Life History and Conservation Needs of Freshwater Mussels

Webinar Presentation to NRCS Biologists, December 1, 2011

Celeste Mazzacano, Aquatic Program Director
Sarina Jepsen, Endangered Species Program Director

The Xerces Society for Invertebrate Conservation
www.xerces.org

Photo: Pat Burns, Oregon Department of Fish and Wildlife, *Margaritifera falcata* in the Pistol River, Oregon

The Xerces Society
for invertebrate conservation

The Xerces Society is an international nonprofit organization that protects wildlife through the conservation of invertebrates and their habitat

628 NE Broadway, Suite 200
Portland, OR 97232

(503) 232-6639
www.xerces.org

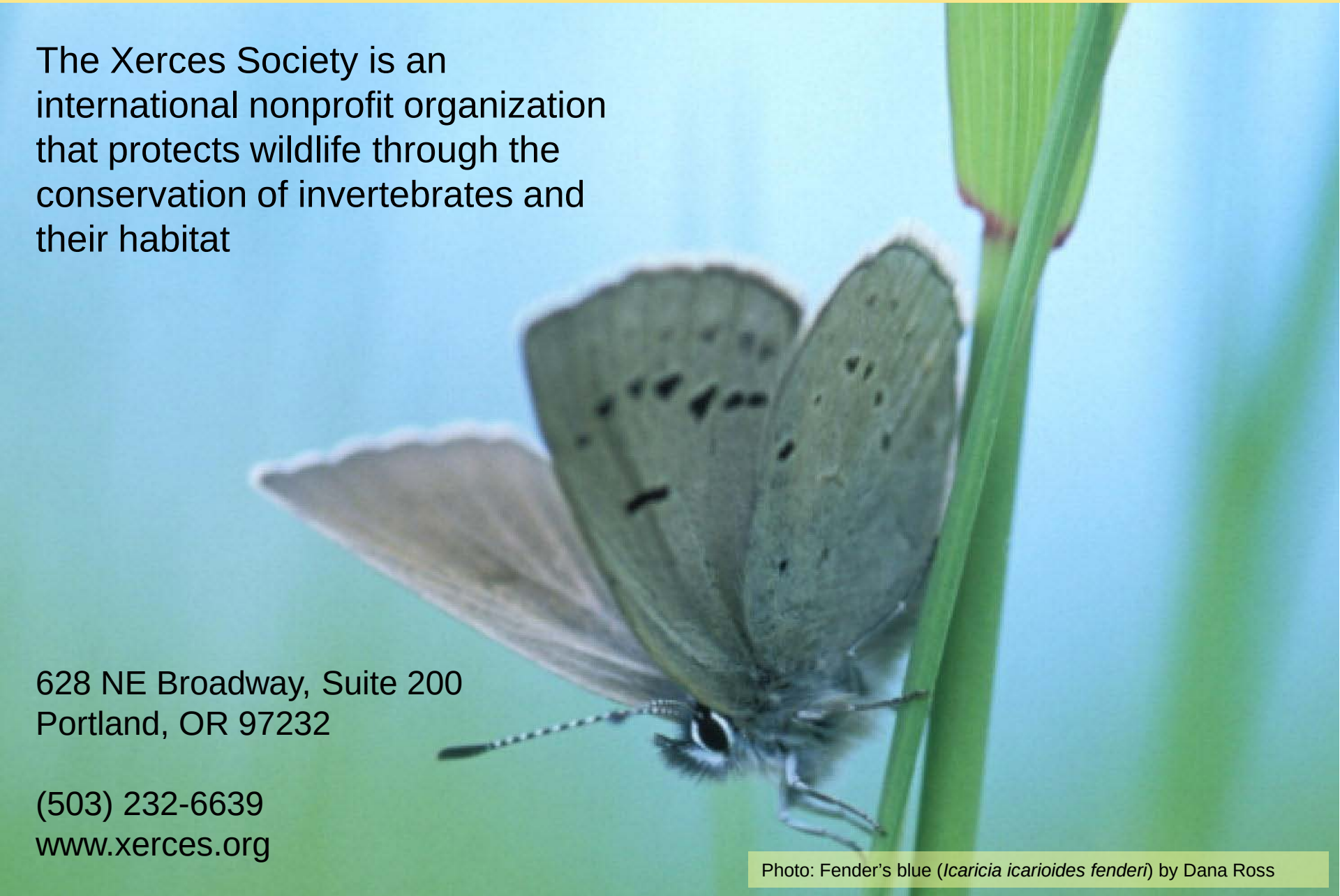
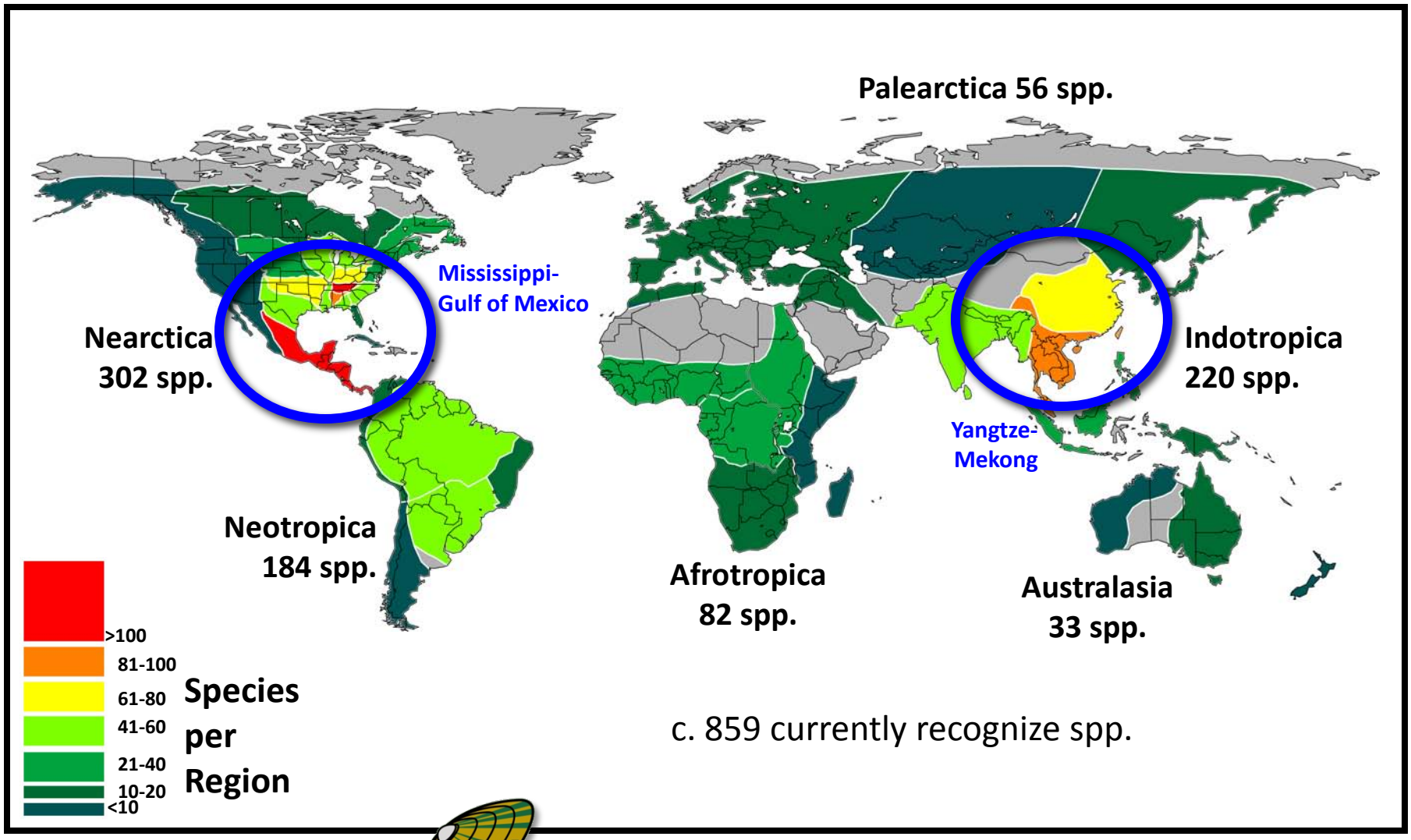


Photo: Fender's blue (*Icaricia icarioides fenderi*) by Dana Ross

Global diversity

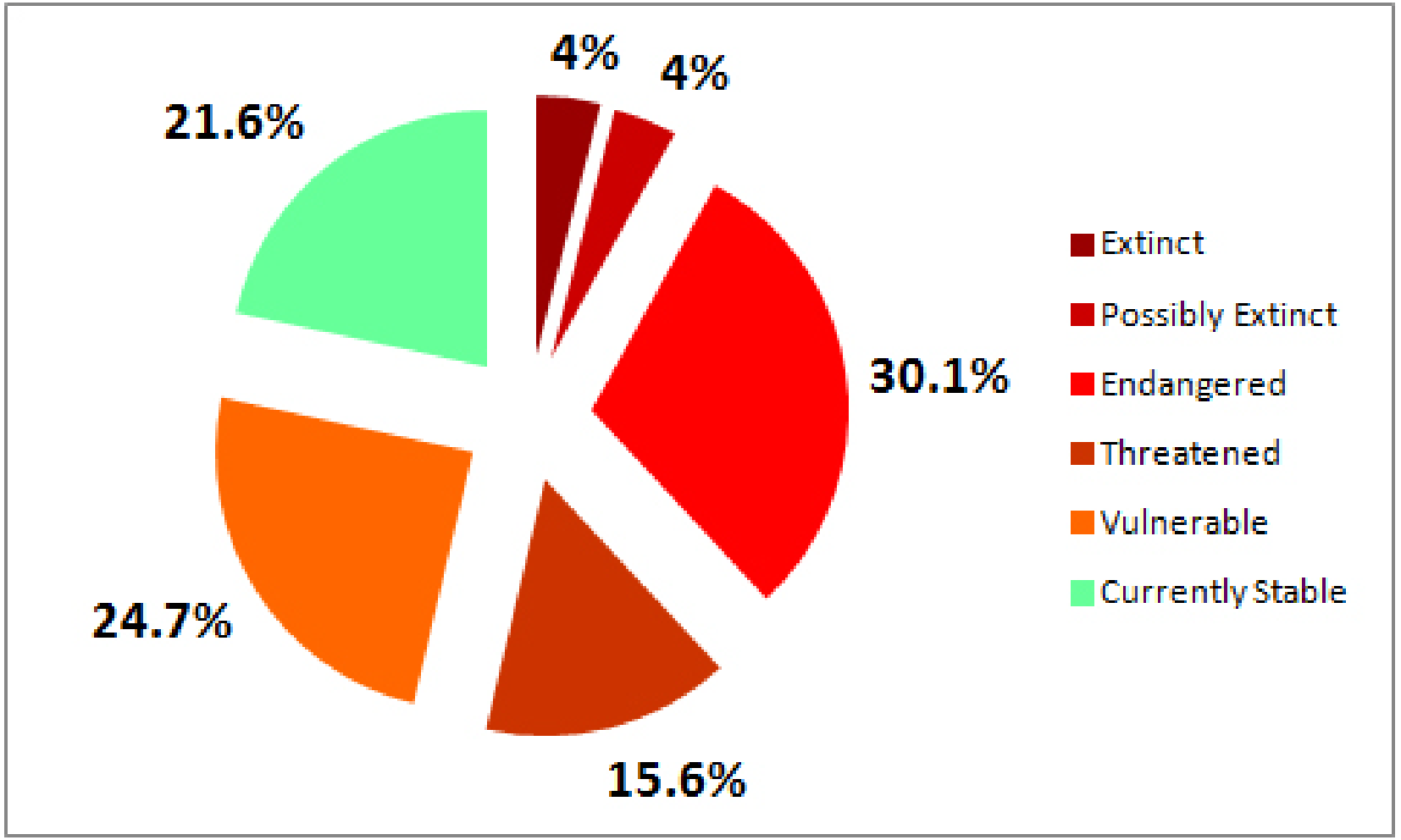


c. 859 currently recognize spp.

