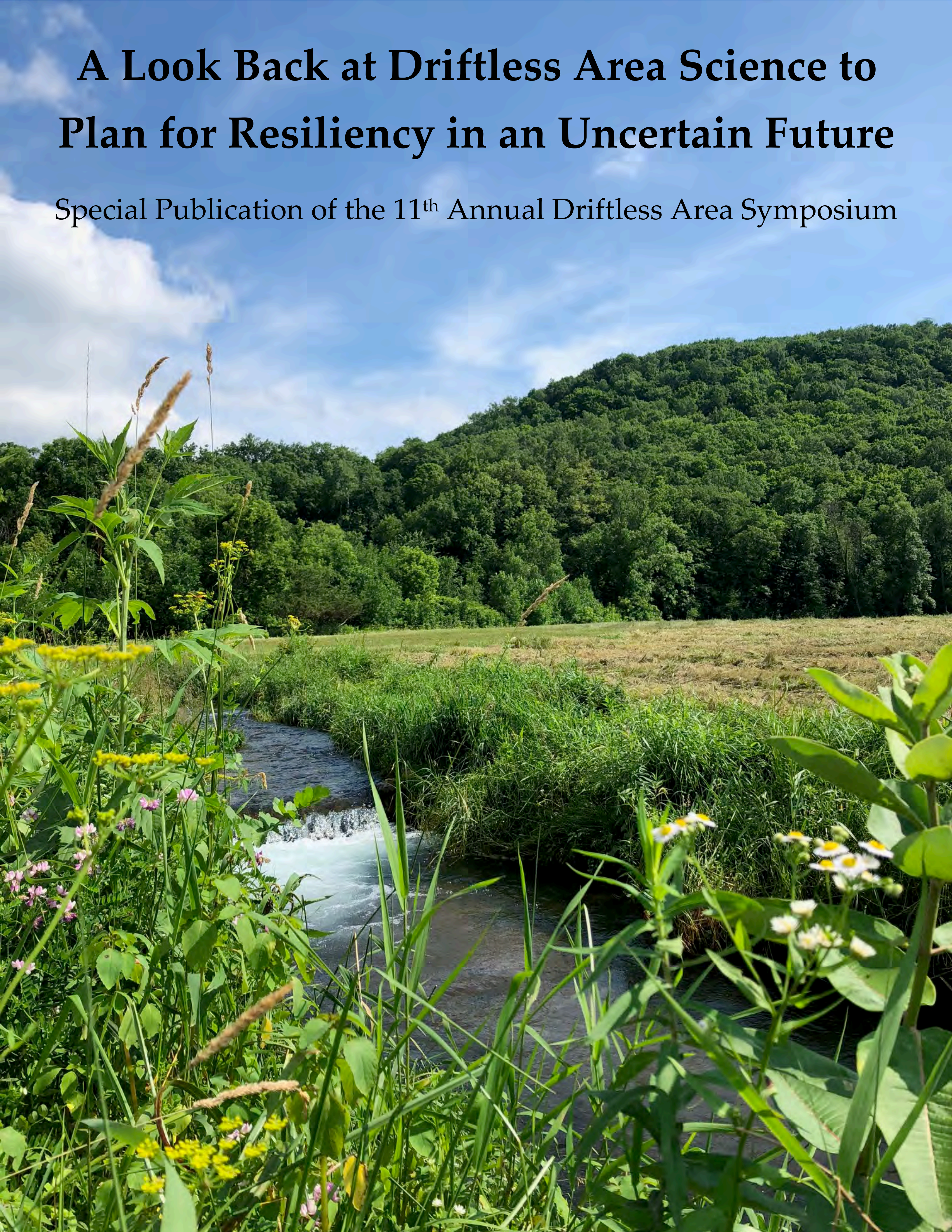
A Look Back at Driftless Area Science to Plan for Resiliency in an Uncertain Future

Special Publication of the 11th Annual Driftless Area Symposium



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Special Publication of the 11th Annual Driftless Area Symposium

Radisson Hotel, La Crosse, Wisconsin

February 5th-6th, 2019

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Cover Photo:

Pine Creek, Pierce County, Wisconsin: Credit: Jan Johnson.

Photo: Historical gully erosion in the Driftless Area. Credit: NRCS.

Preface: A Look Back at Driftless Area Science to Plan for Resiliency in an Uncertain Future

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This Special Publication of the 11th Annual Driftless Area Symposium is a review of the science conducted in the Driftless Area that is relevant to stream restoration (including habitat improvement), with each section written by scientists or restoration practitioners who have worked in the region. The review is driven by an interest in understanding the current state of the science in the Driftless Area to allow better planning into the future, which is essential given the increased frequency of floods over the past decade and the fact that climate projections predict an increased frequency of high-intensity rainfalls into the future. The intense rains and subsequent flooding in late-August and early-September of 2018 highlight the issue, thus begging the question: What can we glean from past science to plan for flood resiliency in an uncertain future?

Climate | Resiliency | Adaptation | Science | Driftless Area

This Special Publication of the 11th Annual Driftless Area Symposium is intended to be a review of past and current science related to the physical and biological attributes of streams and watersheds in the Driftless Area, a geographic region including southeastern Minnesota, southwestern Wisconsin, northwestern Illinois, and northeastern Iowa. The Driftless Area was bypassed during the last glacial period and, therefore, lacks glacial drift - sediments carried and deposited by glaciers. As such, the Driftless Area is a region with steep hills and limestone bluffs, and it contains over 600 cold, spring-fed creeks that support a vibrant trout fishery with a substantial socioeconomic impact to the regional economy. Legacy impacts to streams and rivers from historical agricultural practices have led to an active stream habitat enhancement and restoration community. One purpose of this publication is to review this history of restoration in the Driftless Area with special regard to climate change. The Fourth National Climate Assessment Volume I was released in November of 2017 and it unequivocally states that the climate is changing (1), and Volume II released in November of 2018 suggests that changes in climate are highly likely to have substantial impacts on global economies, including in the midwestern United States (2). Because the Driftless Area has a substantial trout fishery resource with an active stream restoration community, this publication will also review stream restoration standards of practice with a focus on resiliency given the projected increases in the temperatures, droughts, and especially the frequency and magnitude of high intensity precipitation events from the present through the latter half of this century (1, 3).

Why a Science Review Now?

A Decade of Flooding. Climate projections portend an increase in frequency and magnitude of high intensity precipitation events, but these events have already been observed with high frequency over the last decade in the Driftless Area. In 2007, 15 inches of rain fell in 24 hours in the Whitewater River drainage in southeastern Minnesota, which resulted in catastrophic flooding that re-arranged stream channels, flooded towns, caused millions of dollars of damage to state parks, and killed seven people (see Pioneer Press, 19 April 2015). In 2013, over three feet of rain fell over three days in the Root River drainage (southeastern Minnesota), again resulting in large floods. Similar high-intensity rainfalls have caused flooding in northeastern Iowa and southwestern Wisconsin in 2004, 2007, 2008, 2013, 2014, 2016, and even in 2017 (see summary here). In fact, the frequency of high-intensity rainfall events has increased over the last half century (4), and those events are predicted to become even more frequent given future climate projections (4, 5). Record floods were again observed in 2018 (reviewed by National Weather Service).

Fig. 1. Flooding in near Viola, Wisconsin in August, 2018. Over 20 inches of rain fell in some areas. Credit: E. Daily, La Crosse Tribune.

Observations from the 2018 Floods. In September 2018 two high intensity precipitation events on August 27-29 and September 2-4 again caused major flooding in parts of the

Statement of Interest

The Driftless Area is an iconic landscape in the Upper Midwest. It contains over 600 coldwater streams that have been subject to an increased number of record floods over the past decade, including - yet again - in 2018.

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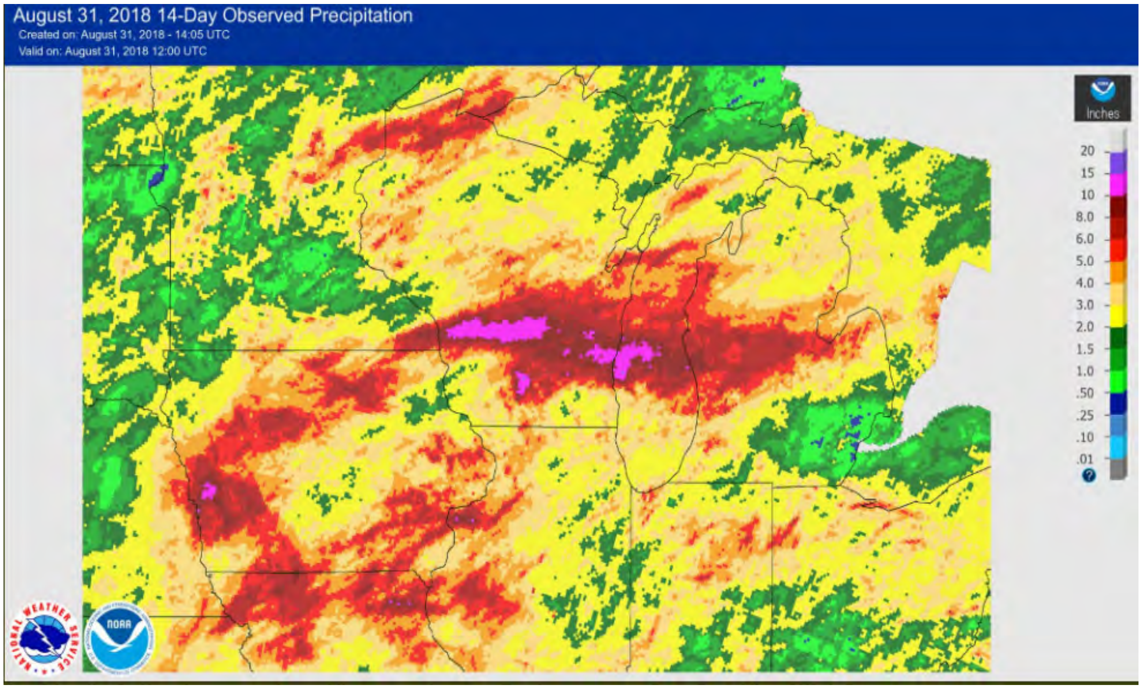

Fig. 2. Observed 14-d precipitation totals (inches) prior to August 31, 2018. Data from National Weather Service.

