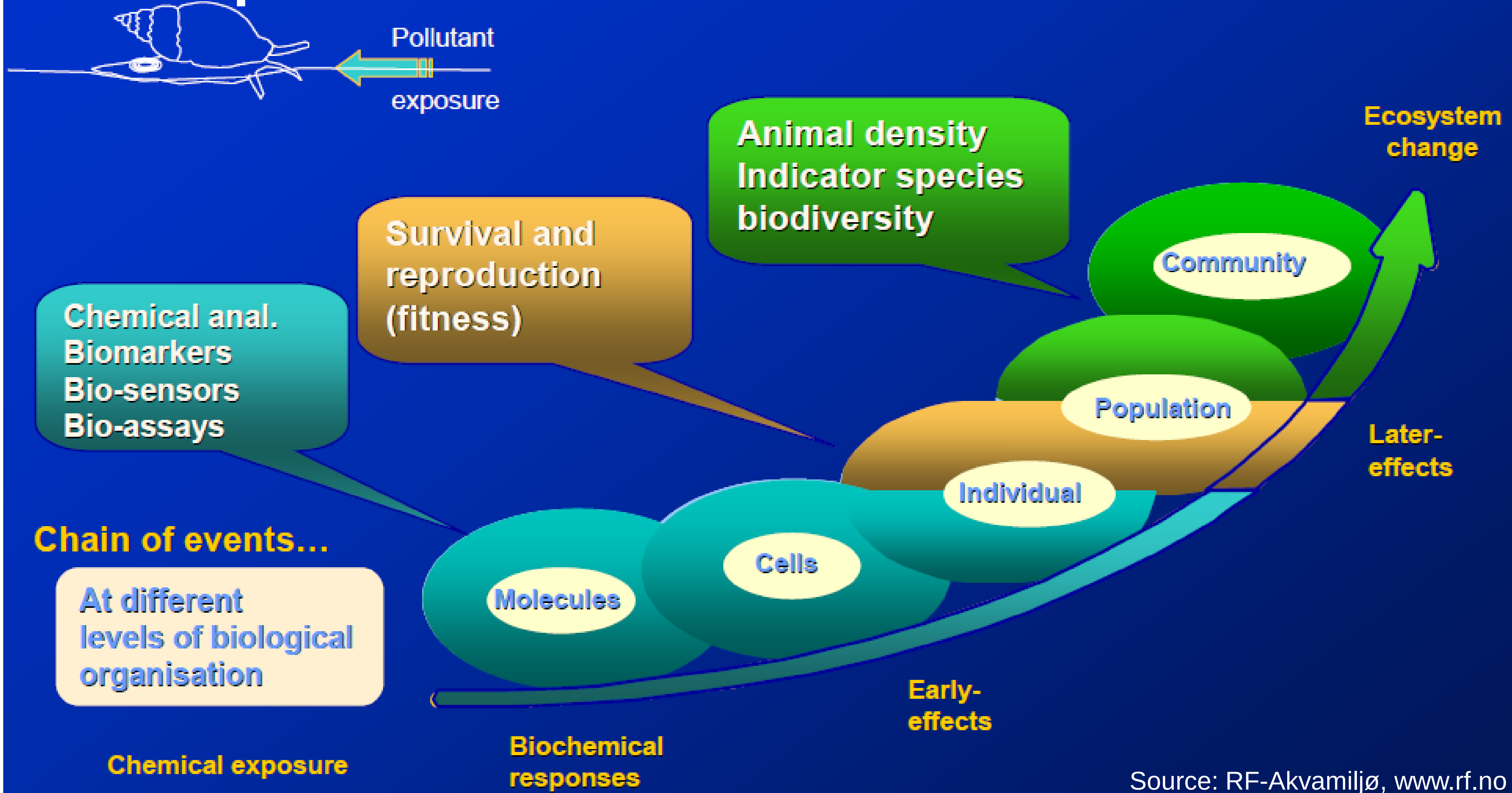


Biological organisms reflect <u>cumulative effects</u> of stressors over time.