The MUSSELp
www.mussel-project.net

Source: Graf & Cummings 2007+

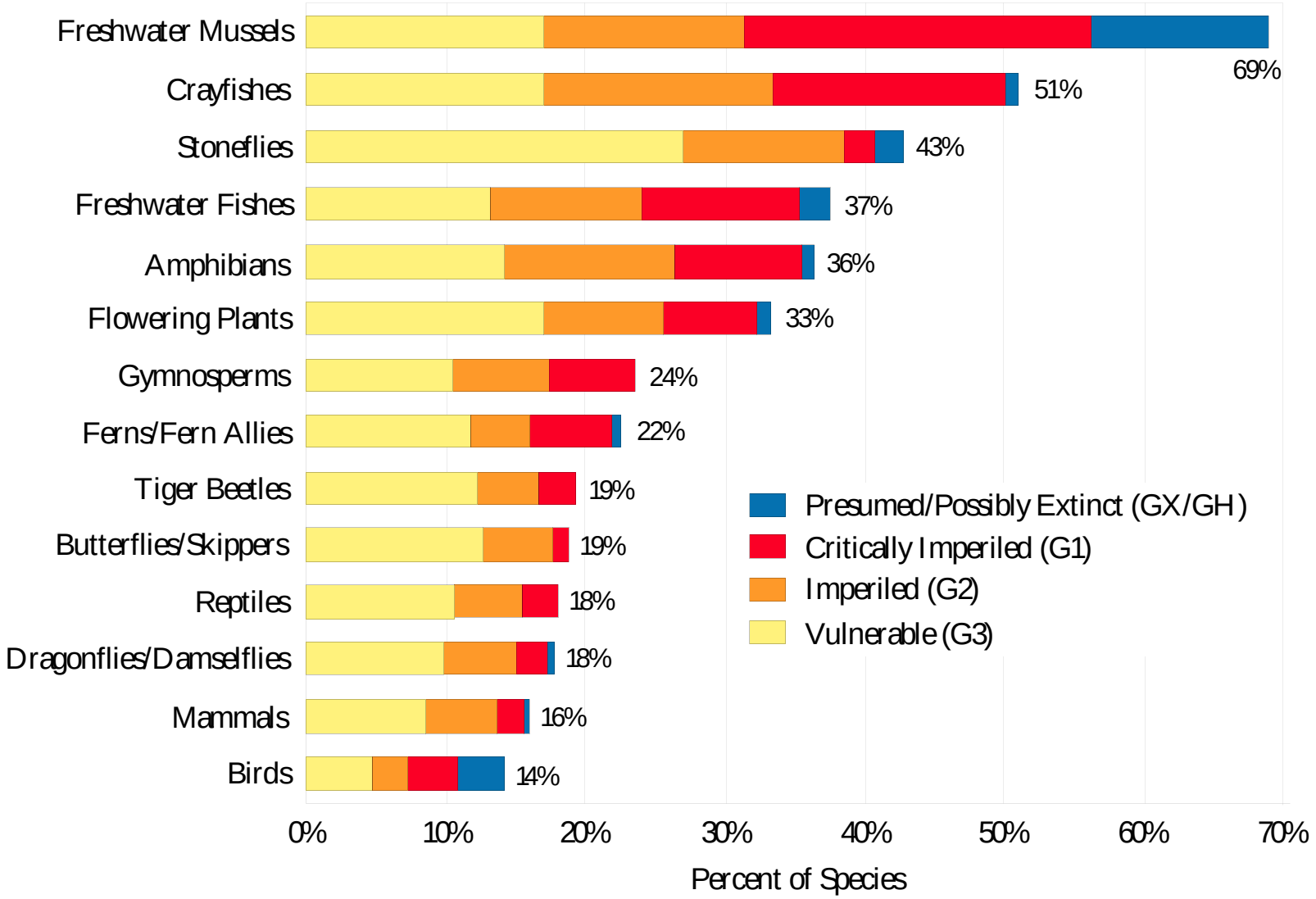
Status



Imperiled taxa comprise 78.4% of North American freshwater mussel fauna

Source: AFS Endangered and Threatened Mussel Committee. In prep.

Status



Source: Stein *et al*. 2000

Status

US Endangered Species Act

64 species listed Endangered
8 species listed Threatened
8 Candidate Species

Photo: *Epioblasma triquetra,* M. C. Barnhart, http://unionid.missouristate.edu/gallery/
Source: USFWS

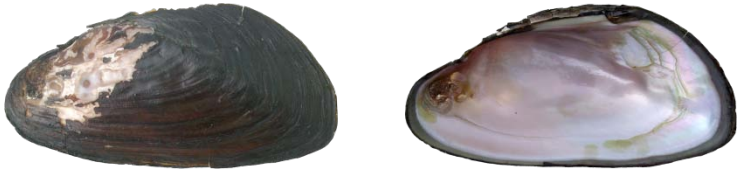
Status: Western Mussels

Margaritifera

Margaritifera falcata – Vulnerable

Gonidea

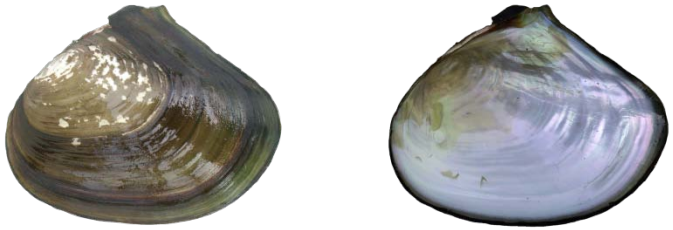
Gonidea angulata – Vulnerable



Anodonta*

A. beringiana – Currently Stable
A. californiensis – Vulnerable
A. kennerlyi – Currently Stable
A. nuttalliana – Vulnerable
A. oregonensis – Currently Stable
A. dejecta – probably not a valid species

*taxonomy of western *Anodonta* in need of revision



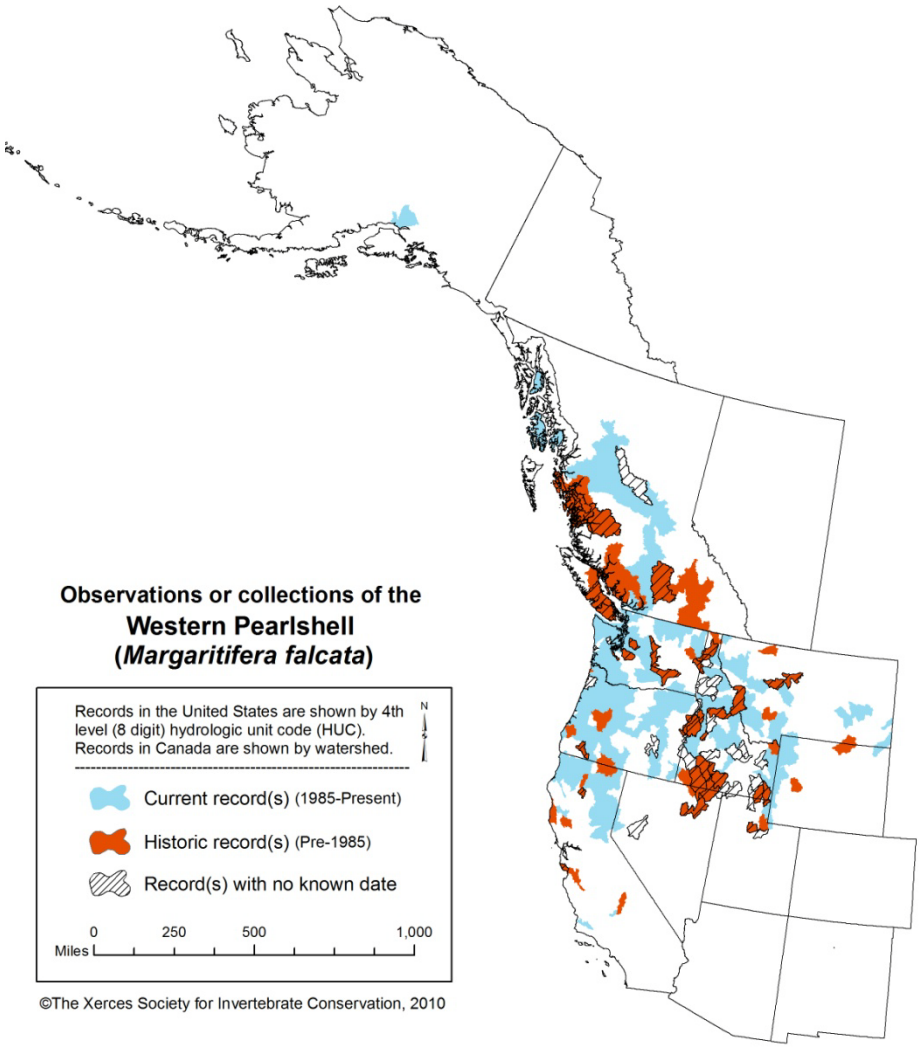
Photos: Ethan Nedeau, Freshwater Mussels of the Pacific Northwest 2nd Edition
Source: Turgeon *et al.* 1998, AFS Endangered and Threatened Mussel Committee. In prep., Chong *et a*l. 2009