Driftless Area (Figs. 1,2). The heaviest impacts of the two rainstorms generally followed Highway 33 from north of Coon Valley to Cashton, Hillsboro and Reedsburg in Wisconsin. But they were not a narrow band. While Ontario received 15.6 inches of rain between August 26 and September 3, Westby got over 18 inches, Elroy over 23 inches and Readstown 11.6 inches, according to the National Weather Service. Just before these events occurred, another event dumped 15.3 inches of rain on Cross Plains and Black Earth Creek in 24 hours, a state record.

That rain resulted in substantial flooding and flood damage (Fig. 3). Six flood-control dams failed, and others suffered damage. When dams failed, as in the case of one in the Upper Rullands Coulee drainage in Monroe County, large amounts of water were released downstream and caused substantial damage (Fig. 4).

Rullands Coulee was a mess (Fig. 5), with barn and shed parts scattered across the landscape, and tipped-over gravestones at the Skogsdalen Lutheran Church. For many years, the late Palmer Olson had a small fly shop along Rullands, with a pond from an impounded spring where he would cast nearly every day. That pond's berms are gone, and his house sat cantilevered over an undercutting bank immediately after the flood. A tree slide on the ridge to the north of Rullands at County Highway P and Oakdale Avenue brought trees and mud 350 feet down a swath of hillside. Where box elders edged the stream, many were torn out and washed down into Timber Coulee where the stream became wide and shallow for some distance below the Highway P bridge. Some older restoration work in Timber Coulee (from the 1970s and 1980s) failed below the confluence, as did some older project work on Bohemian Valley.

Now might be a good time to consider revisiting affected areas of Timber Coulee and Bohemian Valley that were restored decades ago. And these results should prompt us to question how we do restoration work in narrow upper valleys that have higher gradient streams. We may need to address these areas differently then our efforts on middle reaches. For example, maybe in these areas we will need to focus on using available materials (e.g., no LUNKERS) and diversity, and try and be cost effective and not fix every foot knowing that we may likely need to do maintenance again in the near future.

Fig. 3. The view of West Fork downstream from Highway S bridge at Bloomingdale Road, September, 2018. Credit. D. Welter.

Two dams also failed in the West Fork of the Kickapoo River in Vernon County, Wisconsin (notably the Jersey Valley Dam, where repairs cost $3 million a half-dozen years ago), which along with the rains caused significant flooding. The West Fork Sports Club and past restoration projects upstream were damaged.

More recent restoration projects on lower Timber and lower Spring Coulees, however, appeared to have withstood the floods well. The Bob Jackson and Neperud properties are

Fig. 4. Heavy rains created this mudslide above Skogdalen Lutheran Church, September, 2018. Credit. D. Welter.

in excellent shape. Snowflake Ski Club's property on upper Timber Coulee showed serious damage.

Farther down the Kickapoo, towns from La Farge to Gays Mills flooded twice. Tributary streams, however, seemed to be undamaged other than Brush Creek west of Ontario. The Weister Creek restoration project north of La Farge withstood the floods. Readstown suffered badly, with most of the houses in the flood plain partly submerged. During the floods, one resident paddled his kayak out to check his and his mother's homes. Both were total losses.

Continuing a pattern seen from past storms, dry runs brought significant amounts of sediments down hillsides and into yards and stream corridors. Many homes were historically built in little nooks along the edges of bluffs. Those are funnels for the dry runs, and homes showed significant damage even if they weren't located in or near flood plains.

What About the Projected Future?

With the Midwest projected to see increased temperatures and more frequent high-intensity rainfall events likely to cause flooding (1–3), what do projected increases in precipitation and flooding mean for stream restoration in the Driftless Area? What do we know about the effectiveness of various elements of stream restoration and habitat improvement design, and how can they be used guide projects and better plan for resiliency in the face of extreme climate events (Fig. 6)? Stream and river restoration is still a relatively young discipline that integrates several scientific disciplines (engineering, hydrology, geomorphology, ecology), and it has progressed through a combination adaptive management and increased scientific knowledge (6). While many stream habitat improvement and restoration practices are grounded in science, the links between restoration practices and science are not always made explicit. Luckily, the Driftless Area is one of the best-studied landscapes in the United States, and as a result there is a rich body of scientific literature to draw upon.

Fig. 5. Prior to September 2018 flooding, a barn and shed flanked this silo. Credit. D. Welter.

This Special Publication of the 11th Annual Driftless Area Symposium will highlight region-specific science examining how stream ecosystems function in relation to stream and watershed restoration. Certain sections will also touch on the history of restoration and current restoration standards of practice and how they may be used to increase resiliency of stream systems and trout fisheries in a changing climate (7). One common way to judge whether practices reflect the current state of the science and which practices may help plan for resiliency in an uncertain future is to conduct a review of restoration science as it relates to Driftless Area streams. How do we know that certain conservation practices increase infiltration and improve base flows or that brook trout *Salvelinus fontinalis* are projected to decline substantially in distribution in future climates? Someone studied it, and in some cases those people have studied it for a good portion of their careers and lifetimes. Those are the people contributing to this special publication, and we have much to learn from the studies they have conducted and the knowledge they have accrued as the restoration community continues to restore streams and watersheds of the iconic Driftless landscape into an uncertain future.

ACKNOWLEDGMENTS. We would like to acknowledge the agencies, organizations, and individuals that have participated in and funded stream restoration in the Driftless Area.

Fig. 6. The confluence of Rullands and Timber coulees, September 2018. Credit. D. Welter.

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The Driftless Area - A Physiographic Setting

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1. The Driftless Area is a unique geographic region of the upper Midwest.
2. The geologic and geomorphic processes responsible for the creation of the Driftless Area are spatially diverse, but the dissected topographic signature is rooted in long term stream erosion.
3. Post-settlement agricultural practices have altered streamflow processes across the Driftless Area.

Glaciation | Drift | Geology | Topography | Soils | Karst

The region of southwest Wisconsin, northeast Iowa, southeast Minnesota, and northwest Illinois encompasses a topography that is uniquely different from the adjoining landscape. The colloquial term for this region is the Driftless Area. The Driftless Area is identified as a region approximately 24,000 square miles that constitutes a rugged topography with dissected valleys and well-developed stream networks of the Mississippi River that traverse the four-state region.

Early Observations on Drift

Examination of glacial deposits and sediments have found that much of the Driftless Area is not actually driftless and that only southwest Wisconsin and northwest Illinois were ice free during the Pleistocene (1–3). Evidence for glacial deposits have been identified in southeast Minnesota and northeast Iowa (4, 5). These glacial deposits are >500,000 years old (Pre-Illinoian) and found on hilltop ridges. Geomorphologists and geologists generally agree that the signature hill and valley erosional topography of southeast Minnesota and northeast Iowa was not overly manipulated during this glaciation and thus retains a similar topography to southwest Wisconsin and northwest Illinois (3). Research shows that southwest Wisconsin, northwest Illinois, southeast Minnesota, and northeast Iowa were not directly impacted by glacial ice during the last glaciation 10,000-30,000 years ago (late Wisconsin) and allows for the region's signature topography and geologic features (Fig. 1).

Geologists and geomorphologists have debated the origin of the Driftless Area since the early 19th century. In 1823 W.H. Keating's description of the Driftless Area helped defined a region unlike those they traversed from the east. The geologist from Pennsylvania traveled from Chicago to Prairie Du Chien, Wisconsin noting the lack of granitic boulders that were common among glaciated landscapes (6). Field studies by geologists in the mid-19th century presented evidence that the troughs associated with Lake Superior and Lake Michigan basins diverted northern ice to the west and south around the current extent of the Driftless Area (7, 8). Till deposits found within the Iowa and Minnesota sections of the Driftless Area resulted from glaciers flowing east from the northern Great Plains (9).

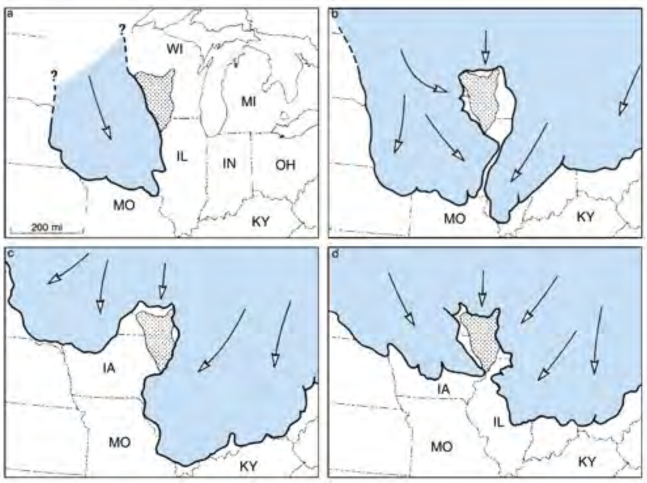

Fig. 1. Maximum extent of (a) early Pre-Illinois glacial episode (1,000.000±years age); Driftless Area shown by stippled pattern; arrow indicates direction of ice movement; (b) late Pre-Illinois glacial episode (600,000±years ago); (c) Illinois Glacial Episode (250,00±years age); (d) late Wisconsin Glacial Episode (22,000 years age). Note: Panel (d) portrays glacier advancement into the Iowan Surface, which is not accurate. Source: Illinois State Geological Survey.

Bedrock Geology

The bedrock geology of the region is primarily sedimentary-age Paleozoic. Between 500 to 250 million years ago a marine environment existed off the continent where eroded particles of sand, silt, and clay were deposited and later lithified into sandstone, shale, limestone, and dolostone. Downcutting of the Mississippi River and associated tributaries during the Pleistocene has helped to expose the Paleozoic rocks (3, 10). Differential weathering and a resultant resisting framework has helped establish the dissected and high relief landscape (∼1,100 ft) of the Driftless Area. The more resistant limestone and dolostone rocks often form cliffs and bluffs, whereas the more erodible shale is indicative of gentle slopes (3, 11). Joints in the bedrock impart pathways for stream courses across the Driftless Area (1).

Statement of Interest

Drift is "a general term for all rock material transported by glaciers and deposited directly from the ice or through the agency of meltwater. It is generally applied to Pleistocene deposits in large regions that no longer contain glaciers." Dictionary of Geologic Terms, 1984

This chapter was reviewed by B. Vondracek and P. Jacobs.