(Karr and Dudley 1981)

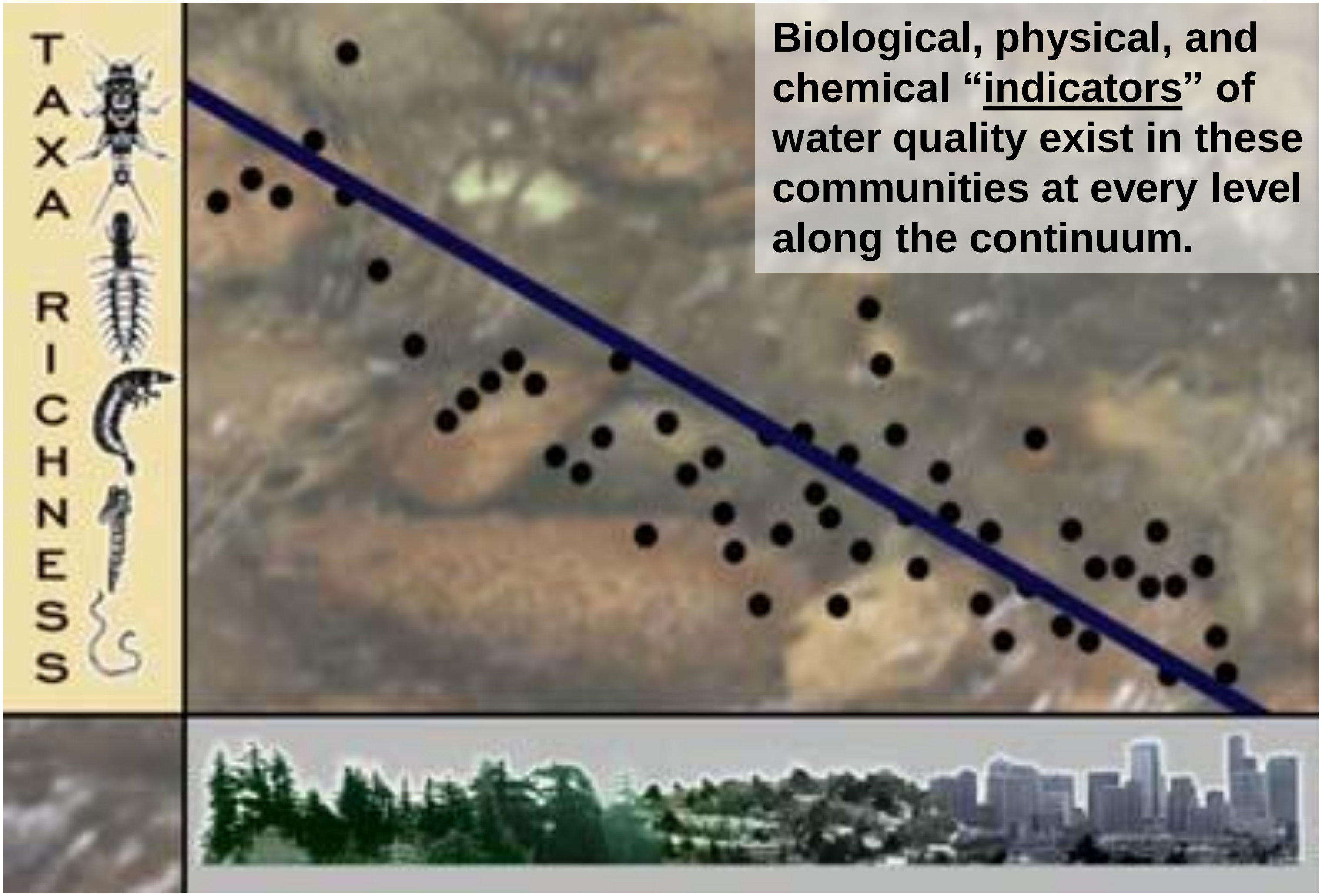
Effects of Stressors can Exhibit at Different Biological Levels