Western pearlshell

- *Margaritifera falcata* is the most common species in Pacific Northwest
- Associated with native salmonids and upper reaches of high gradient streams
- Live in dense beds
- Can live to be >100 years old

Photo: Jayne Brim Box, CTUIR Mussel Project

Western pearlshell

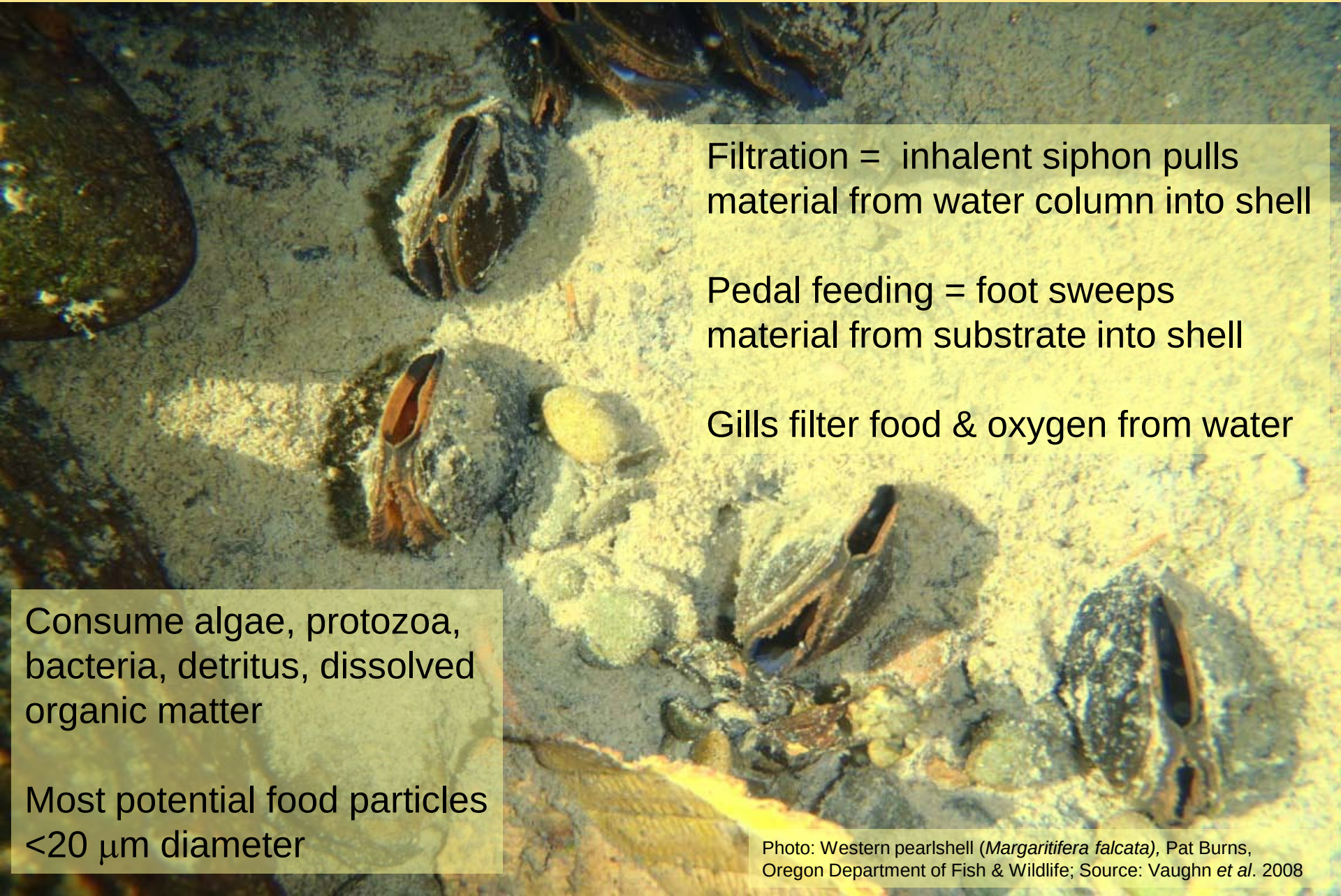


Margaritifera falcata

- Extirpated from numerous water bodies in every state
- Reduced reproduction documented in CA, MT, and WA
- Highly inbred, consistent with hermaphroditic lifestyle

Photo: Ethan Nedeau; Sources: Chong *et al*. 2009, Hovingh 2004, Western Mollusk Sciences 2008, Jepsen *et al*. 2008, Murphy 1942

Life History: Feeding



Filtration = inhalent siphon pulls material from water column into shell

Pedal feeding = foot sweeps material from substrate into shell

Gills filter food & oxygen from water

Consume algae, protozoa, bacteria, detritus, dissolved organic matter

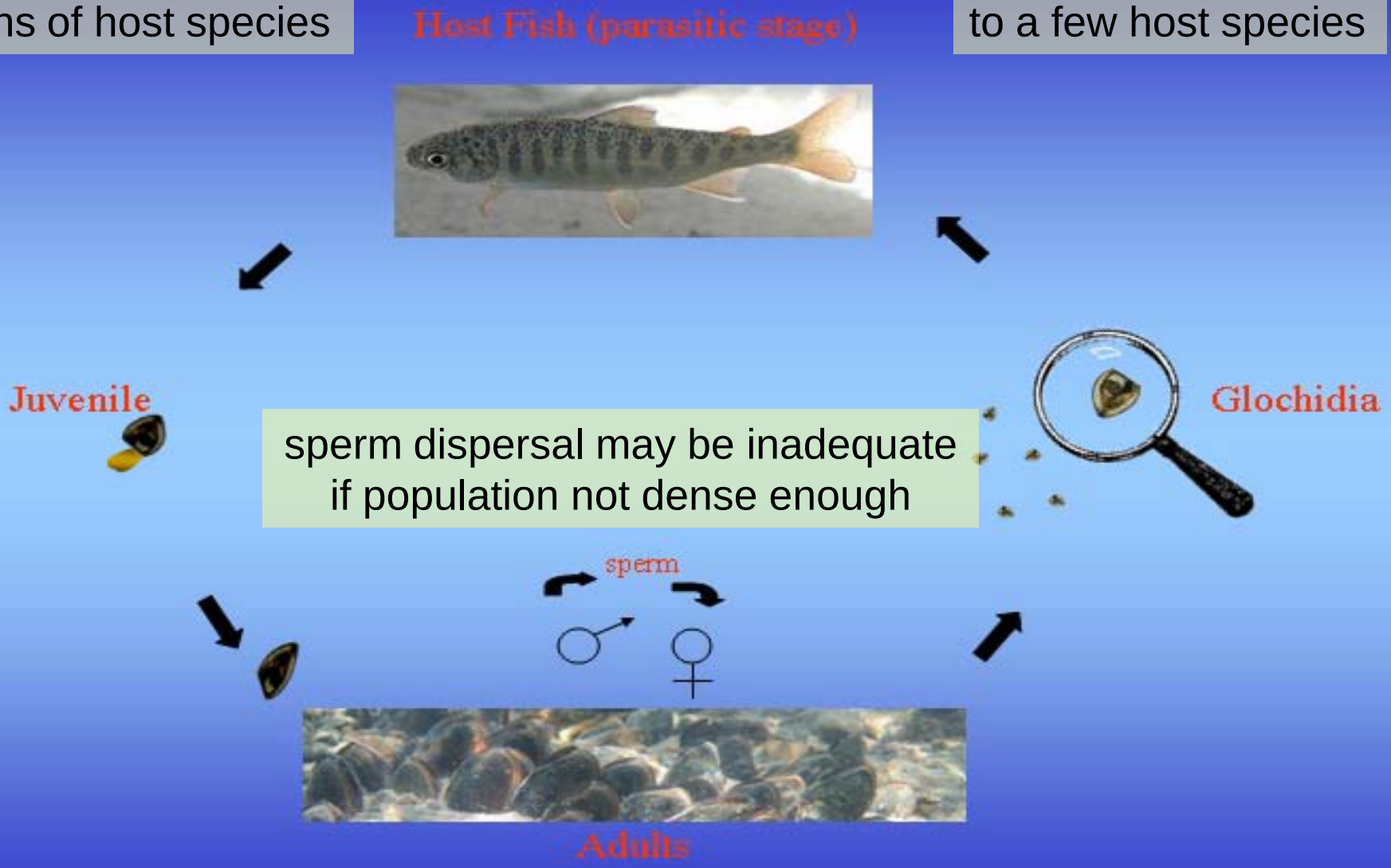
Most potential food particles <20 μm diameter

Photo: Western pearlshell (*Margaritifera falcata),* Pat Burns, Oregon Department of Fish & Wildlife; Source: Vaughn *et al*. 2008

Life History: Reproduction

generalists = use dozens of host species

specialists = use one to a few host species



sperm dispersal may be inadequate if population not dense enough

Figure: Pacific Northwest Native Freshwater Mussel Workgroup
Source: Burky 2003; Bauer 1987; Downing *et al*. 1989

Life History: Reproduction

Glochidia released via:

- Free broadcast
- Conglutinates & lures
- Host trapping

Photo: snuffbox (*Epioblasma triquetra)* with logperch, M. C. Barnhart, http://unionid.missouristate.edu/gallery/Epioblasma/trapped.jpg

Life History: Reproduction

Photo: Female broken rays mussel (*Lampsilis reeveiana),* M. C. Barnhart, http://unionid.missouristate.edu/gallery/L_reeveiana-lure.jpg
Source: Neves & Widlak 1988

THE XERCES SOCIETY
FOR INVERTEBRATE CONSERVATION

Life History: Reproduction

Photo: Rainbow mussel (*Villosa iris*) crayfish lure; Bill Roston, http://unionid.missouristate.edu/gallery/Villosa_iris/irislure6c.htm

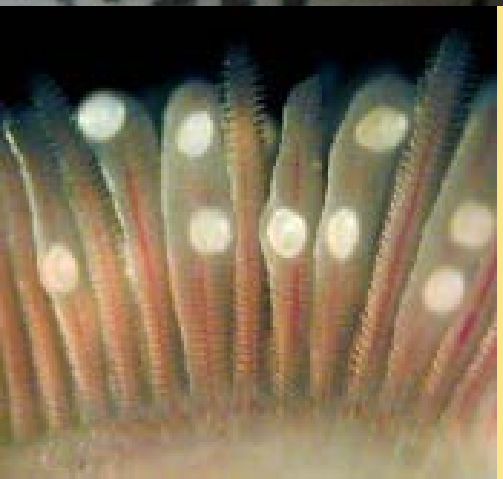
Photo: worm-shaped conglutinate of fanshell (*Cyprogenia aberti*) Unio Gallery http://molluskconservation.org/MUSSELS/Adaptation.html