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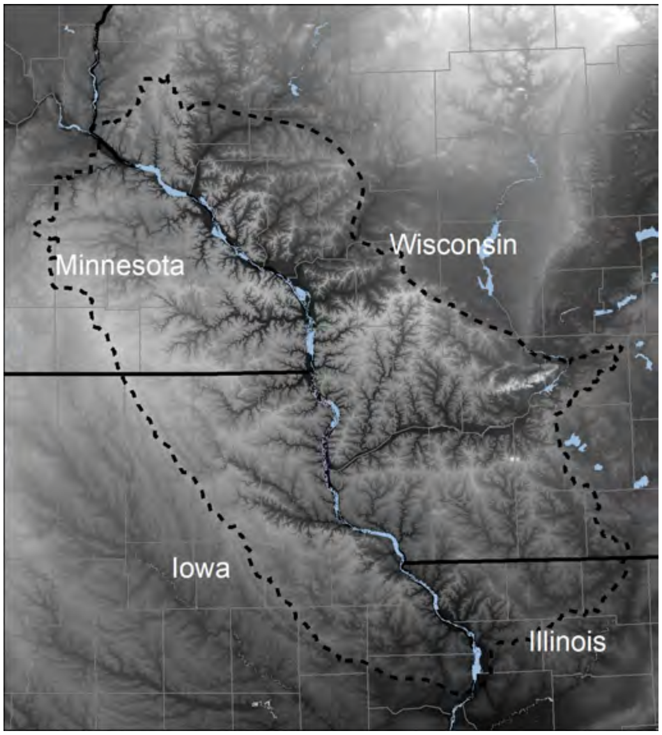

Fig. 2. Topography of the Driftless Area and adjacent regions in southwestern Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois. The region is a heavily dissected landscape that is often referred to as coulee or bluff country. The dashed line shows one representation of the Driftless Area boundary.

Topography

The topography of the Driftless Area is strikingly different from its surrounding landscape regions (Figs. 2, 3). The high relief, dissected, and eroded landscape is like no other in the upper Midwest. It is a product of little to no glaciation during the late Wisconsin. The geologic origins and geomorphic processes responsible for the creation of the Driftless Area differ are variable across its wide expanse, but the one consistency is long term stream erosion since the area was unglaciated during the last 500,000 years.

Soils

Traversing the landscape are a combination of plateaus, cliffs, bluffs, and hillslopes that help define the physiographic region. Loess derived soils often mantle the Paleozoic rocks. The loess thickness is greatest on low gradient uplands and lower to non-existent on steep slopes. Mass wasting on upland and hillslopes during the late Wisconsin glacial period was responsible for the removal of the loess cap in areas of the Driftless Area (12, 13).

European Settlement

Pre-Settlement Land Cover. In the first geological report to the Governor of Wisconsin, Daniel Edwards described the vegetation as a combination of prairie, savanna, and deciduous forest (14). As European settlement increased in the Driftless Area, much of the broad uplands and flat valley bottoms were cleared for agriculture and forests are now generally confined to side slopes (15). Where upland forest occur they consist of red and white oak *Quercus rubra* and *Q. alba*, sugar maple *Acer saccharum*, cherry *Prunus spp.*, hickory *Carya spp.* and valley lowlands are often comprised of elm *Alnus spp.*, cottonwood and birch *Populus spp.*, ash *Fraxinus spp.*, silver maple, and willow *Salix spp.* (16). The transition, and ultimately transformation of natural vegetation communities to agriculture, caused severe landscape degradation that has negatively impacted the river systems across the Driftless Area (see Vondracek, page 8).

Fig. 3. Aerial imagery of southwestern Wisconsin showing upland farm fields, forested hillslopes, and developed valleys. Source: Google Earth, Inc.

Fig. 4. Driftless Area hillslopes cleared for pasture with rills as evidence of past erosion. Credit: D. Splinter.

Post-Settlement Land Use. Beginning in the early 19th century, European settlement in the Driftless Area promoted landscape disturbance as soon as the trees were removed and the plow broke ground (17). Erosion developed on hillslopes as rain detached the topsoil, which led to the development of rills and gullies (Fig. 4). The eroded soils ended up in small streams and valleys across the Driftless Area (12, 17, 18). Stream aggradation altered the flow hydrology of the fluvial system and resultant channel habitats required for coldwater fish communities, including native Brook Trout *Salvelinus fontinalis* (19). The degradation of the fluvial system in the

Fig. 5. Row crop agriculture on an Driftless Area upland plateau, southwest Wisconsin. Valley initiation and forested hillslopes appearing in the background. Credit: D. Splinter.

Fig. 6. Driftless Area stream flowing through the Bohemian Valley, southwest Wisconsin. Credit: D. Dauwalter.

Driftless Area has been extremely problematic because it harbors thousands of coldwater springs that provide suitable water temperatures to support trout in the upper Midwest (20)(Figs. 5, 6).

Karst Features

Within the Driftless Area karst features are common and include caves and sinkholes. The catalyst for karst topography in this region is shallow carbonate bedrock and a minimal amount of sediment covering the limestone and dolostone rock. Karst features are uniformly distributed across the Driftless Area. As acknowledged by Bounk and Bettis (10), karst features "are concentrated where lithologic, hydrologic, and geomorphic conditions have promoted their development and preservation." Karst features and associated topography have promoted the development of springs across the Driftless Area, which provides coldwater streams for trout. These springs often serve as the origin of first-order streams for the resultant dendritic channel pattern that characterizes the region.

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Driftless Area Land Cover and Land Use

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1. Settlement of the Driftless Area by Europeans between 1850 and 1935 altered the landscape through intensive agriculture and removal of forest cover, which resulted in significant sediment delivery to streams.
2. Replacement of forest and vegetative cover with row crops or continuously grazed pastures altered flow regimes in streams because of reduced ability of the catchment to absorb precipitation.
3. Beginning in 1935, after instituting the first watershed-scale soil and water conservation demonstration project in the United States in the Coon Creek watershed, cropping systems and land management changed in the Driftless Area, which led to reduced sediment losses from the landscape.

Land Cover and Use | Agriculture | Water Quality | Stream Habitat | Biotic Integrity

Stream quality, stream habitats, and fish communities respond to land use at catchment and riparian scales in the Driftless Area. The relationship between land use/land cover and instream characteristics and aquatic organisms is complex and is affected by catchment size, soil, geology, slope, vegetative cover, and other abiotic characteristics (1–5). Sediment and chemical input and discharge are primarily governed by hydrology, geology, soils, and vegetation at a watershed scale (6). However, land use, primarily agriculture, can substantially influence the quality and quantity of sediment, nutrient inputs, and discharge in streams (7–9).

Land Use and Aquatic Systems

Agriculture, urbanization, timber harvest, and other human modification of the landscape has altered and degraded stream ecosystems in multiple ways that reduce water quality, and which in turn affect fish spawning and rearing habitat related to siltation and erosion, and nutrient and chemical pollution from subsurface and overland flow (7, 10, 11). In areas of high topographic relief, such as the Driftless Area of southwest Wisconsin and southeastern Minnesota, historical replacement of forest and vegetative cover with row crops or continuously grazed pastures substantially altered flow regimes by reducing the ability of the catchment to absorb precipitation, which has contributed to more frequent and severe flooding and destabilization of streambanks and stream channels (see Potter, page 15, and Melchior, page 20). Flooding physically alters stream habitat and has been shown to reduce recruitment of young-of-year (YOY) trout in southeast Minnesota (12, 13).

Trimble (14), summarizing a number of earlier authors, described the pre-European settlement land cover in the Driftless Area as prairie where the landscape was level to rolling uplands and hillsides tended to be forests, whereas valleys had varied vegetation. Prairies had less than one tree per acre (0.4 per ha). Prairie soils were deep, fertile, and high in organic carbon and nutrients with high infiltration rates. Prairie plants were sometimes taller than a person on horseback. Prairies were maintained by fires caused by lightning during dry conditions and by Native Americans, likely to perpetuate bison and other large animals, e.g. elk *Cervus canadensis*. Forests were northern deciduous hardwoods. Forests on north-facing slopes were sugar maple *Acer saccharum*, beech *Fagus spp.*, and basswood *Tilia americana*, whereas bur oaks *Quercus macrocarpa* were found on sunny slopes. Many steep southern and western slopes were treeless. Vegetation on floodplains and terraces were varied with trees in some areas and grasslands in other areas. Trees were maples *A. spp.*, birch *Populus spp.*, and elm *Ulmus spp.*. Streambanks could often be lined with trees, even when the adjacent areas were grassland. However, sketches by early visitors indicate no more than 20% of the streambanks were lined with trees. Floodplains were characterized as having a dark well-developed non-stratified soil with little vertical accretion. Streams were clear with little lateral migration and channel bottoms were usually sand or gravel.

Settlement by Europeans began as early as the 1820s in Wisconsin south of the Wisconsin River and around 1850 in southeast Minnesota (15). Trimble (14) provides an overview of agriculture and land use practices, which led to significant alteration of the landscape and the extensive erosion and sediment delivery to streams that followed. Early settlers were miners attracted by lead deposits in southern Wisconsin. Mining resulted in spoil piles, which were subject to erosion. As the population increased, other activities contributed to erosion, such as road building and forestry, but agricultural practices, circa 1850, led to significant erosion. Between 1850 and 1935, many savannas and prairies in southern Wisconsin were converted to cropland and pasture (16). Following the arrival of Europeans, extensive land use transformation took place. Agriculture lead to deforestation and overgrazing of bluffland hillsides, and poor soil management led to massive sedimentation, flooding, channel alteration, and severely degraded streams. A major contributor to erosion was a result of the United States rectilinear land survey where land was laid out in rectangles. This system encouraged farmers to lay out their fields along straight lines and led to a practice of

Statement of Interest

Brook Trout *Salvelinus fontinalis*, the only trout species in streams in the Driftless Area prior to settlement, were described to be very abundant. However, following settlement with the advent of mining, forestry, and agriculture, sediment delivery to streams and alterations to stream channels Brook Trout were nearly extirpated. Brook Trout were successfully reintroduced to many streams following the improvements in stream channels bought about by the conservation efforts that began in 1935.

This chapter was reviewed by K. Blann and D. Dauwalter.