Example: Hierarchical Levels of Pollutant Effects



Source: RF-Akvamiljø, www.rf.no

Relationship between Biological Community and Physical Habitat

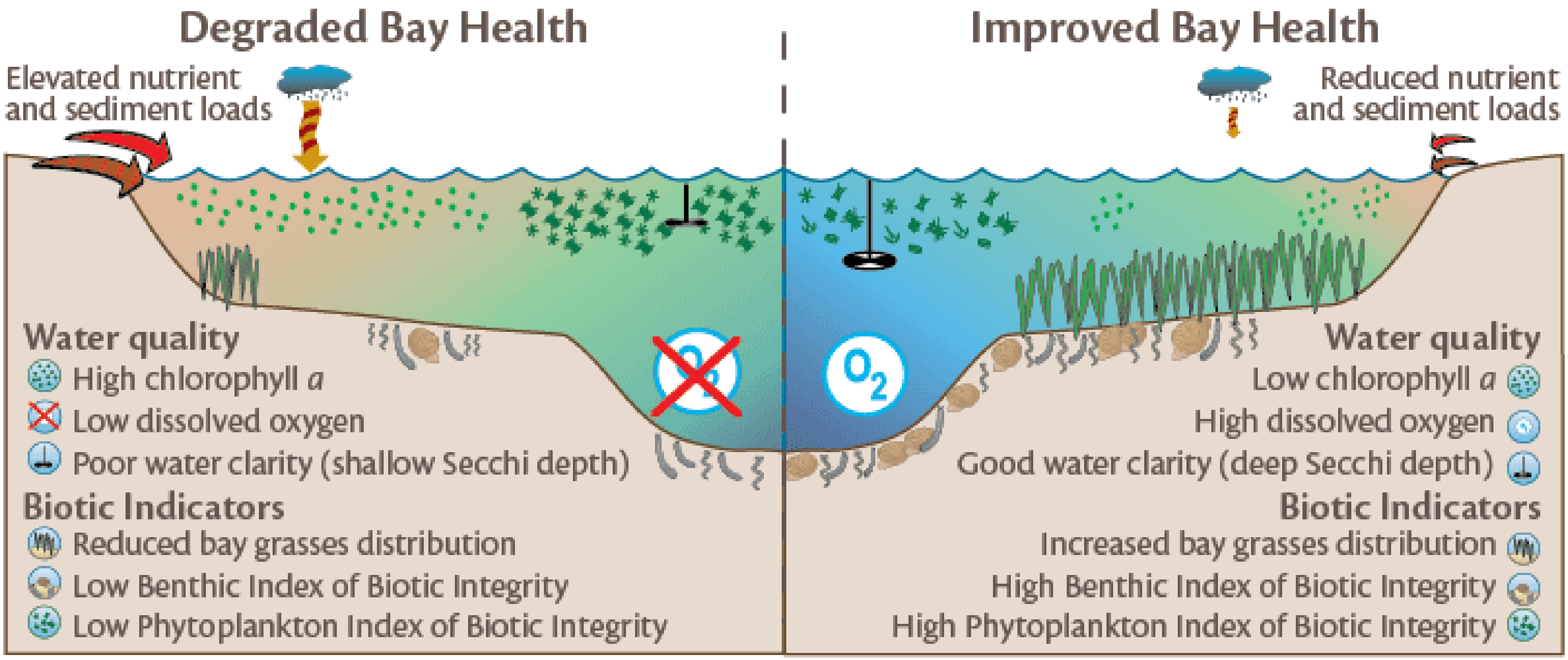


Biological, physical, and chemical "<u>indicators</u>" of water quality exist in these communities at every level along the continuum.

(Source: http://www.cbr.washington.edu)

Indicators of Water Quality

- Chemical Data
- Biological Data
- Pathogen Data
- Physical Data
- Habitat Data
- Other types of Data



(source: Chesapeake Bay Program, April 2009 Newsletter)

What Makes a Good Indicator Species (or Group of Species)?