Photo: Fluted kidneyshell (*Ptychobranchus subtentum*); M. C. Barnhart, http://unionid.missouristate.edu/gallery/Psubtentum/fluted.htm

Photo: Simuliidae pupa, California Dept. of Fish & Game

Life History: Development

Photo: Michelle Steg, TNC



attach →

encyst →

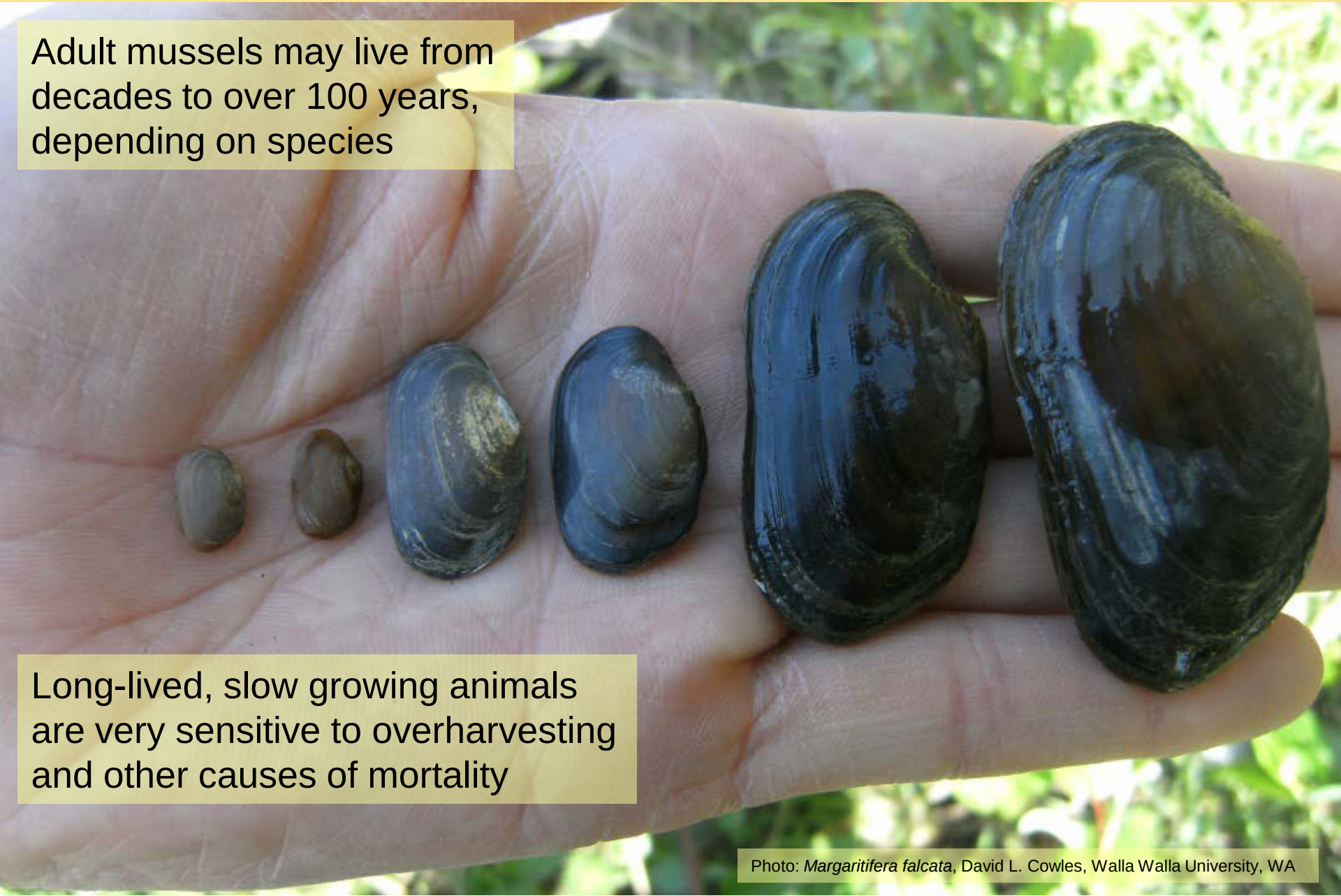
metamorphose →

excyst →

free-living mussel

Photo: CTUIR Freshwater Mussel Project

Life History: Development



Adult mussels may live from decades to over 100 years, depending on species

Long-lived, slow growing animals are very sensitive to overharvesting and other causes of mortality

Photo: *Margaritifera falcata*, David L. Cowles, Walla Walla University, WA

Life History: Strategies

Photo: Fatmucket (*Lampsilis siliquoidea*); M. C. Barnhart, http://unionid.missouristate.edu/gallery/good_bad_ugly_zebra1.jpg
Source: Strayer 1999; Vaughn & Spooner 2006

Parasitic glochidia
vs.
planktonic veligers:

and the winner is….

Photo: Asian clam (*Corbicula fluminea*); Noel M. Burkhead, USGS, http://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=92

Invasive bivalves have:

- higher filtration rates
- faster reproduction
- younger age to sexual maturity

Ecological Services

“Pearl mussels and salmonids form an important symbiotic community in which each species finds optimal conditions for survival. The protection and restoration of these valuable species is therefore interdependent, and the conservation of either one will benefit both.”

-Ichthyologist Valery Ziuganov, working on the Kola Peninsula, northern Russia

Photo: R. Koopmans, istock

Ecological Services

Mussels filter water as they feed, improving water quality and clarity

- Visibility near a dense mussel bed is 20 times greater than away from the bed
- An individual mussel can filter 20-70 liters of water / day
- The amount of water filtered by dense beds of freshwater mussels can be equivalent to or exceed daily stream discharge

Photo: Dr. Richard Neves, Sources: Ziuganov 1998, Vaughn & Hakenkamp 2001

Ecological Services

Freshwater mussels increase the abundance of benthic macroinvertebrates:

- Consuming suspended particles from the water column; transferring those nutrients to the sediment as ‘pseudofaeces’
- Increasing substrate complexity

Filter feeding activity can decrease algal blooms

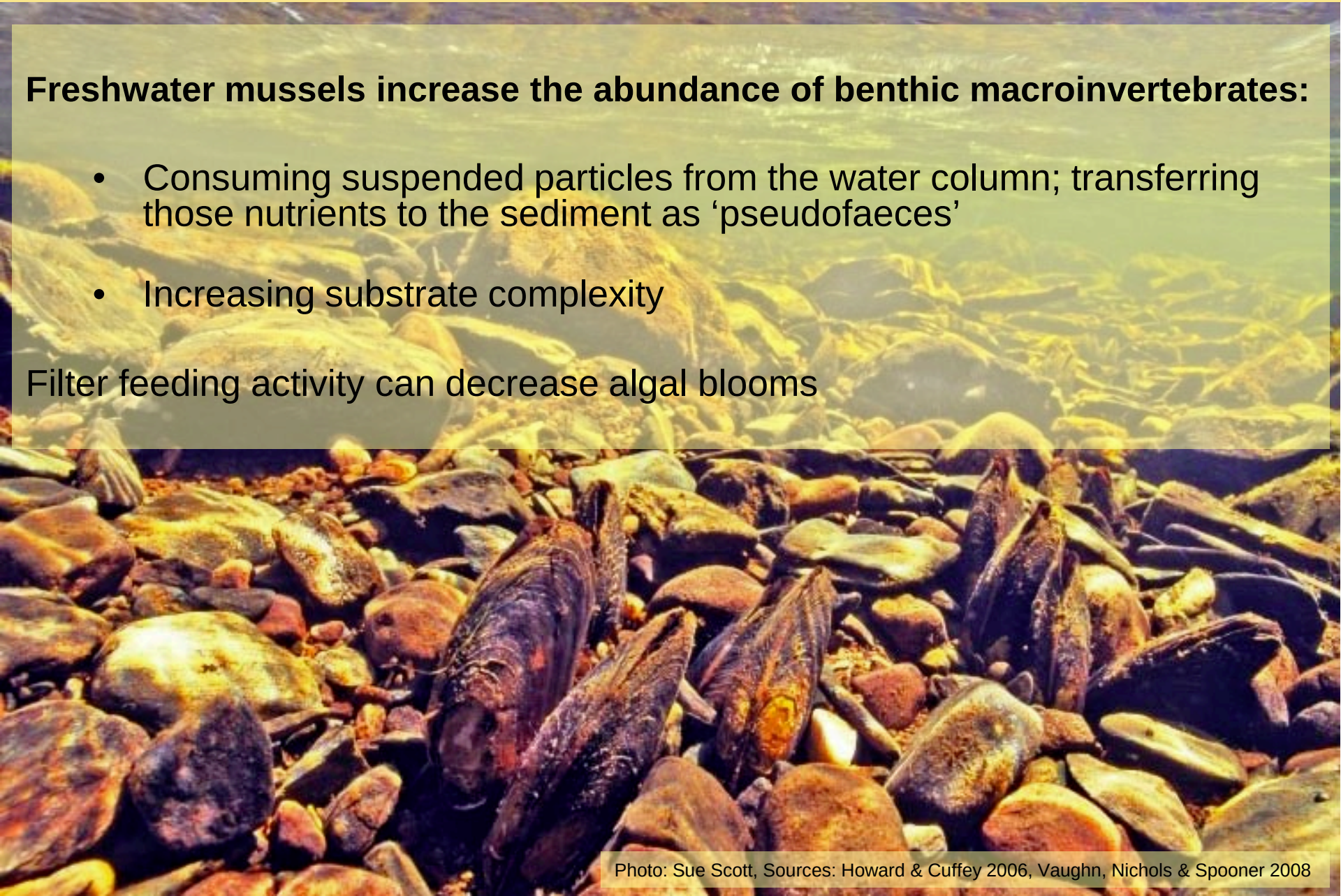


Photo: Sue Scott, Sources: Howard & Cuffey 2006, Vaughn, Nichols & Spooner 2008

Ecological Services

Food source for:

- Muskrats
- Predatory fish
- Mammals
- Waterfowl
- Crayfish
- Turtles
- Frogs
- Aquatic salamanders