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Fig. 1. Massive gully and erosion in the Driftless Area. Credit: USDA-NRCS

plowing up and down or across steep slopes, which resulted in eroded hillsides and formation of gullies that contributed significant sediment delivery to streams (Figs. 1, 2). Initially, wheat was the major crop with little crop rotation. Wheat production was replaced with corn and oats as agriculture shifted to dairy and grazing, but grazing was often practiced on steep hillsides or in riparian areas, which also resulted in significant erosion. The loss of upland vegetative cover led to frequent and severe flash flooding in downstream communities. For example, the town of Beaver in the Whitewater watershed in southeast Minnesota was buried under 9-ft (3-m) of sediment (17). Altering natural land cover for agricultural land use altered stream channel cross sections related to increased flooding (18).

Agriculture, Floods, and Sediment

Floods and increased sedimentation were correlated with agricultural practices (e.g., tillage and grazing) and timber harvest in riparian areas and upland habitats in the past two centuries (19). Low flows and average flows in agricultural watersheds increased in Wisconsin between 1915 and 2008 (20). However, Juckem, et al. (21) noted an abrupt increase in baseflow around 1970, which coincided with increased precipitation and changes in agricultural land management. Conversion of natural land cover to agriculture in the Platte watershed of southwestern Wisconsin lead to an increase in the magnitude of floods (18). Increased flooding has resulted in streambank erosion and loss of aquatic habitat. Past land use, particularly agriculture, has resulted in long-term effects on aquatic diversity regardless of reforestation of riparian zones (22). Natural resource policymakers acknowledge that the legacies of land-use activities may influence ecosystems decades or centuries after activities have ceased (23). These activities have included plowing, overgrazing, channel diversions and alteration, reductions in and wider extremes of instream flow, riparian habitat loss and degradation, point and non-point source pollution, and streambank erosion (17) (Fig. 3). As a result of these land use practices native Brook Trout *Salvelinus fontinalis* were virtually eliminated by degraded instream habitat and overfishing by 1900 in the Driftless Area (15).

Conservation Practices

Interventions to address these issues on the broader landscape began with the formation of the Soil Erosion Service in 1933, which became the Soil Conservation Service in 1935 (now named the Natural Resources Conservation Service) (15, 24). Coon Creek, Wisconsin, located in the Driftless Area, was the first watershed-scale soil and water conservation demonstration project in the United States (21). Widespread adoption of soil conservation practices led to a decrease in flood peaks and in winter/spring flood volumes in streams, such as the East Branch of the Pecatonica River in Wisconsin (25). Trimble and Lund (26) found significant reductions after 1935 in erosion and sedimentation in the Coon Creek basin following improvements in land management and changes in land use. Although the crops grown did not change improved crop rotations and contour plowing began to be implemented, which decreased erosion (14). Trimble and Lund (26) reported that between 1934 and 1975 several land management practices which included contour plowing, contour stripcropping, long rotations, crop residue management, cover crops, and controlled grazing were instituted (Fig. 2). The rate of alluvial sediment accretion in the agricultural Coon Creek Basin decreased dramatically compared to the 1930s, but the changes were variable across the basin (27).

Public Law (PL) 566 in the 1950s and 1960s reduced flooding, erosion, and sedimentation and increased infiltration and base flow in streams in southeast Minnesota (15). PL566 provided support to landowners working with federal agencies to build small dams, stabilize gullies, and protect eroding streambanks (14, 28). Base flow in watersheds in southern Wisconsin increased from 13% from 1981 to 2010, to 18% from 1950 to 1980 (29), but part of the increase may have been related to an increase in precipitation after 1970 (21). Agricultural land use practices, such as no-till and conservation tillage, were also developed and supported by the Natural Resources Conservation Service. Concurrent with the environmental movement in the late 1960s and 70s, state fisheries managers and conservation groups, such as Trout Unlimited, employed site-level management strategies to increase fish populations in streams. The advent of "stream restoration" led to the recognition that improving stream quality and fish populations required site-based restoration and management strategies and landscape-scale interventions, such as making stream channels narrower and deeper to increase water velocity and maintain cool stream temperatures during the summer and sloping stream banks to dissipate flood energy into the floodplain rather than eroding streambanks. These restorations and interventions require expertise found within multiple disciplines (e.g., engineering, geomorphology, ecology).

Stream Habitat Management

Investigations of streams usually focus on the local or riparian scales, and much progress has been made in instream and site-level habitat management, such as stream restoration. However, land use at catchment scales may confound or constrain influences on the structure of aquatic communities (6). Processes at larger scales may account for many of the observed habitat losses that are often poorly addressed (30). Removal of riparian vegetation, whether for agriculture or timber harvest affects streams in a number of ways. Stream water temperature can increase, as much as 4.5°F (2.5°C), along streams when vegetation is removed because of reduced shade on the water surface (31). Trimble (32) reported that four reaches in Coon Creek streams bordered by grassed streambanks were narrower and stored more sediment than reaches with forested streambanks. Interestingly, Wang, et al. (5) reported habitat quality and index of biotic integrity (IBI; a way to use fish or insect assemblage information to assess stream health) scores were positively correlated with the amount of forested land and negatively correlated with the amount of agricultural land in watersheds in 103 streams in Wisconsin, and IBI scores decreased when agricultural land use exceeded 50% (Fig. 4). Coldwater IBI scores increased over time in streams in high Conservation Reserve Program (CRP) areas relative to streams in low-CRP areas (33).

Catchment and Riparian Land Use

A discussion of the relative importance of managing riparian areas versus modifying land use at a catchment scale to protect streams is important to consider. This discussion is important because most stream restoration efforts are focused primarily on modifying stream channels and altering streambanks and riparian areas to improve stream habitat and fish, usually trout, abundance. Importantly, riparian areas with forest or grass cover removes minimal land from agricultural production. Riparian zone management plays essential roles in restoration of aquatic systems (34). Riparian vegetation has been found to reduce overland water flow, sediment, and nutrients entering streams. Riparian areas affect water chemistry by trapping nutrients, sediment, and other nonpoint source pollutants in agricultural settings (35–38). Riparian areas can influence instream water temperature, habitat structure, hydraulic complexity, channel morphology, and nutrient inputs (7, 27, 31, 39–42). Riparian areas can influence fish productivity and other aquatic biota (4, 43, 44). For example, fish assemblages were more related to reach-scale habitat rather than to watershed agricultural land cover (45, 46). Nerbonne and Vondracek (47) found the percent of fine sediment and embeddedness in stream channels in the Whitewater River, Minnesota decreased with riparian buffer width. In addition, Nerbonne and Vondracek (47) found fine sediment, embeddedness, and exposed streambank soil were lower along stream reaches with grass buffers compared with grazed or wooded buffers. Riparian vegetation can slow the timing and amount of peak discharge from rainfall events and snowmelt, which can be important in the Driftless Area in light of winter snowfall and increased precipitation since 1970.

Grazing. Grazing and dairy operations, although declining in the Driftless Area, are still an important land use. Continuous grazing, whether for beef cattle or dairy, in riparian zones can result in significant streambank erosion and nutrient input to streams (48, 49). An alternative, often labelled rotational grazing, can affect stream channel stability and significantly reduce streambank erosion and nutrient input, which can lead to increased abundance of fish and aquatic invertebrates (3, 50–52).

Urbanization. Although there are few large urban areas in the Driftless Area, Wang, et al. (5) and Wang, et al. (53) indicate that low levels of urban development can affect coldwater stream systems (Fig. 5), specifically, land cover within the riparian area (30-m, or 100-ft) explained more variance in fish assemblages than land cover beyond 30-m. Wang, et al. (53) suggested that minimizing imperviousness may limit damage to stream systems. Low levels of urban development can affect coldwater streams, primarily due to increased impervious surfaces, which can increase water temperature and alter base flow (53). Allan, et al. (6) found higher levels of total nitrogen and phosphorus adjacent to urban land than for agricultural or forested land cover.

Agriculture. Several researchers suggested that land use at a watershed scale governs nutrient, sediment, and water yield, regardless of the extent of buffers (6, 54–56). Land use at broader scales can affect trout habitat by physically and chemically altering stream channel structure and water quality. Increased flooding and increased stream discharge lead to streambank erosion. Agricultural practices continue to affect water quality and channel structure and function related to increased nutrient and sediment delivery to streams. Richards, et al. (57) found surficial geology at a catchment scale influenced channel morphology and hydrologic patterns, which influenced macroinvertebrate assemblages in 58 catchments, but macroinvertebrate species traits (feeding habits, etc) were