- Taxonomically sound and easy to identify
- Widespread distribution
- Numerically abundant
- Large body size, relatively easy to survey/collect
- Ecological requirements known (autecology)
- Narrow ecological demands
- Relatively stationary
- Reflects effects of disturbance

Common Biological Indicators in Wetland Ecosystems

- Common biological indicators
  - Algae (phytolankton, periphyton)
  - Macroinvertebrates
  - Fish ("mobile indicators of condition")
- Factors indicating water quality
  - Taxa Richness, Diversity
  - Pollution Tolerance
  - Functional Group

photo source: http://www.dwaf.gov.za

Phytoplankton & Periphyton

- Algae serve as good indicators of water quality
  - Naturally high number of species
  - Fast response to change
  - Easy to sample
  - Tolerance levels are known for many spp
- Algae are a useful indicator of
  - Primary productivity (food source)
  - Excess nutrients (e.g., man-made contributions of phosphorus)


(photo source: www.koiphen.com)


(photo source: http://pondsolutions.com)

Aquatic Macrophytes & Riparian Vegetation

- Aquatic macrophytes and riparian vegetation serve as ecological indicators for
  - Primary production (food)
  - Habitat for wildlife (e.g., sensitive species)
  - Shade for temperature control (cold water refuges)
  - Root system for streambank integrity
  - Reduced runoff, sedimentation
  - Reduced flash flooding
  - Nutrient modification (organic material for energy)
  - Disturbance levels (natural and anthropogenic)

(photo source: www2.dnr.cornell.edu)

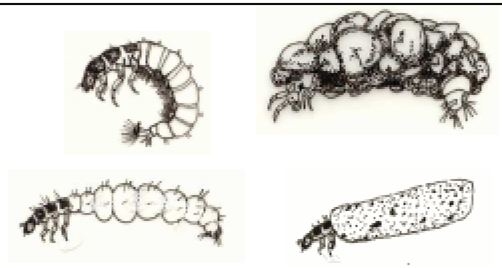
- Physical habitat structure affects the distribution and abundance of other organisms

Macroinvertebrate Indicators

- **Aquatic macroinvertebrates are good indicators of stream quality because:**
  - They are a critical part of the stream's food web.
  - There's a wide diversity (species & functional groups) and they're abundant
  - They are relatively sedentary
  - They are affected by the physical, chemical, and biological conditions of the stream.
  - Some are very intolerant of pollution.
  - They may show the impacts from habitat loss not detected by traditional water quality assessments.
  - They can show short-term, long-term, and cumulative effects of pollution events.
  - They are relatively easy to sample and identify.

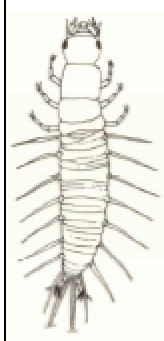
Pollution Intolerant Group
(High Water Quality Bioindicators)

Pollution Intolerant (High Quality Group)



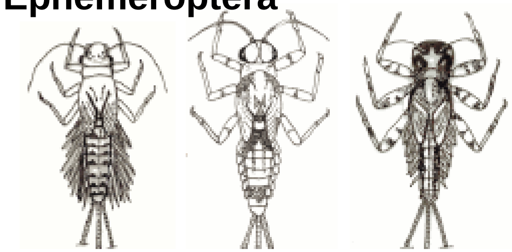
Caddisfly: 6 hooked legs on upper body, 2 hooks on end, may have stick, rock or leaf case, 2-40 mm in length.

Trichoptera

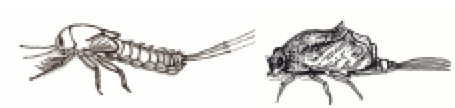


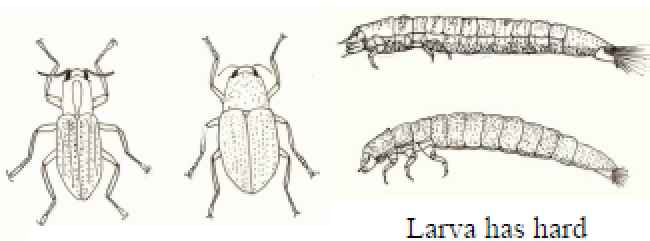
Dobsonfly: 6 legs, 8 pairs of feelers and gill tufts on lower half of body, short antennae, 25-90 mm in length.