Photo: M.C. Barnhart, http://unionid.missouristate.edu, Source: McMahon 1991

THE XERCES SOCIETY
FOR INVERTEBRATE CONSERVATION

Ecological Services

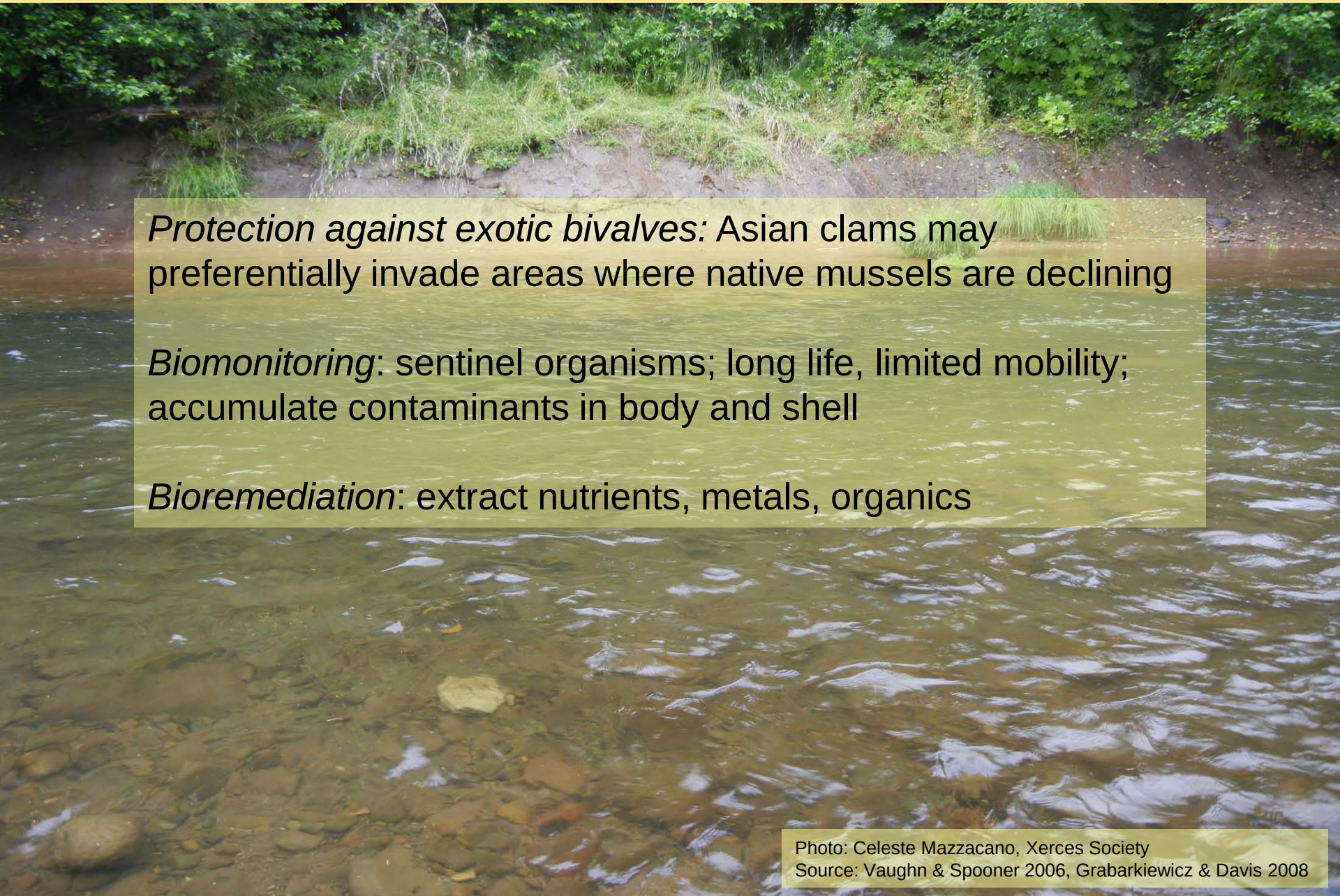
Substrate stabilization: buried mussels may help stabilize streambed sediments

Bioturbation: increases water, nutrient, and oxygen content of sediment; releases nutrients from sediment to water column

Photo: Celeste Mazzacano, Xerces Society
Source: Vaughn & Hakenkamp 2001; Vaughn *et al*. 2008

THE XERCES SOCIETY
FOR INVERTEBRATE CONSERVATION

Ecological Services



Protection against exotic bivalves: Asian clams may preferentially invade areas where native mussels are declining

Biomonitoring: sentinel organisms; long life, limited mobility; accumulate contaminants in body and shell

Bioremediation: extract nutrients, metals, organics

Photo: Celeste Mazzacano, Xerces Society
Source: Vaughn & Spooner 2006, Grabarkiewicz & Davis 2008

Human Uses

- Mussels were consumed when other food sources were scarce
- Many Native American tribes fashioned tools and ornaments out of shells

Photo: Chief Joseph Dam Project, Source: Parmalee & Klippel 1974

Human Uses

- Pearl buttons
- Shells used as ‘seeds’ in oyster pearl industry

Sources: Anthony & Downing 2001, Neves 1999

Habitat Requirements

Fish Hosts

- Reliance on a fish host is the most vulnerable part of a mussel's life cycle
- 5% of North American native fish fauna are extinct
- Many eastern species have gone extinct as a direct result of dam construction

Photo: Marie Fernandez, USFWS, Sources: Williams 1992, Bogan 1993

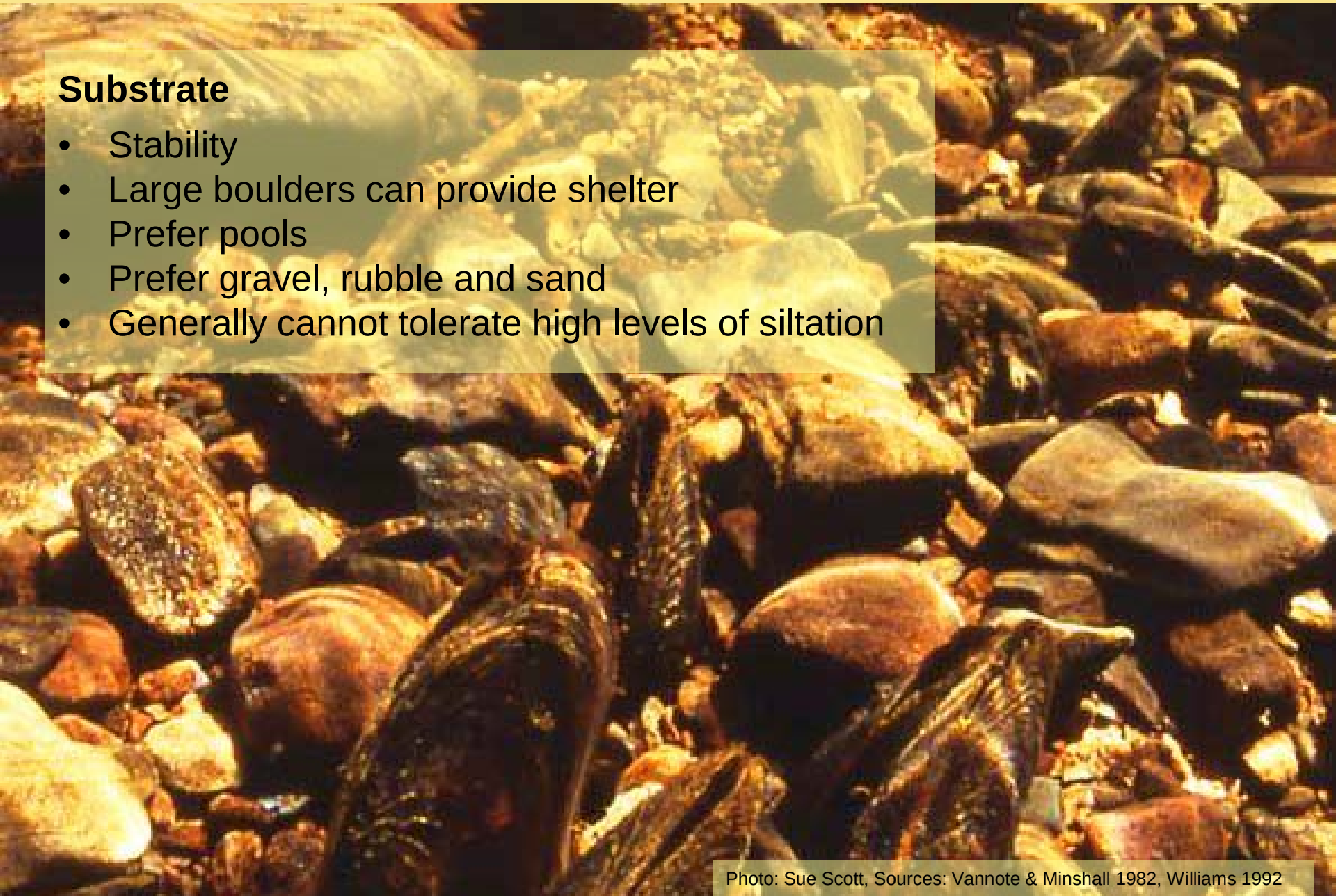
Habitat Requirements

Hydrology

- Perennial flow
- Depth sufficient to provide refugia during low water periods
- Consistent flow velocity
- High levels of dissolved oxygen
- Artificial (pulsed) flows from dams cause:
  - Reproductive interference
  - Reduced density of mussels
  - Increased hermaphrodism and parasitism
  - Reduced body condition

Photo: *Gonidea* and *Anodonta*, Jayne Brim Box, CTUIR Mussel Project,
Source: Vannote and Minshall 1982, Spring Rivers 2007, Galbraith & Vaughn 2010

Habitat Requirements



Substrate

- Stability
- Large boulders can provide shelter
- Prefer pools
- Prefer gravel, rubble and sand
- Generally cannot tolerate high levels of siltation

Photo: Sue Scott, Sources: Vannote & Minshall 1982, Williams 1992

Habitat Requirements

Water Quality

- Contaminants can have direct and indirect effects
- Pollution implicated in extirpation of freshwater mussel populations
  - Chemical pollution
  - Thermal pollution