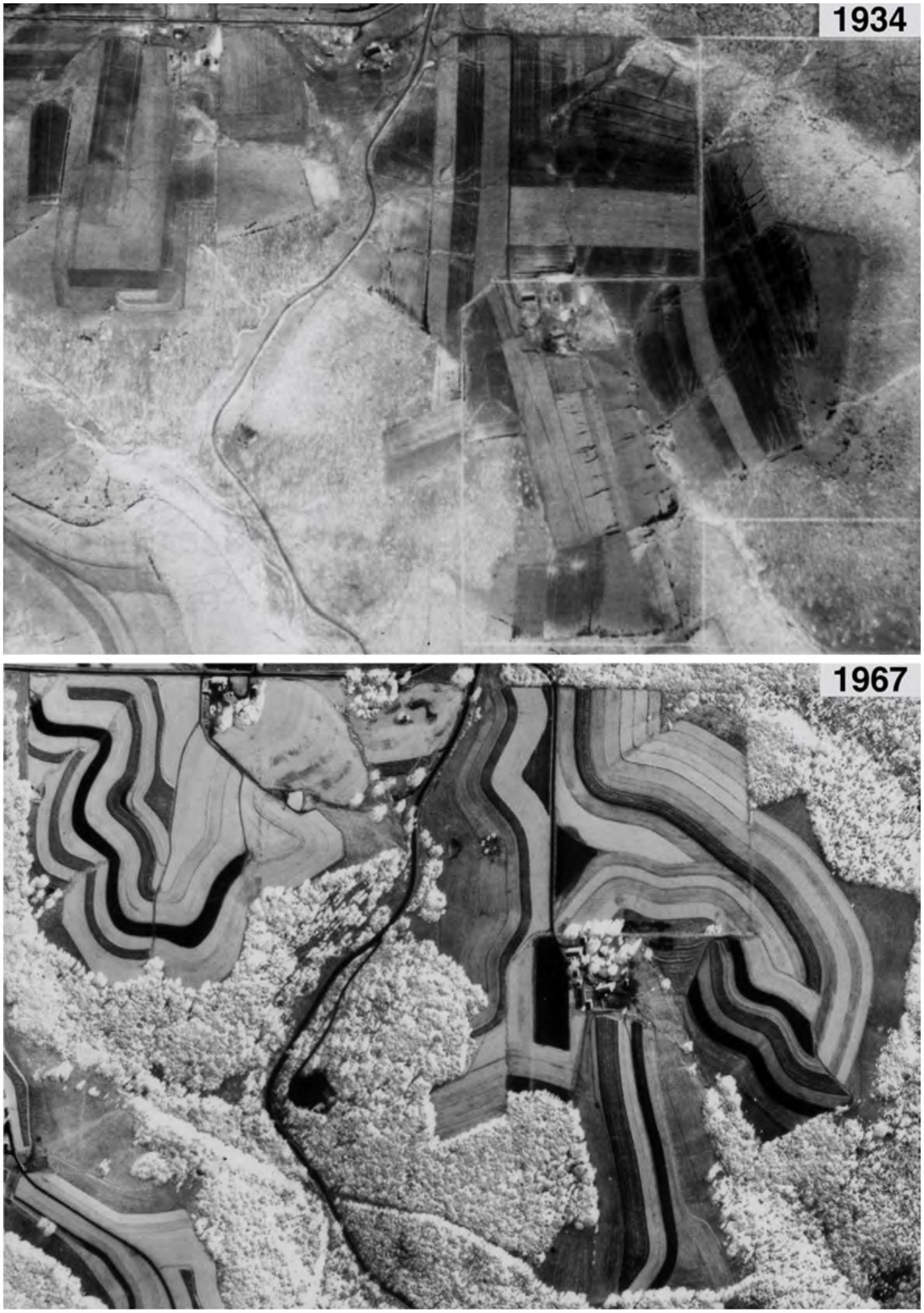

Fig. 2. Air photos of Coon Creek landscape, 1934 and 1967, just north of Coon Valley (SE1/4,T15N, R5W, Vernon Co.). 1967: Note contoured and strip cropped fields with no rills or gullies. From Trimble (14).

Fig. 3. Streambank erosion due to lack of buffer between farm fields and streams. Credit: J. Hastings.

related to local environmental conditions. Agricultural land at a catchment scale across 103 sites in Wisconsin negatively affected habitat quality and the IBI when agricultural land use exceeded 50% and relationships were generally stronger for the entire watershed than for the buffer (5) (Fig. 4).

Vaché, et al. (8) used the Soil Water Assessment Tool to compare historical and then current agricultural land use practices with scenarios of potential land use. Interestingly, incorporating no-till cultivation (a practice currently in wide use) only slightly decreased mean sediment delivery to streams. A scenario that included riparian buffers 30-m (100-ft) on both sides of perennial streams and 15-m (50-ft) on both sides of ephemeral streams, as well as no-till, further decreased sediment delivery. A scenario that doubled the width of buffers, but also reduced monocultures of corn and soybean rotations and incorporating a strip of native perennials in fields of corn and soybeans reduced loadings of sediment by 37 to 67% and nutrients by 54 to 75%. A similar modeling effort was conducted by Zimmerman, et al. (9) that examined the relationship between water quality and fish communities within two agricultural areas using the Agricultural Drainage and Pesticide Transport (ADAPT) model. One of the streams was Wells Creek in southeastern Minnesota. A scenario in Wells Creek that included conservation tillage with recommended fertilizer application rates and 30-m (100-ft) riparian buffers along all waterbodies reduced sediment loading by approximately 30%. Land use changes that included maintenance of year-round permanent cover on agricultural land conversion to managed intensive rotational grazing and prairie and wetland restoration and 90-m (300-ft) riparian buffers led to reductions in sediment loading of up to 84% in Wells Creek; the reduction in sediment loading was directly related to a reduction in runoff by about 35%. These two modeling efforts found reductions in sediment loading can be achieved by no-till cultivation or conversation tillage (practices in current use), but including 30-m (100-ft) buffer areas along streams further reduced sediment delivery to streams. Although the Natural Resources Conservation Service currently supports installing buffer strips (see September 2016 NRCS filter strip Code 393), current agricultural practices, and importantly, national farm policy may offer limited ability to affect land use at broad scales because contaminants flowing off of farm fields - non-point source pollution - are exempt from regulations.

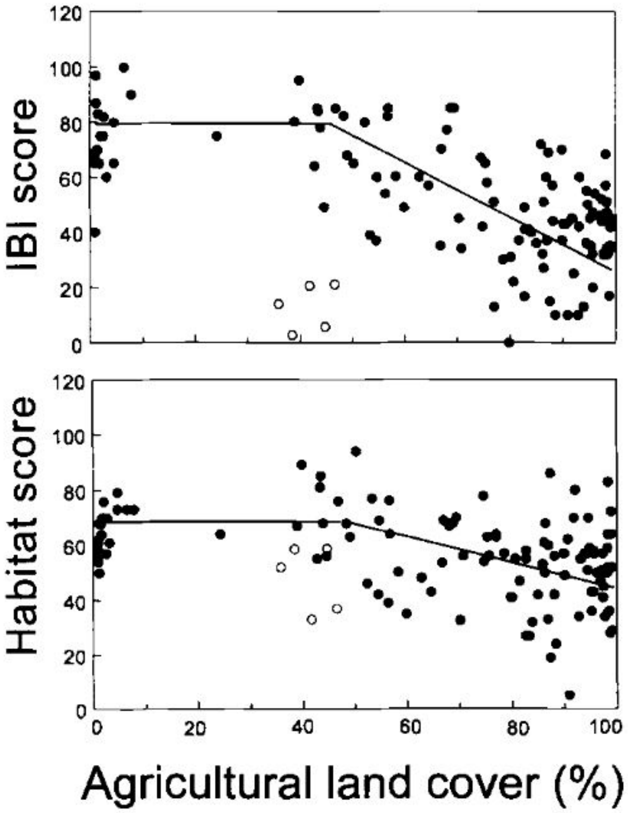

Fig. 4. Relationships between watershed agricultural land use and habitat and IBI scores. The open circles represent sites considered as outliers from the forest land use-IBI relationship. Lines were fitted by eye. From Wang, et al. (5)

Stream Buffers. Recognizing the potential for buffers to improve stream water quality the Governor of Minnesota developed a Water Quality Buffer Initiative. A 'buffer bill' was passed in 2015 by the state legislature that required that buffer strips be placed along streams and ditches in Minnesota. The state of Wisconsin also instituted a buffer initiative that predated the Minnesota law. The University of Wisconsin, College of Agricultural and Life Sciences (UW-CALS) was asked by the Wisconsin Department of Natural Resources (DNR) in March of 2002 to provide an overview of the science behind riparian buffers (58). The UW-CALS ad hoc committee, presented a report that included a 700-item bibliography to the DNR in early May 2002 (UW-CALS website). The report emphasized an adaptive management approach with an ultimate recommendation to take a broad, systems approach to implementing agricultural conservation practices to improve water quality. The DNR Natural Resources Board, in consultation with key legislators, passed a resolution supporting the ad hoc committee's recommendations.

Field- and Farm-Based Conservation Practices

Carvin et al. (59) compared two 5,000 ha (12,360 ac) watersheds in the Driftless Area of south-central Wisconsin to examine the UW-CALS recommendation to take a systems

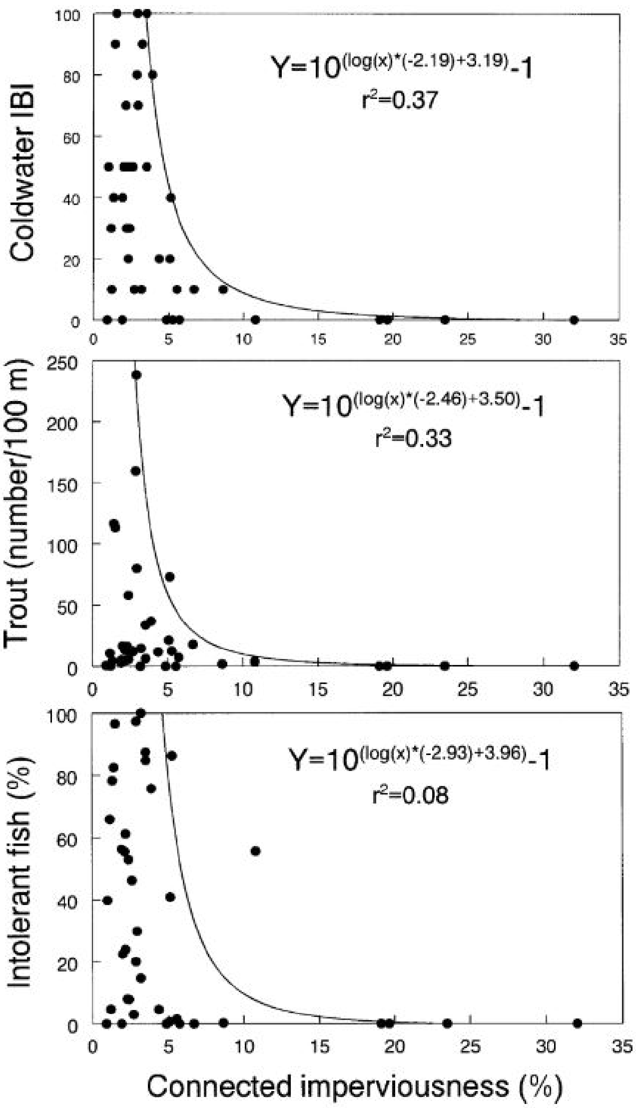

Fig. 5. Relations between percent watershed connected imperviousness and the coldwater index of biotic integrity (IBI), trout abundance, and percent intolerant fish in Minnesota and Wisconsin trout streams. From Wang, et al. (53).

approach to implement agricultural conservation practices. The design of the study was to implement baseline monitoring (2006 to 2009) followed (primarily in 2011 and 2012) by implementation of both field- and farm-based conservation practices. Both conservation practices were implemented in one watershed (treatment), whereas there were no out-of-the-ordinary conservation efforts in the second watershed (control). The watersheds were then monitored for four years (2013 through 2016). Storm-event suspended sediment loads in the treatment watershed was significantly reduced compared to the control watershed when the ground was not frozen. Year-round suspended sediment event loads appeared lower, but were not statistically significant. Total P loads were reduced for runoff events with a median reduction of 50%. Total P and total dissolved P concentrations during low-flow conditions were also significantly reduced in the treatment watershed.