Ephemeroptera



Mayfly: 6 legs, feathery or oval-shaped gills on lower body, 2 to 3 long tails, 3-30 mm in length.

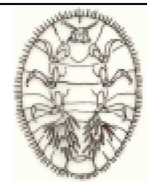




Riffle Beetle: Adult has 6 legs, body covered with tiny hairs, walks slowly underwater, 1-8 mm in length.

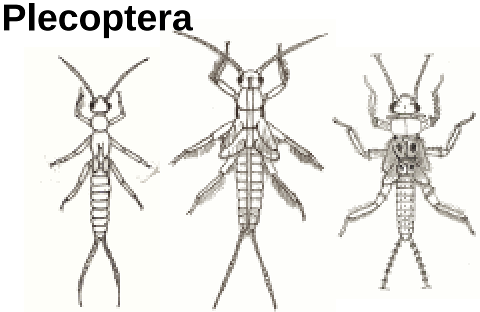
Larva has hard plates on each segment, 2-60 mm in length.

Snail (not pouch): When opening is facing you, shell opens on right, operculum (flap over opening) present.



Water Penny Beetle: Flat saucer-shaped body, 6 tiny legs and gills on underside, 4-6 mm.

Plecoptera

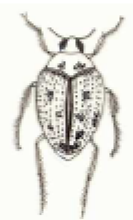


Stonefly: 6 legs with hooked tips, antennae, 2 tails, gill tuffs under legs or no visible gills, 5-60 mm in length.

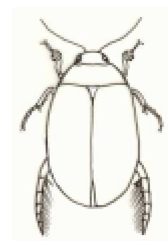
Figure source: www.ioawater.net

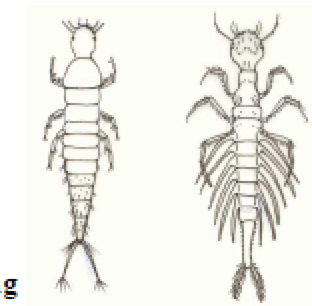
Somewhat Pollution Tolerant

Somewhat Pollution Tolerant (Middle Quality Group)



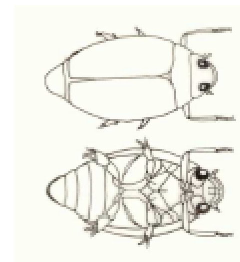
Crawling Water Beetle: Larva has one long tail and legs with one hook-like claw, 2-10 mm in length. Adult is often patterned or spotted, 2-6 mm.

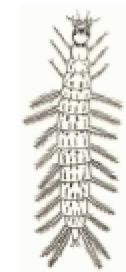




Predaceous Diving Beetle: Adults have an oval streamlined body, longer antennae than Whirligig Beetle, 1-80 mm in length.

Larva has many hairs on body, two feathery tails, large head, 5-70 mm in length.



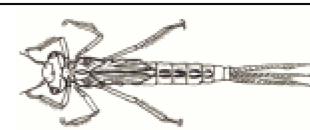


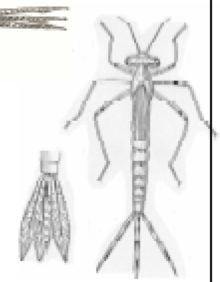
Whirligig Beetle: Flattened oval body, short, clubbed antennae, erratic swimmer, 3-15 mm.

Larva has many hairs on body, short tail or no tail, up to 30 mm in length.

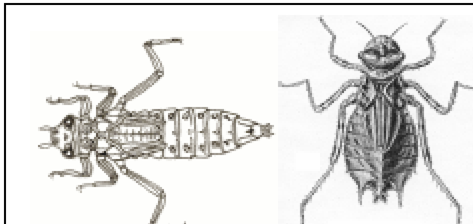
Backswimmer: Forelegs not as spoon-shaped as Water Boatman's, swims upside-down, body is V-shaped, 5-17 mm in length.