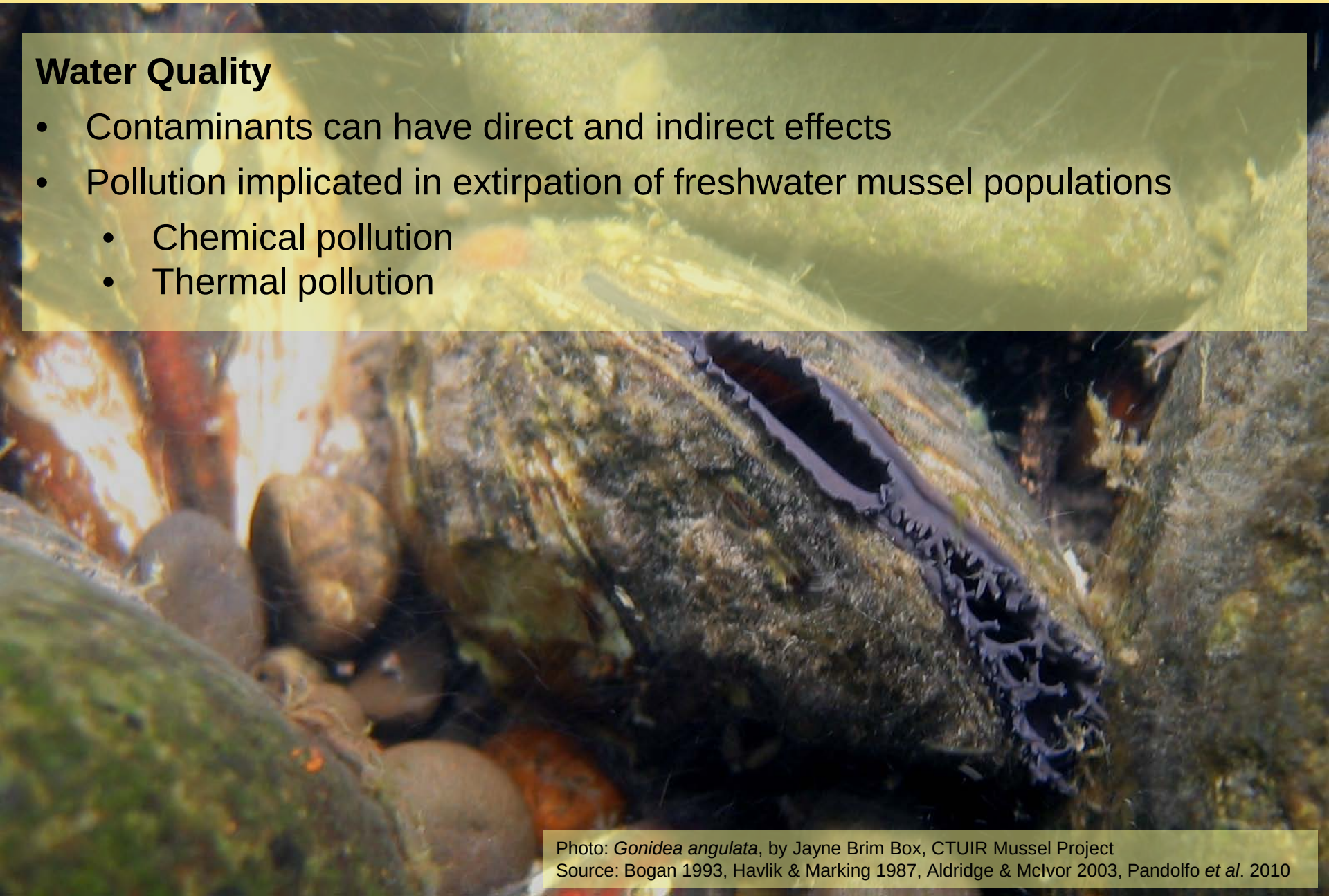


Photo: *Gonidea angulata*, by Jayne Brim Box, CTUIR Mussel Project
Source: Bogan 1993, Havlik & Marking 1987, Aldridge & McIvor 2003, Pandolfo *et al*. 2010

The Xerces Society for Invertebrate Conservation

Causes of mussel declines

Water quality

Chemical contaminants
Thermal pollution
Sedimentation
Nutrient enrichment
Livestock over-grazing

Host fish

Invasive fish species
Extirpation of native fish

Water quantity

Water withdrawal and diversion

Habitat

Channel modification
Impoundments
Invasive bivalves
Restoration activities

Upland Conservation Practices

Water quality

(+) 393 – Filter strip
(+) 601 – Vegetated Barrier
(+) 635 – Vegetative Treatment Area
(+) 558 – Roof Runoff Structure
(+) 645 – Upland Wildlife Habitat Management
(+) 590 – Nutrient Management
(–) 568 – Trails and Walkways

Host fish

Water quantity

Habitat

(-) 460 – Land Clearing

The Xerces Society for Invertebrate Conservation

Riparian Conservation Practices

Water quality

(+/-) 390 – Riparian Herbaceous Cover
(+/-) 391– Riparian Forest Buffer
(+) 472 – Access Control
(+/-) 528 – Prescribed Grazing

Host fish

(+/-) 612 – Tree/Shrub Establishment
(+) 646 – Shallow Water Development

Water quantity

(+) 657 – Wetland Restoration
(+) 659 – Wetland Enhancement

Habitat

(+/-) 580 – Streambank and Shoreline Protection
(+/-) 395 – Stream Habitat Improvement

THE XERCES SOCIETY FOR INVERTEBRATE CONSERVATION

Conservation Practices In Water

Water quality

(-) 399 – Fishpond Management
(-) 578 – Stream Crossing

Host fish

(+/-) 326 – Clearing and Snagging
(+) 396 – Fish Passage

Water quantity

(-/+) 320– Irrigation Canal
(-/+) 388 – Irrigation Field Ditch
(-/+) 430 – Irrigation Pipeline
(-/+) 516 –Pipeline
(-) 574 – Spring Development
(-) 640 – Waterspreading

Habitat

(+/-) 584 – Channel Bed Stabilization
(+/-) 395-Stream Habitat Improvement
(-) 348 – Diversion Dam
(-) 402 Dam

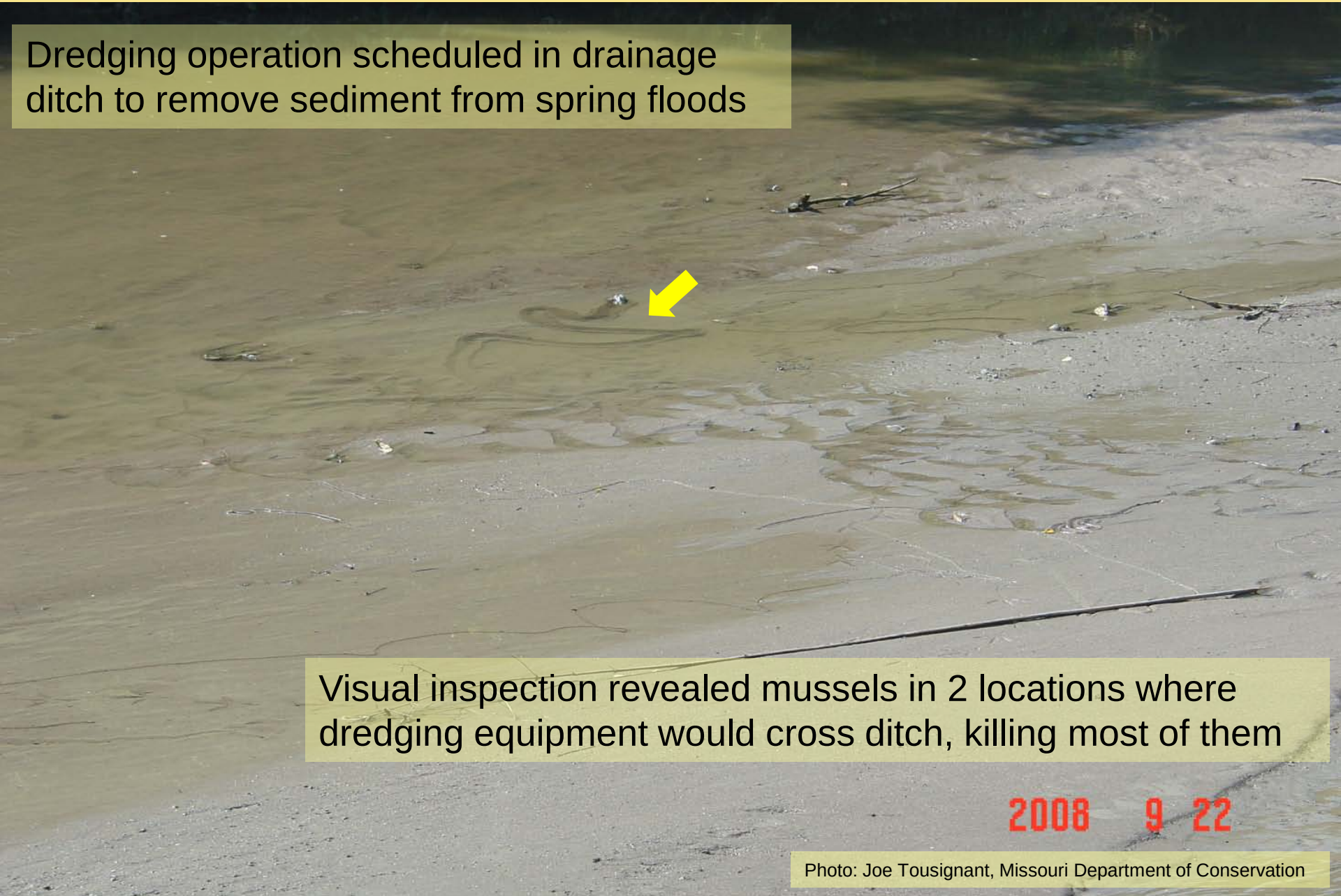
Case Study: Missouri

Emergency Watershed Program cost-share assistance

Photo: Joe Tousignant, Missouri Department of Conservation

The Xerces Society for Invertebrate Conservation

Case Study: Missouri



Dredging operation scheduled in drainage ditch to remove sediment from spring floods

Visual inspection revealed mussels in 2 locations where dredging equipment would cross ditch, killing most of them

Photo: Joe Tousignant, Missouri Department of Conservation

THE XERCES SOCIETY
FOR INVERTEBRATE CONSERVATION

Case Study: Missouri

Photo: Joe Tousignant, Missouri Department of Conservation

Case Study: Missouri

Significant mortality occurred, likely due to temporary dewatering and decreased water quality as dredges operated, but downstream population is still diverse, dense, and surviving

Lessons learned:

- Conduct dredging when base flow is higher to avoid dewatering effects
- Have irrigation well pumping into ditch downstream of dragline
- Coordination among NRCS, MDC, and county commissioners allowed mussel bed to be saved