Stream Restoration

Agencies and organizations, such as Trout Unlimited through the Driftless Area Restoration Effort, work diligently to restore habitat and water quality to restore habitat for fish and other non-game species and to provide recreational fishing access to restored areas. Stream restoration focuses on stream reaches with the intent to create narrower, deeper stream channels and stable streambanks. Thus, regardless of the broader debate about riparian versus larger land use scales, a focus on riparian areas can affect stream habitat quality. Restored stream channels may improve water quality and trout habitat, but they also help promote naturally reproducing, self-sustaining trout populations (see Dieterman and Mitro, page 29). However, streams prior to and after stream restoration are affected in a number of ways that are related to land use at riparian and larger scales and should be included in long-term planning and management.

ACKNOWLEDGMENTS. I wish to acknowledge past University of Minnesota graduate students who have studied land use influences on streams and rivers of the Driftless Area.

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Hydrology of the Driftless Area

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1. The abundant supply of cold water in Driftless Area streams is due to high rates of groundwater recharge.
2. Groundwater recharge rates are highest on the steep hillsides, which receive runoff from the hilltop areas in addition to direct precipitation.
3. Many headwater streams in the Driftless Area have unusually high baseflows as a result of the high recharge rates and the presence of horizontal bedrock layers that are relatively impermeable and divert groundwater to springs.
4. Poor agricultural practices in the first half of the twentieth century resulted in severe runoff and soil erosion, massive sediment deposition on the floodplains, and large increases in peak flows at the expense of baseflows.
5. The adoption of soil conservation practices in the later half of the twentieth century resulted in increased infiltration, a decrease in peak flows, and an increase in baseflows.
6. Future increases in air temperatures due to increases in atmospheric greenhouse gases will gradually increase stream water temperatures, although the impact will be somewhat buffered by the large amount of spring flow to the stream.

Hydrology | Groundwater | Streamflow | Hydrogeology | Temperature

Driftless Area streams generally provide ideal habitat for a coldwater fishery. The headwater portions of these streams are relatively long and include relatively steep reaches. Perennial flow occurs throughout the extent of these streams, including the headwater portions with very small drainage areas. This perennial "baseflow" results from groundwater inflows that enter the stream from numerous discreet springs as well as from diffuse flow through channel bottoms. Because groundwater temperatures about equal the mean annual air temperature, groundwater inflows from springs and the channel bed keep segments of the streams relatively cool in the summer and prevent them from freezing in the winter (1). Groundwater inflows through the channel bottom also provide ideal habitat for fish spawning. Such groundwater inflows provide refuges for coldwater fish species during extended hot periods (2).

This paper begins by using data from the U.S. Geological Survey (USGS) and other researchers to quantify the ideal hydrologic conditions in Driftless Area streams. It then summarizes the adverse hydrologic impacts of agricultural development in the early twentieth century and the subsequent recovery resulting from the adoption of conservation practices. It ends with a discussion of the potential impact of climate change.

Baseflow in the Driftless Area

The most important factor supporting the coldwater fishery in the Driftless Area is occurrence of relatively high baseflow in its streams, especially in the headwater portions. Gebert, et al. (3) provides estimates of the magnitude of baseflow at 1,618 locations in Wisconsin for the period 1970 through 1999. For this paper, the USGS provided a subset of these estimates for the 409 stream locations in the Wisconsin portion of the Driftless Area of the Wisconsin Driftless Area estimates, 61% were made using stream gage data, and 39% were made using 6 to 15 discharge measurements collected during low-flow conditions (Gebert, personal communication, 2018).

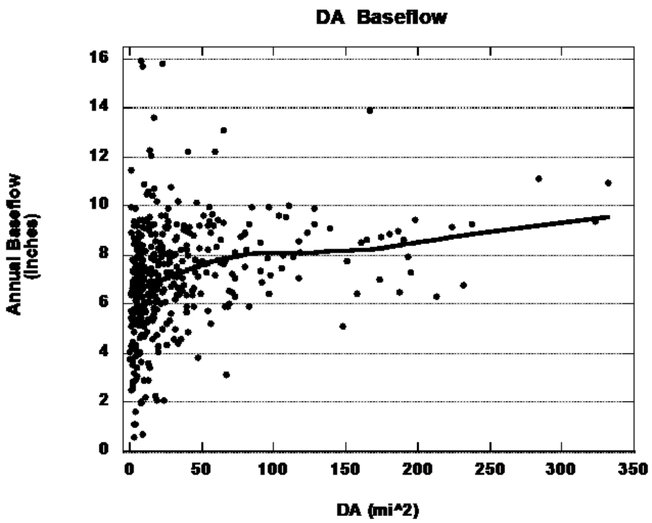

Fig. 1. USGS annual baseflow estimates (per unit of drainage area) as a function of drainage area (DA) for 409 stream locations from 1970-1999.

Fig. 1 is a plot of the estimates of annual baseflow discharge per unit drainage (watershed) area vs. drainage area. The area weighted mean is 8.0-in (20-cm), a value that is higher than average baseflow in Wisconsin (Gebert, personal communication, 2018). For headwater sites with very small drainage areas, the baseflow discharges vary greatly, ranging from below 1-in (2.5-cm) to just below 16-in (40.5-cm). The fact that

Statement of Interest

The coldwater fishery in Driftless Area streams is excellent because of unusually high inflows of relatively cold groundwater, especially in the headwaters. The high inflows of cold water are largely a result of unusually high rates of groundwater recharge, especially on the steep hillslopes. However, in the first half of the twentieth century, groundwater inflows to the streams were much lower as a result of poor agricultural practices. Subsequent adoption of conservation practices largely reversed this impact, although there is no guarantee that conservation practices will persist. Expected increases in air temperatures also threaten the persistence of cold-water conditions.

This chapter was improved through discussions with W. Gebert.

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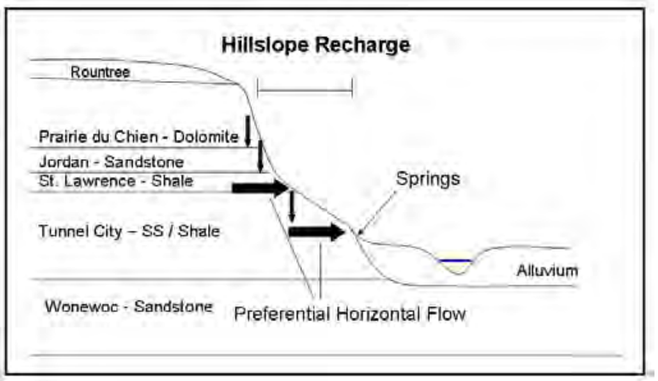

Fig. 2. Diagram of geologic units and groundwater flow in headwaters near study sites. Larger arrows indicate larger groundwater discharges. Figure from Schuster (4), adapted from Clayton and Attig (5) and Juckem (6).

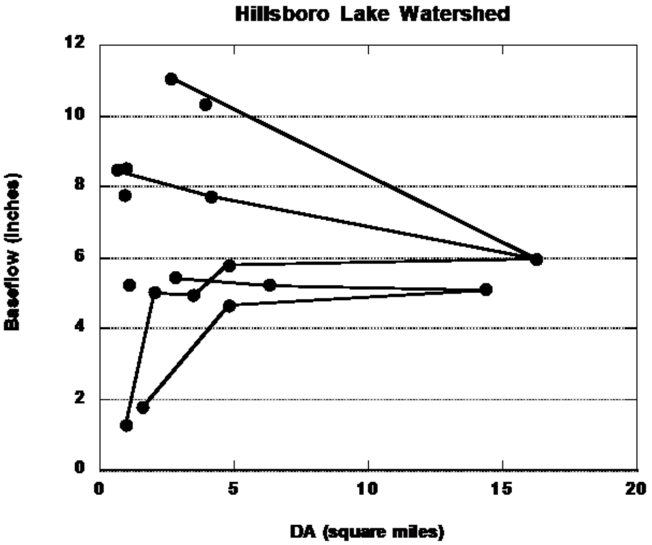

Fig. 3. Baseflow estimates for locations in the headwaters of the West Branch Baraboo River and the adjacent Kickapoo River. The connecting lines indicate flow paths.

many sites have baseflow discharges below the regional mean is not unusual, as streambeds high in a watershed are commonly above the local water table. However, it is unusual for small headwater watersheds to have baseflow discharges that are significantly larger than the regional mean.

There are two possible reasons for the unusually high estimates of mean baseflow discharge in the headwater watersheds. First, it is possible that the land area contributing to groundwater is greater than the area contributing to surface water. This would result in an upwardly biased estimate of the annual depth of baseflow, as the drainage area is used to convert discharges from volume per unit time (e.g., cubic feet per second) to volume per unit area/time (e.g, inches per year). In such a case the estimates are simply incorrect.

However, the high baseflow discharges at headwater locations could also result from the nature of bedrock, which consists of nearly horizontal layers of sandstone, carbonates, and shales. These layers have widely varying capacities to store and transmit water. When water seeping downward reaches a relatively impermeable layer, some or even all of it moves laterally. This lateral flow of water is likely to reach the channel, either via springs that flow overland to the channel or groundwater flow directly into the channel bottom. When a relatively impermeable layer is high in the watershed, it will produce anomalously high baseflow discharges in the headwater streams. Fig. 2 illustrates the geology of the region, and indicates the strata that produce high groundwater discharge.