Water Boatman: Forelegs spoon-shaped and shorter compared to Backswimmer, 3-11 mm in length.





Damselfly: 6 thin hooked legs; large eyes; 3 broad oar-shaped "tails" (gills), 10-50 mm in length.

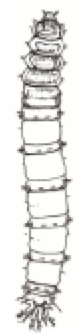


Dragonfly: Wide oval abdomen, 6 hooked legs, large eyes, 10-60 mm in length.

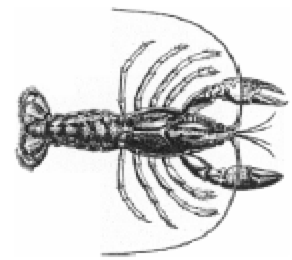
Figure source: www.ioawater.net

Somewhat Pollution Tolerant, *cont.*

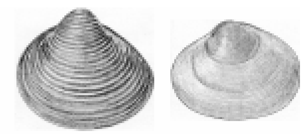
Somewhat Pollution Tolerant (Middle Quality Group) continued



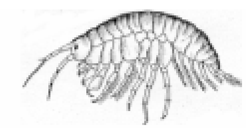
Crane Fly: Milky, green, or light brown color, caterpillar-like segmented body, 4 finger-like lobes at back end, no visible head, 10-100 mm.



Crawdad: 2 large claws, 8 legs, up to 6 inches long.

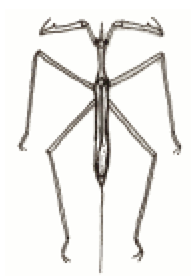


Mussels/Clams: Fleshy body enclosed between 2 clamped shells (bivalve), 2-250 mm.

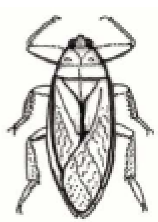


Scud: White to grey, more than 6 legs, swims sideways, body higher than wide, 5-20 mm

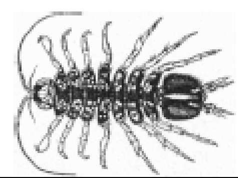
Water Strider: Slender body, long legs "walk" on water surface, 3-21 mm.



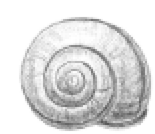
Water Scorpion: Raptor-like forelegs for catching prey, long breathing tube, stick-like long body, 15-45 mm.



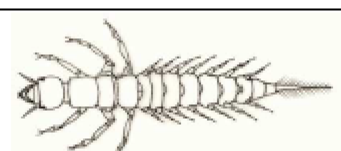
Giant Water Bug: Raptor-like forelegs for catching prey, leathery textured, oval body, 15-65 mm in length.



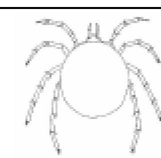
Sowbug: Gray body wider than it is high, more than 6 legs, 5-20 mm.



Orbsnail: One shell, coiled and flattened, a.k.a. rams-horn, 3-30 mm



Alderfly: Looks like a small Dobsonfly but has one long tail and no gill tufts, 10-25 mm.



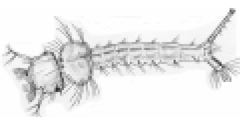
Water Mite: 8 legs, round body, may be brightly colored, 2-3 mm

Limpet: One shell, not coiled, shaped like a flat cone 3-7 mm

Figure source: www.ioawater.net

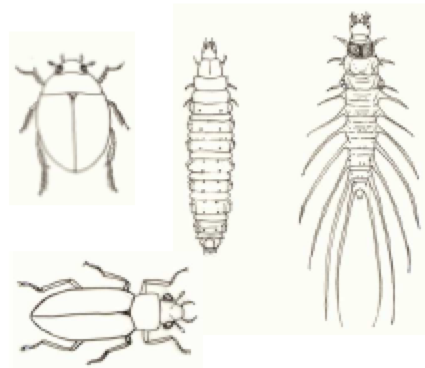
Pollution Tolerant Group (Bioindicators of Low Water Quality)

Pollution Tolerant (Low Quality Group)



Mosquito: Head has small mouth brushes and short antennae; abdomen has breathing siphon, surfaces for air, 4-12 mm.