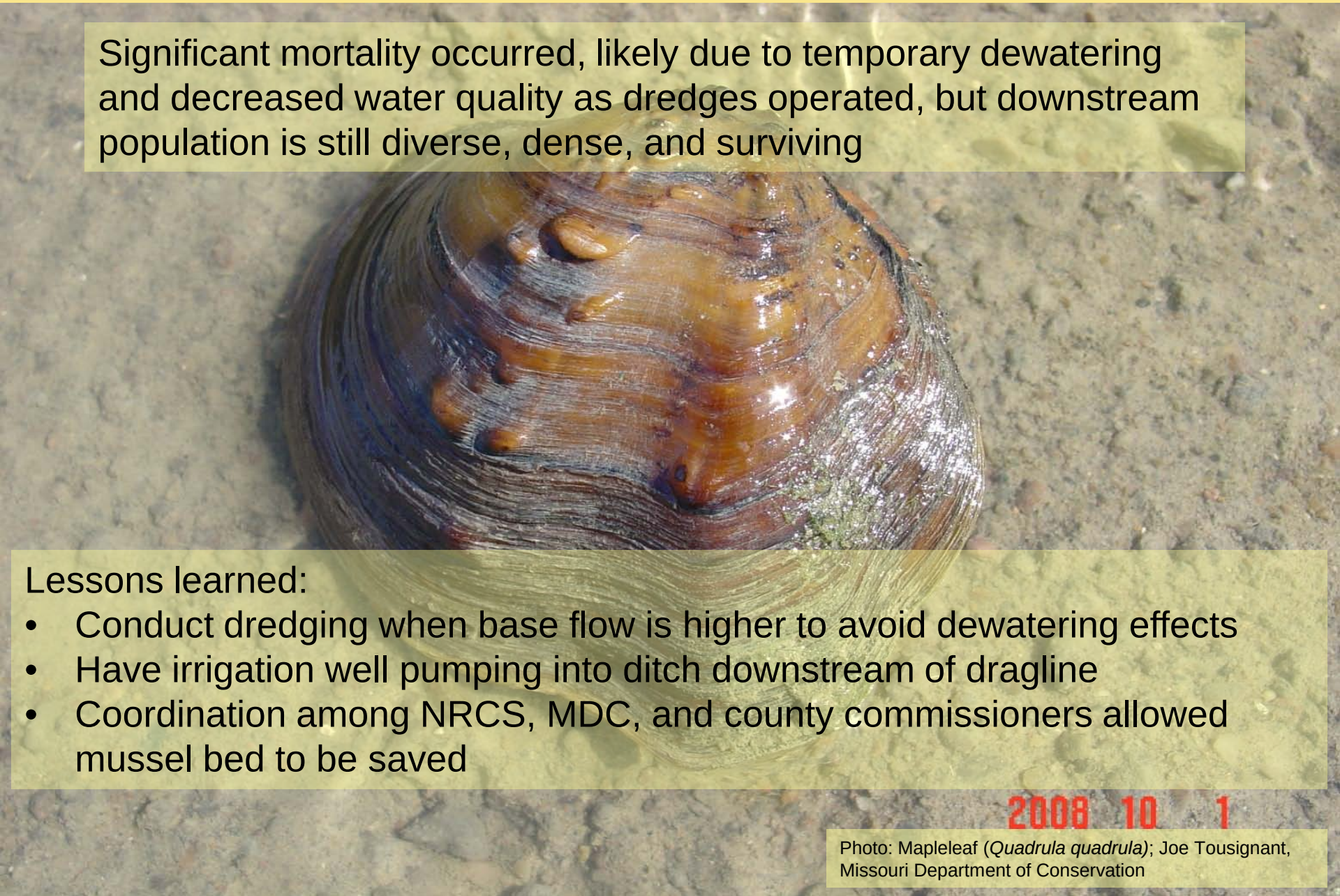


Photo: Mapleleaf (*Quadrula quadrula)*; Joe Tousignant, Missouri Department of Conservation

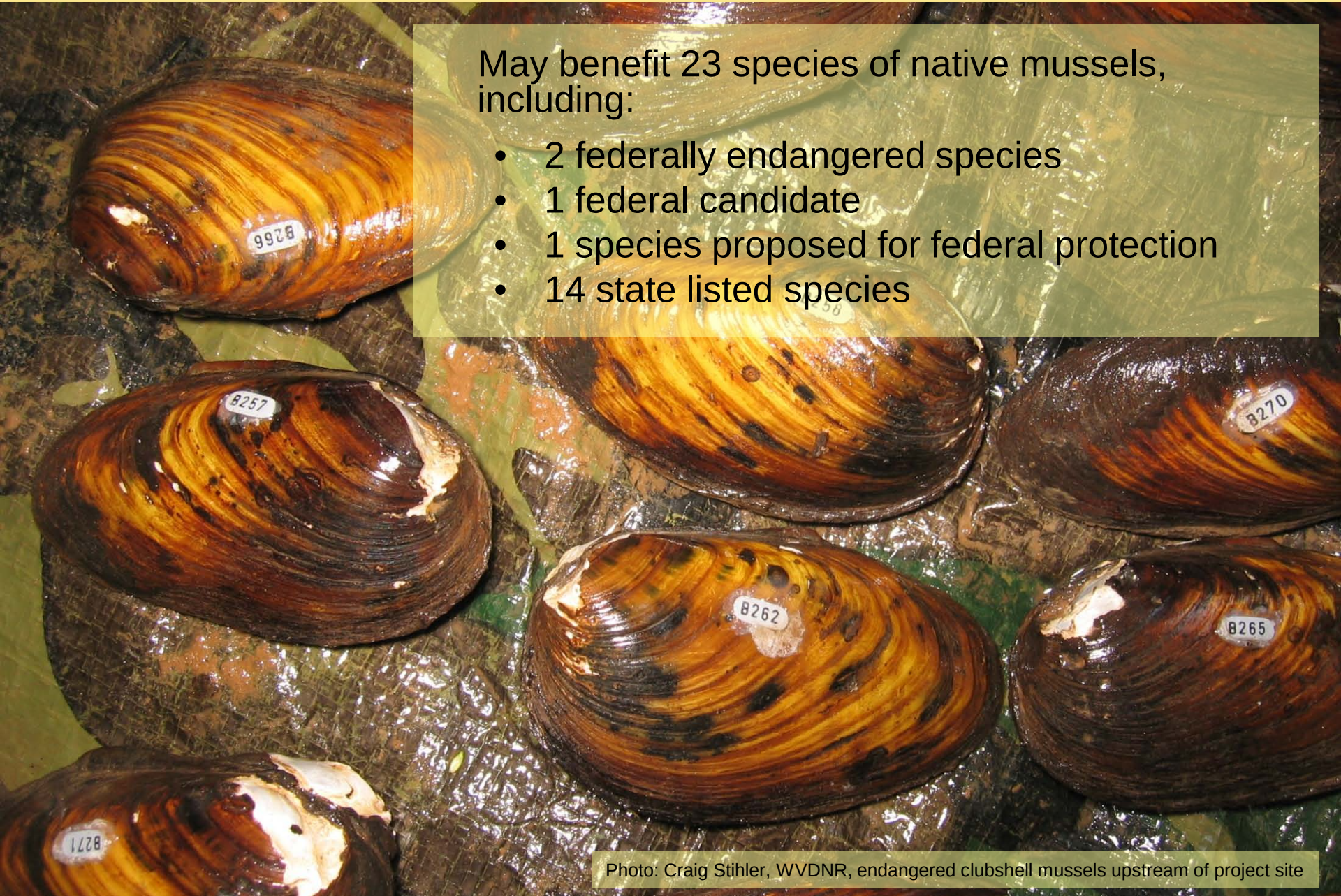
The Xerces Society for Invertebrate Conservation

Case Study: West Virginia

- Planned operation in West Fork River to remove three dams and install Aquatic Life Passage structure
- 40 miles of the West Fork River will be opened for fish passage

Photos by Casey Shrader: West Milford Dam (top left), Highland Dam (top right), Two Lick Dam (bottom left), Hartland Dam (bottom right)

Case Study: West Virginia



May benefit 23 species of native mussels, including:

- 2 federally endangered species
- 1 federal candidate
- 1 species proposed for federal protection
- 14 state listed species

Photo: Craig Stihler, WVDNR, endangered clubshell mussels upstream of project site

Case Study: West Virginia

Multiple partners involved in the project:
USDA NRCS
US Fish and Wildlife Service – West Virginia Field Office
West Virginia Division of Natural resources
Clarksburg Water Board
Canaan Valley Institute

Agencies and NGOs consulted:
US Army Corps of Engineers – Pittsburgh/Huntington District
West Virginia Department of Environmental Protection
West Virginia Culture and History
West Virginia Conservation Agency
Rivers Coalition
American Rivers
The Nature Conservancy
Trout Unlimited

Photo by Janet Clayton, WVDNR, Jack Wallace (left) and Craig Stihler (right) just completing a mussel survey on the West Fork River in 2004

NRCS programs benefit mussels

- Environmental Quality Incentives Program → water quantity, water quality
- Wildlife Habitat Incentive Program → host fish, stream habitat
- Wetlands Reserve Program → host fish, stream habitat, hydrologic regime, water quality
- Emergency Watershed Protection Program → stream habitat, hydrologic regime

Photo: wetland restored under WRP; Celeste Mazzacano, Xerces Society

THE XERCES SOCIETY
FOR INVERTEBRATE CONSERVATION

Mussel surveys

"scoping and groping"
snorkeling
shoreline surveys for middens
nets in thick sediment or deep water

Photo: Celeste Mazzacano, Xerces Society
Source: Strayer & Smith 2003

Photo: *M. falcata* viewed through AquaScope; courtesy Johnson Creek Watershed Council

Acknowledgements

Kathryn Boyer, NRCS, WNTSC
Bill Hohman, NRCS, CNTSC
Chris Hamilton, NRCS, Columbia, MO
Joe Tousignant, Missouri Department of Conservation, Jackson, MO
Casey Shrader, NRCS State Biologist, West Virginia
Janet Clayton, West Virginia DNR
Todd Miller, Canaan Valley Institute
Callie McMunigal, USFWS
Michael Bush, NRCS, Gainesville FL
Chris Barnhart, Missouri State University
Jayne Brim Box, Confederated Tribes of the Umatilla Indian Reservation

Photo: CTUIR Freshwater Mussel Project

Resources

Freshwater Mollusk Conservation Center at Virginia Tech: http://fishwild.vt.edu/mussel/index.html

Freshwater Mollusk Conservation Society: http://molluskconservation.org/

The Mussel Project – University of Alabama: http://mussel-project.ua.edu/

Pacific Northwest Native Freshwater Mussel Workgroup: http://www.fws.gov/columbiariver/musselwg.htm

Translocation guidelines: http://www.xerces.org/wp-content/uploads/2009/10/mussel-relocation-position-statement.pdf

UNIO Gallery: http://unionid.missouristate.edu/

USFWS Threatened and Endangered Mussels: http://www.fws.gov/endangered/species/us-species.html

The Xerces Society: www.xerces.org/western-freshwater-mussels/

Photo: CTUIR Freshwater Mussel Project

THE XERCES SOCIETY FOR INVERTEBRATE CONSERVATION

Resources

REGIONS

Midwest: Cummings K. S. and Meyer, C. A. 1992. Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey Manual 5. 194 pp.