Fig. 3 is a plot of estimates of mean annual baseflow discharge per unit area vs. drainage area for 14 locations in the portion of the West Branch Baraboo River watershed upstream of Hillsboro Lake, as well as for four sites from the headwaters of the adjacent Kickapoo River. Ten of the estimates were published in Potter and Gaffield (7), and were based on four to five synoptic streamflow measurements at each site made between May 1995 and July 1999. The remaining 7 estimates, including the four estimates in Kickapoo watershed, were based on three synoptic measurements at each site made between July, 2013 and May, 2015 (4). In both cases the method developed by Potter (8) was used to estimate mean annual baseflow from the synoptic baseflow measurements. The lines connecting the mean baseflow estimates indicate the flow path in the West Branch Baraboo watershed. The four sites in the adjacent Kickapoo watershed were chosen to determine whether the high baseflow values in the headwaters of the West Branch Baraboo River were biased as a result of the groundwater watershed being larger than the surface watershed. The fact that three of the four baseflow estimates in the upper Kickapoo watershed are also relatively large strongly suggests that the surface water and groundwater watersheds do not differ significantly. As in the case of the overall Driftless Area, the headwater baseflow values in the West Branch Baraboo River vary widely. The high baseflow headwater sites 11, 12, 13, and 14 are likely receiving groundwater discharge from the St. Lawrence formation (Fig. 2).

Groundwater Recharge

Groundwater recharge rates vary widely in the Driftless Area, but are less variable when considered in the context of the three major landscapes units that exist there - the ridgetops, hillslopes, and the valley bottoms. The ridgetops are rolling uplands. The hillslopes are generally steep, and valley bottoms contain the river floodplains. Fig. 4 delineates these landscape units in the portion of the West Branch Baraboo River watershed upstream of Hillsboro Lake.

Olson (9) monitored spring runoff from a ridgetop/hillside complex in the Garfoot Creek watershed during the spring snowmelt periods of 1993 and 1994 and found that during the event 6-in (15-cm) infiltrated the hillside, while only 3-in (7.5-cm) infiltrated the hilltop.

Juckem (6) conducted a series of infiltration tests at 15 sites in the Coon Creek watershed, 4 on the ridgetop, 4 on the hillside, and 7 on the valley bottom. The results indicated that infiltration rates on the ridgetop were higher than on the valley bottom, and that the infiltration rates on the hillside were 2 to 10 times higher than on the ridgetop and valley bottom.

Water Temperatures

The geology and geomorphology of the Driftless Area and the resulting impact on baseflows result in large spatial variations

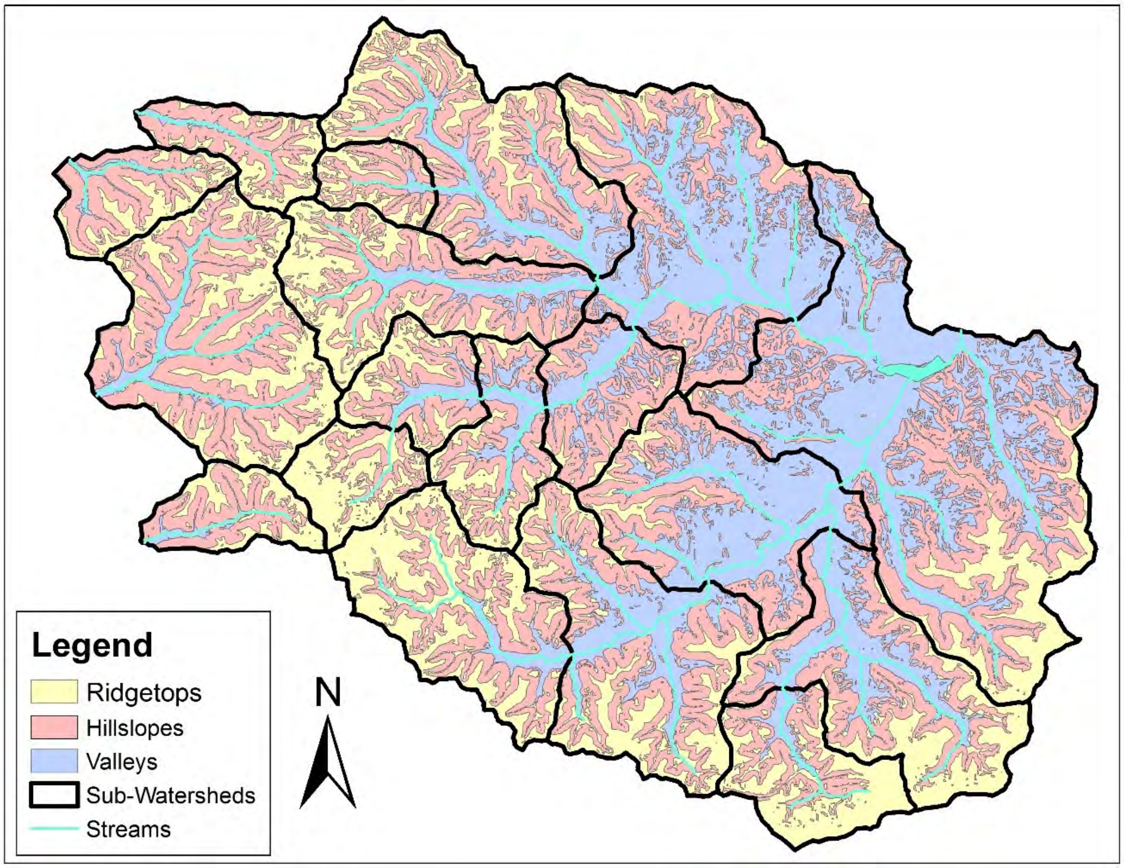

Fig. 4. Landscape units in the West Branch of the Baraboo River above Hillsboro Lake.

in water temperatures, particularly in headwater streams. This is illustrated in Figs. 5, 6, which provide daily maximum water temperatures measured in the summer of 1999 at multiple locations in two small headwater streams, Joos Creek and Eagle Creek (10). Each stream was sampled over a distance of about 2.2-mi (3.6-km). In Joos Creek, the coolest location is at the most upstream location (J7), which is just below the location of spring inflow. Water temperatures steadily increase downstream to the location at which it joins Eagle Creek. In the case of Eagle Creek, the coolest location is also at the most upstream location (E7). However, the second coolest location is just above the point at which it joins Joos Creek (E3). At all sites on both streams the daily maximum temperatures during the period from June 15 through August 14 range from 59-68°F (15-20°C). The maximum difference between the stream temperatures was 59°F (15°C) on Joos Creek and 60°F (15.6°C) on Eagle Creek.

Clearly inflows of relatively cold groundwater explain most of the spatial variability in summer water temperatures in the Driftless Area. However, another significant factor is shading by trees, particularly in headwater streams. Shading dampens the increase in temperatures in stream water that is cooler because of nearby upstream inflows of groundwater. However, the impact of shading on water temperature clearly decreases with increasing stream width. And, trees or large tree branches that fall into streams can cause significant channel widening (11).

Historical Impacts of Agriculture on Driftless Area Streams

The Driftless Area of today is much different from the one experienced by the early European settlers, largely because of the impact of agricultural development. Though many of the settlers were familiar with farming in steep terrain, most were not accustomed to the intense summer rainfalls that occur there. As a result, pre-conservation agriculture in North America significantly increased the amount and rate of stormwater runoff, causing a cascading set of destructive environmental impacts that still persist today, even after the adoption of conservation practices in the later half of the twentieth century (Vondracek, page 8).

Knox (12) estimated that pre-conservation agriculture increased the magnitude of 10-year floods discharges in the Platte River by a factor of three to five. Similar increases occurred throughout the Driftless Area. This increased surface runoff caused massive soil erosion and created thousands of gullies, both on the hilltops and in the steep hillsides. The hilltop gullies have mostly been filled, but virtually all of the hillside gullies remain today. Fraczek (13) mapped hundreds of large gullies in the 142-mi^2 (368-km^2) Coon Creek watershed. These gullies have a combined length of 243-mi (391-km), which is over 10 times the main channel length. In addition to increasing the downstream peak flows, the gullies cause runoff from the hilltops to bypass the highly permeable hillslopes, reducing groundwater recharge.

Most of the soil eroded from the uplands and hillsides was deposited on floodplains. Knox (12) estimated that deposition

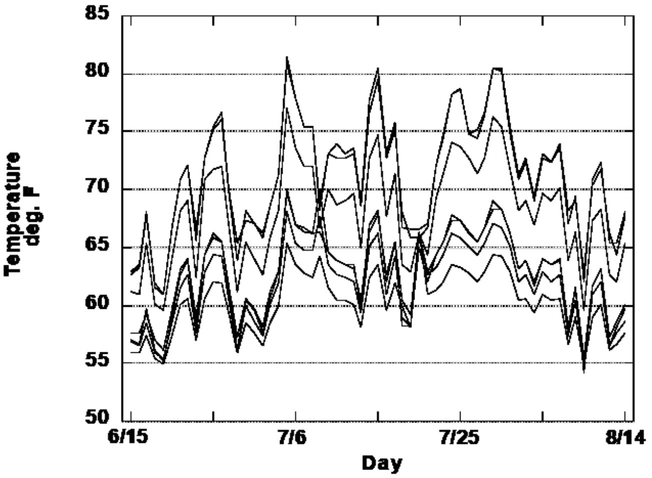

Fig. 5. Daily maximum temperature for Joos Creek.

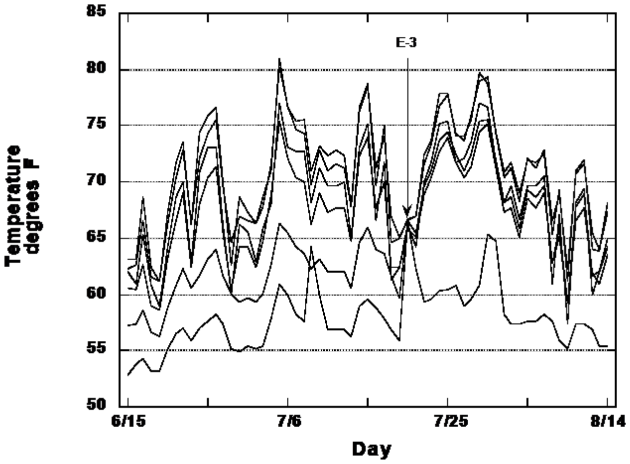

Fig. 6. Daily maximum temperature for Eagle Creek. Note sharp increase in temperature at station E3 about July 20, which is likely to represent a data collection error.

rates on Midwest floodplains during this period were 10 to 100 times larger than the pre-settlement rates. As a result, the elevation of the land adjacent to streams increased by about a half to several meters (1 to 10+ ft) (12), resulting in widespread loss of riparian wetlands (These lands are commonly referred to as terraces, as they are at higher elevations than the active floodplain). For example, based on field surveying and hydraulic modeling, Woltemade and Potter (14) determined that the modern terrace of the low-order tributaries in the Grant River watershed is generally not inundated by the two-year flood, and in some cases, is not inundated by the ten-year flood. In undisturbed watersheds, alluvial floodplains are typically inundated by floods that occur every one to two years (15).