Water Scavenger Beetle: Adult may or may not be streamlined, most have no hairs on legs, short clubbed antennae, 1-40 mm. Larva have short antenna, 8 soft body segments, 4 -60 mm.



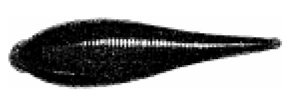
Pouch Snail: When opening is facing you, shell opens on the left, no operculum (flap over opening).

Flatworm (Planarian)**:** Flat, soft-bodied worm with arrowhead-shaped head, 1-30 mm in length.

Midge Fly: Small, dark head, 2 tiny legs on each end, 2-20 mm.

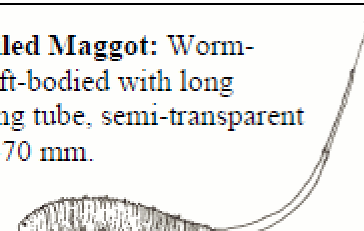
Bloodworm: One type of midge fly, has a red body due to hemoglobin.

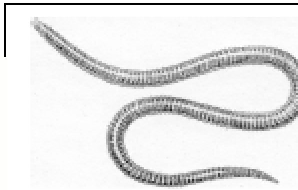
Black Fly: One end of body wider, black head and suction pad on other end, 3-12 mm.



Leech: Brown, slimy body, suction pads on body, 5-400 mm.

Rat-tailed Maggot: Worm-like, soft-bodied with long breathing tube, semi-transparent skin, 4-70 mm.





Aquatic Worm: Thin, worm-like, 0.5-700 mm.

Figure source: www.ioawater.net

Fish as Indicators

Advantages

- Relatively easy to collect and identify
- Environmental requirements, life history information, and distributions are well known for most species
- Reflect long-term effects and habitat conditions
- Represent a variety of trophic levels (toxic substances tend to biomagnify, community structure reflects community health)