Pacific Northwest: Nedeau, E.J., A.K. Smith, J. Stone and S. Jepsen. 2009. Freshwater mussels of the Pacific Northwest, second edition. http://www.xerces.org/wp-content/uploads/2009/06/pnw_mussel_guide_2nd_edition.pdf

Southeast: Williams, J.D, A.E. Bogan & J.T. Garner. 2008. Freshwater Mussels of Alabama & the Mobile Basin in Georgia, Mississippi & Tennessee. The University of Alabama Press, Tuscaloosa. 908 pp.

STATES

Colorado: Harrold, M.N. and R.P. Guralnik. 2010. A field guide to the freshwater mollusks of Colorado Second Edition. Colorado Division of Wildlife. http://wildlife.state.co.us/SiteCollectionDocuments/DOW/WildlifeSpecies/Profiles/FreshwaterMollusks.pdf

Connecticut: A field guide to the freshwater mussels of Connecticut. http://www.ct.gov/dep/lib/dep/wildlife/pdf_files/nongame/fwmusl.pdf

Idaho: Lysne, S. 2009. A guide to southern Idaho's freshwater mollusks. 35 pp.

Illinois: Klocek, R., J. Bland and L. Barghusen. 2011. A field guide to freshwater mussels of the Chicago Wilderness. 92 pp. www.fieldmuseum.org/chicagoguides

Kansas: Unionid Mussels in Kansas. Great Plains Nature Center. http://www.gpnc.org/unionid.htm

Minnesota: Sietman, B.E. Field Guide to the Freshwater Mussels of Minnesota. Minnesota Department of Natural Resources.

Missouri: Oesch, R. D. 1984. Missouri naiades: a guide to the mussels of Missouri. Missouri Department of Conservation, Jefferson City. 270 pp.

Montana: Stagliano, D. Freshwater Mussels of Montana. Montana Natural Heritage Program. http://mtnhp.org/reports/Mussel_Booklet.pdf

New Jersey: Freshwater Mussels of the New York Metropolitan Region and New Jersey. http://cbc.amnh.org/mussel/

New York: Strayer, D. L. and K. J. Kirka. 1995. The pearly mussels of New York state. New York State Museum Memoir 26, 188 pp.

North Dakota: Cvancara, Alan M. 1983. Aquatic mollusks of North Dakota. North Dakota Geological Survey, Report of Investigation No. 78. Jamestown, ND: Northern Prairie Wildlife Research Center. http://www.npwrc.usgs.gov/resource/inverts/mollusks/index.htm (Version 15AUG97)

Ohio: Watters, G., M. Hoggarth, and D. Stansbery. 2009. The freshwater mussels of Ohio. Ohio State University Press.

South Carolina: Bogan, A. E., J. Alderman, and J. Price. 2008. Field guide to the freshwater mussels of South Carolina. South Carolina Department of Natural Resources, Columbia. 43 pp. http://www.fws.gov/charleston/pdf/South%20Carolina%20Mussel%20Field%20Guide.pdf

Tennessee: Parmalee P. W. and A. E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville TN. 328 pp.

Wisconsin: Wisconsin Department of Natural Resources. 2003. Freshwater mussels of the upper Mississippi River. WDNR, Madison WI. 60 pp.

Photo: CTUIR Freshwater Mussel Project

References

Aldridge, D.C. and A.L. McIvor. 2003. Gill evacuation and release of glochidia by Unio pictorum and Unio tumidus (Bivalvia: Unionidae) under thermal and hypoxic stress. Journal of Molluscan Studies 69:55-59.

American Fisheries Society Endangered and Threatened Mussel Committee. Conservation Status of North American Freshwater Mussels. In prep.

Anthony, J.L., and J.A. Downing. 2001. Exploitation trajectory of a declining fauna: a century of freshwater mussel fisheries in North America. Canadian Journal of Fisheries and Aquatic Sciences 58:2071-2090.

Barnhart, M. C., W. R. Haag and W. N. Roston. 2008. JNABS 27(2): 370-394.

Bauer, G. 1987. Reproductive strategy of the freshwater pearl mussel *Margaritifera margaritifera*. J. Anim. Ecol. 56: 691-704

Bogan, A.E. 1993. Freshwater Bilvalve Extinctions (Mollusca: Unionoida): A Search for Causes. American Zoologist 33: 599-609.

Burky, A.J. 1983. Physiological ecology of freshwater bivalves. In: Russell-Hunter, W.D., editor. The Mollusca, Vol. 6. Ecology. Academic Press, New York. p. 281-327.

Chong, J.P., J. Brim Box, D.A. Nez, and K.E. Mock. 2009. Isolation and characterization of microsatellite loci in the western pearlshell mussel, *Margaritifera falcata* (Gould). Molecular Ecology Resources 9(3): 995-999.

Downing, J. A., J. P. Amyot, M. Perusse and Y. Rochon. 1989. Visceral sex, hermaphroditism, and protandry in a population of the freshwater bivalve *Elliptio complanata*. JNABS 8: 92-99

Galbraith, H. S. and C. C. Vaughn. 2010. Effects of reservoir management on abundance, condition, parasitism and reproductive traits of downstream mussels. River Res. Applic. 27(2): 193-201

Graf & Cummings, 2007+. Poster: Unionoida cum Grano Salis. http://mussel-project.ua.edu/proj/grano_salis/index.html

Havlik, M.E. and L.L. Marking. 1987. The effects of contaminants on naiad mollusks (Unionidae): A review. Resource Publication 164, United States Department of the Interior, Fish and Wildlife Service, Washington DC.

Photo: CTUIR Freshwater Mussel Project

References

Hovingh, P. 2004. Intermountain freshwater mollusks, USA (*Margaritifera*, *Anodonta*, *Gonidea*, *Valvata*, *Ferrissia*): geography, conservation, and fish management implications. Monographs of the Western North American Naturalist 2(1):109-135.

Howard, J.K., and K.M. Cuffey. 2006. The functional role of native freshwater mussels in the fluvial benthic environment. *Freshwater Biology* 51:460-474.

Jepsen, S.J., C. LaBar and J. Zarnoch. 2008. Status review of *Margaritifera falcata* (Gould, 1850), Western Pearlshell. The Xerces Society for Invertebrate Conservation. Available at: http://www.xerces.org/western-pearlshell/

Master, L.L., S.R. Flack, and B.A. Stein (Eds.). 1998. Rivers of Life: Critical Watersheds for protecting biodiversity. The Nature Conservancy, Arlington, Virginia. Available at: http://www.natureserve.org/library/riversoflife.pdf

McMahon, R.F. 1991. Mollusca: Bivalvia. Pages 315-399 *in*: J.H. Thorp and A.P. Covich, eds. *Ecology and Classification of North American Freshwater Invertebrates*. Academic Press, Inc. 911 pp.

Murphy, G. 1942. Relationship of the fresh water mussel to trout in the Truckee River. California Fish Game 28: 89-102.

Neves, R. J. and J. C. Widlak. 1987. Habitat ecology of juvenile freshwater mussels (Bivalvia: Unionidae) in a headwater stream in Virginia. Amer. Malacol. Bull. 5(1): 1-7.

Neves, R.J. 1999. Conservation and commerce: management of freshwater mussel (Bivalvia: Unionoidea) resources in the United States. *Malacologia* 41:461-474.

Pandolfo, T.J., W.G. Cope, and C. Arellano. 2010. Thermal tolerance of juvenile freshwater mussels (Unionidae) under the added stress of copper. Environmental Toxicology and Chemistry 29(3): 691-699.

Parmalee, P.W., and W.E. Klippel. 1974. Freshwater mussels as a prehistoric food resource. American Antiquity 39:421-434.

Stein, B.A., L.S. Kutner, and J.S. Adams. 2000. Precious Heritage: The Status of Biodiversity in the United States. Oxford University Press, 416 pages.

Photo: CTUIR Freshwater Mussel Project

References

Shrader, C. 2010. Final EA for Dam Modifications on the West Fork River, Harrison County, WV. NRCS and USFWS.

Spring Rivers. 2007. Reproductive Timing of Freshwater Mussels and Potential Impacts of Pulsed Flows on Reproductive Success. California Energy Commission. PIER Energy-Related Environmental Research Program. CEC-500-2007-097.

Strayer, D. L., J. A. Downing, W. R. Haag, T. L. King, J. B. Layzer, T. J. Newton, and S. Nichols. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. BioSci. 54(5):429–439.

Strayer, D. L. and D. R. Smith. 2003. A guide to sampling freshwater mussel populations. American Fisheries Society Monograph 8: 1-0103.

Strayer, D. L., 1999. Effects of alien species on freshwater mollusks in North America. JNABS 18: 74–98.

Turgeon, D.D., J.F. Quinn, Jr., A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P.M., Mikkelsen, R.J. Neves, C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F.G. Thompson, M. Vecchione, and J.D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: Mollusks. 2nd Edition. American Fisheries Society Special Publication 26, Bethesda, Maryland: 526 pp.

U.S. Fish and Wildlife Service. Endangered Species Program. http://www.fws.gov/endangered/species/us-species.html

Western Mollusk Sciences. 2008. Strategic inventory of freshwater mussels in the northern Sierra Nevada province. Prepared for USDA Forest Service, Pacific Southwest Region.

Williams, J.D., S.L.H. Fuller, and R. Grace. 1992. Effects of Impoundments on Freshwater Mussels (Mollusca: Bivalvia: Unionidae) in the Main Channel of the Black Warrior and Tombigbee Rivers in Western Alabama. Bulletin of the Alabama Museum of Natural History 13:1-10.

Vannote, R.L., and G.W. Minshall. 1982. Fluvial processes and local lithology controlling abundance, structure, and composition of mussel beds. Proceedings of the National Academy of Sciences 79:4103-4107.

Photo: CTUIR Freshwater Mussel Project

References

Vaughn, C. C., S. J. Nichols, and D. E. Spooner. 2008. Community and foodweb ecology of freshwater mussels. JNABS 27(2): 409-423.

Vaughn, C. C. and Hakenkamp, C. C. 2001. The functional role of burrowing bivalves in freshwater ecosystems. Freshwater Biol. 46: 1431-1446.

Vaughn, C. C. and D. E. Spooner. 2006. Scale-dependent associations between native freshwater mussels and invasive *Corbicula.* Hydrobiol. 568: 331-339.

Ziuganov, V. V., V. V. Beletsky, R. J. Neves, V. A. Tretiakov, I. V. Mikhno and S. M. Kaliuzhin. 1998. The recreational fishery for Atlantic salmon and the ecology of salmon and pearl mussels in the Varzuga River, Northwest Russia. Virginia Tech, VA.

Photo: CTUIR Freshwater Mussel Project

QUESTIONS?