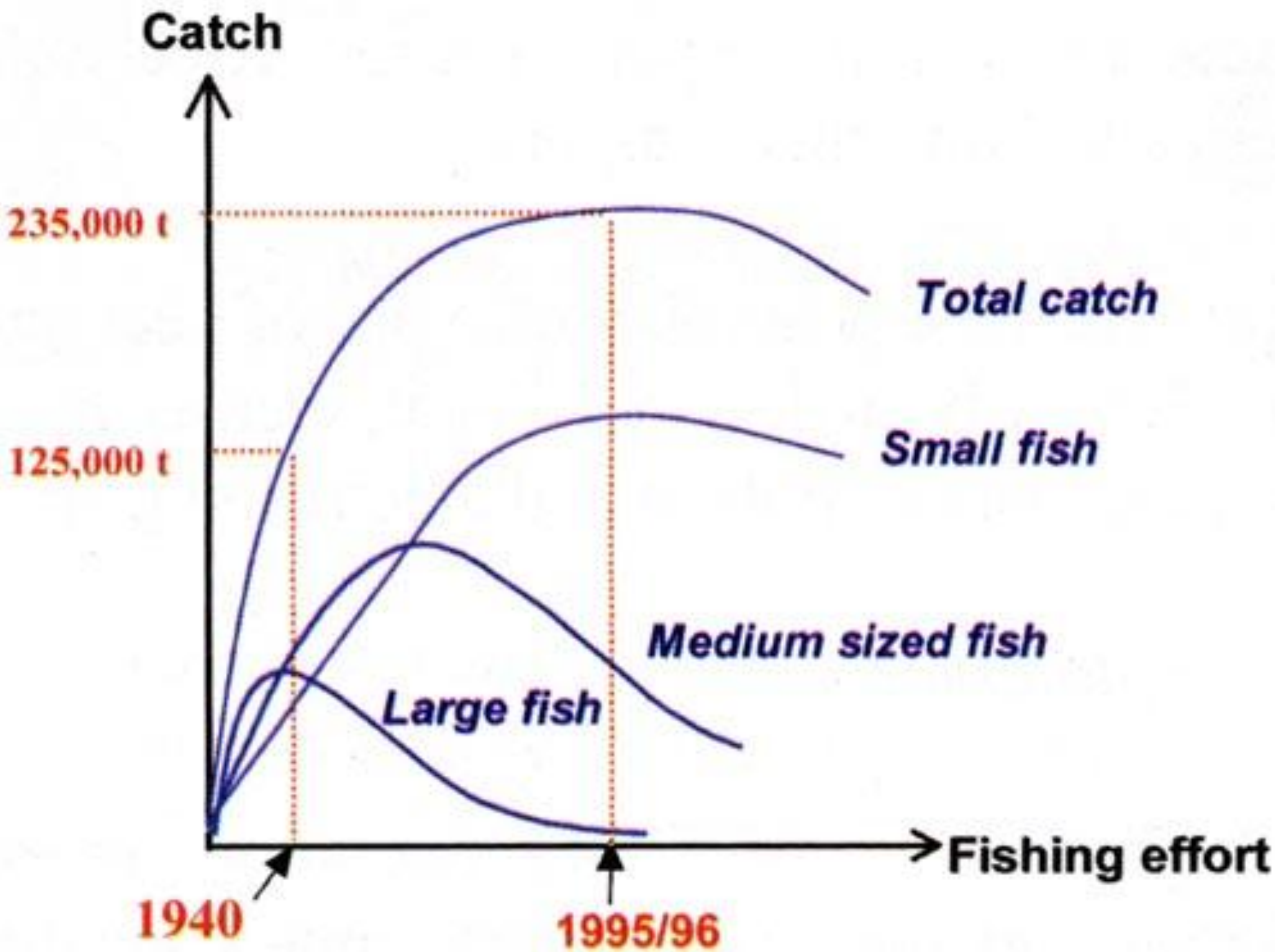
Fish as Indicators

Advantages , cont.

- Certain species/groups are particularly sensitive to dams, altered flow regimes, overharvest, etc.
- Extensive fish kills are indicative of severe oxygen depletion or toxic pollution.
- Erratic behavior (e.g., swimming close to the surface, slow move-ments, swimming in circles, and gasping for oxygen) is indicative of water contamination or severe oxygen depletion.


(photo source: http://pool32mag.blogspot.com)

Example of Fish Community Changes from Over-Harvesting



(figure source: www.fao.org)

Fish as Indicators

Disadvantages

- Motility and migration cause difficulty in pinpointing a pollutant as the cause of abnormalities.
- Monitoring only certain fish species will miss changes in the benthic community or in other species in the community that over time will affect the fish species.

(photo by: Justin Cook, USFWS)

- Fish are not as sensitive as their food (macroinvertebrates) to pollution.
- An assessment of fish alone will not ensure "ecosystem health."

Herpetofauna as Indicators


(photo source: www.gazprom.com)


(photo source: http://www.herpetofauna.eu)


(photo by: Patricia Heithaus, http://biology.kenyon.edu)

Advantages

- Amphibians and reptiles depend on wetlands for all or part of their life cycle
- Amphibians are particularly sensitive to chemical contaminants (due to permeable eggs and skin)
- Excess nutrients can also be very detrimental, reducing O_2 for tadpoles

Disadvantages

- Difficult to document population trends (secretive, large home ranges, low densities)

Birds as Indicators

Advantages

- Avian diversity reflects habitat quality, ecosystem integrity
- Relatively easy to survey
- Birds can be sentinels for sublethal responses to stressors

Disadvantages

- Migratory species are subject to stressors throughout their range
- Bird presence implies, but does not establish specific habitat usage

Mammals as Indicators

- Freshwater mammals are not widely used as indicators of water quality
  - Difficult to survey
  - They often roam large areas
  - Their ecology is often not well known

(photo by: http://nationalzoo.si.edu)

(photo by: Terry Whittaker, http://iberianature.com)

- Nonetheless, many mammals are semi-aquatic and/or are dependent upon wetlands to some extent.