Aldo Leopold (16), provided the following assessment of the impact of agriculture on the Driftless Area: *"...gone is the humus of the old prairie which until recently enabled the upland ridges to take on the rains as they came... Every rain pours off the ridges as from a roof. The ravines of the grazed slopes are the gutters. In their pastured condition they cannot resist the abrasion of the silt-laden torrents. Great gashing gullies are torn out of the hillside. Each gulley dumps its load of hillslope rocks upon the fields of the creek bottom and its muddy waters into the already swollen streams."*

After the creation of the Soil Conservation Service (now the Natural Resource Conservation Service) and the adoption of conservation practices through most of the Driftless Area, hydrological conditions greatly improved. Argabright, et al. (17) estimated that soil erosion rates on agricultural lands in five Driftless Area counties decreased by 58% between 1930 and 1982. And based on USGS streamflow data, Potter (18) demonstrated that annual peak flows and winter/spring flood volumes of the South Fork of the Pecatonica River decreased significantly during the period 1940 through 1986, while the contribution of winter/spring snowmelt to baseflow increased. Gebert and Krug (19), McCabe and Wolock (20), and Juckem, et al. (21) have documented increases in baseflow in the Driftless Area.

However, both legacy and current impacts of agriculture exist today. For example, Knox (12) estimated that flood peaks that would have been 5 to 6 times the pre-settlement values were reduced to 3 to 4 times by better land management. As previously mentioned, the hillside gullies are still present and reduce the amount of groundwater recharge. The other major legacy of pre-conservation agricultural is the sedimentation of floodplains and the concomitant loss of floodplain wetlands. Also, the high banks shed large amounts of sediment as the channels migrate laterally (Melchior, page 20).

Threats to Driftless Area Streams

Unless there are major interventions, water temperatures in Driftless Area streams will generally increase in the future as a result of increasing global greenhouse gas emissions. Based on flow and temperature modeling, Stewart, et al. (22) estimated the impacts of climate changes for the state of Wisconsin. For the Driftless Area, Stewart, et al. (22) estimated that the number of miles of Driftless Area streams with cold-water conditions will decrease by 47% by the mid-21st century. While these modeling results are instructive, they constitute a rough approximation and are likely overly pessimistic. The results are only based on 371 temperature sites, about a fifth of which were in the Driftless Area. The limited temperature data used in the study does not begin to capture the spatial heterogeneity in stream temperature that results from groundwater inflows, as demonstrated by the data from Joos and Eagle Creek (Figs. 5, 6). As previously mentioned, coldwater discharges into streams can provide refuges for cold-water species during extreme summer temperatures (2). These refuges will likely delay the loss of coldwater fishery. An additional delay will result from the fact that a large proportion of groundwater recharge results from the infiltration of snowmelt. Most climate change models predict an increase in the winter/spring precipitation. Furthermore, a large proportion of groundwater recharge results from melting snow and ice. For this reason, the increase in groundwater temperatures will lag that of air temperatures. Using an infiltration model and the output from four climate models, Murdoch (23) estimated that the amount and temperature of percolating water of a depth of 15-ft (5-m) would increase by about 50%, and the temperature would increased by about 67% of the increase in air temperature.

Regarding agriculture, there is no guarantee that that the all of conservation practices that were adopted in the Driftless Area will continue to be maintained. During the period 2006 to 2011, grasslands in the U.S. Corn Belt were converted to corn and soybean cropping at an annual rate of 1.0 to 5.4%, largely as a result of a doubling of commodity prices (24). Data on grassland conversions are not available for Wisconsin, although it is not unreasonable to speculate that grasslands have been converted to cropland as well. Any significant conversion of grasslands to agricultural lands would result in significant losses in groundwater recharge and hence baseflow, unless the agricultural practices employed the most progressive conservation practices.

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Geology and Geomorphology of the Driftless Area

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1. The geology of the Driftless Area directly influences fluvial geomorphic processes, resulting in stream systems that are unique to the region but not uncommon worldwide.
2. Land management practices impact fluvial geomorphic processes in the Driftless Area streams by changing hydrology and sediment sources, transport, and deposition.
3. The complexity of interaction between climate, landuse, soils, geology, ecology and geomorphic processes in Driftless Area require careful consideration, and generalities regarding cause and effect should be avoided when making management decisions related to landuse and ecology.

Geology | Geomorphology | Sediment Transport and Deposition | Channel Geometry | Streambank Erosion | Riparian Vegetation

To understand the geomorphology of Driftless Area streams, we must consider not only fluvial geomorphology, or the form and processes of moving water on the landscape, but also the surficial geology and landuse history, particularly with regard to vegetation changes. This section examines basic fluvial geomorphic principles, and looks at how glacial and post glacial geology and landuse affects channel forms and processes in the Driftless Area.

Geology of the Driftless Area

The Driftless Area is a 24,000-mi^2 region in southeastern Minnesota, southwestern Wisconsin, northwestern Illinois, and northeastern Iowa that was spared the erosional and depositional effects of glaciation. Advancing glaciers essentially bulldoze the landscape under millions of tons of ice, picking up soil and stone along the way. Retreating glaciers leave behind their cargo of silt, clay, sand, gravel, and boulders in deposits called glacial drift. Glacial till and outwash deposits, layered gravel and sand deposits that are a part of drift left by glacial meltwater streams and common in the upper tier Midwestern states, are uncommon in the Driftless Area. In this region, erosion of bedrock over millions of years and the lack of glacial deposits, or drift, have resulted in a rugged landscape of rolling hills, rock formations, plateaus, and deeply carved river valleys (1).

Although in the final phases of the most recent Wisconsinan glaciation the Driftless Area was totally surrounded by ice (Splinter, page 5), geologists until recently believed that the area had never been covered by glacial ice. Generally, geologists restrict the boundary of the Driftless Area to the east side of the Mississippi River, whereas the Minnesota and Iowa portions have remnants of pre-Illinoian glaciation. However, fisheries management agencies define the Driftless area as including both the Minnesota and Wisconsin sides of the Mississippi. In the glaciated regions adjacent to the Driftless Area, the glacial retreat left behind deep drift deposits, which buried older hills and valleys. Within the Driftless Area, deeply incising valleys cut through a bedrock plateau overlain by deposits of windblown fine soils called loess. The larger river valleys, such as the Mississippi and Wisconsin Rivers, have high bluffs rising over 500-ft (150-m) above the level of the Mississippi. These large rivers and their tributaries have eroded through Paleozoic Era sedimentary rock, primarily Ordivician dolomite, limestone, sandstone and shale.

Fig. 1. Bedload originating from eroding streambanks is often deposited in channel immediately downstream of the eroding outer bend.

Karst topography is found throughout the Driftless Area, although it is more common in southeastern Minnesota. Karst geology is characterized by fractures and fissures in what is typically limestone bedrock, resulting in caves, sinkholes, losing and disappearing streams, underground streams, and numerous coldwater springs. In non-karst streams, drainage divides separate small tributaries that coalesce into higher order streams, and stream hydrology is related to drainage basin area and the effect of precipitation and groundwater recharge can be somewhat predicted based on slope, soil composition,

Statement of Interest

Riparian vegetation plays an important role in fluvial geomorphic processes and stream channel stability. Historically, gross generalizations have been made regarding grass versus forested riparian areas and streambank stability in the Driftless Area, and decisions are often clouded by competing goals of streambank stability, riparian grazing, and desires of anglers. Fluvial geomorphic principles and studies in the Driftless Area suggest that such gross generalizations are misguided, and that riparian management should be considered in a project-by-project basis and consider all interacting factors that determine what riparian vegetation type is likely to be most effective in meeting habitat improvement or restoration goals.

This chapter was reviewed by F. Fitzpatrick, B. Lee, and B. Chapman.

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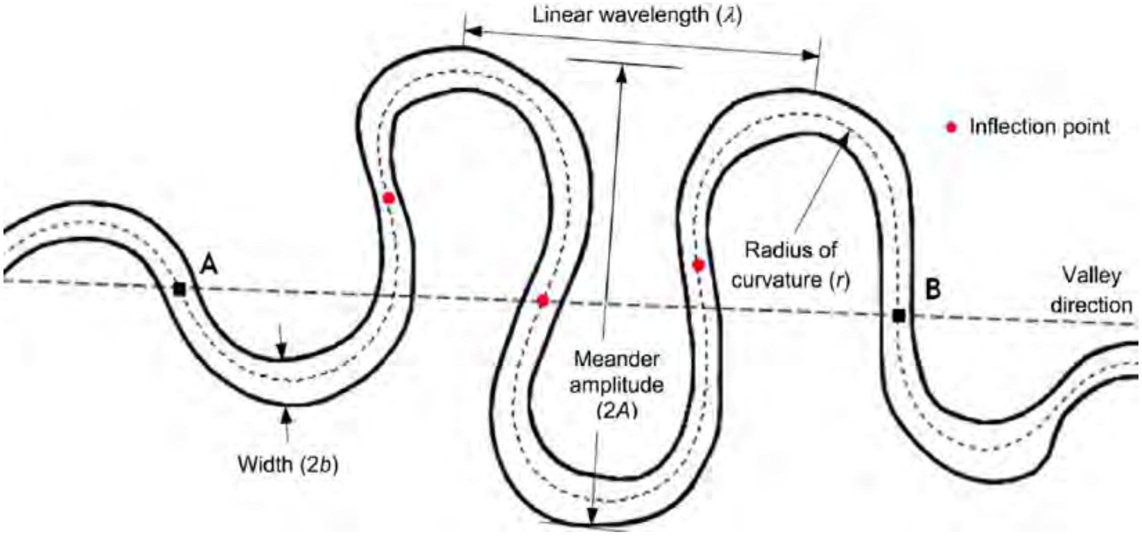

Fig. 2. Planform morphology showing meander wavelength, radius of curvature, and meander amplitude (from Guneralp and Marston (3)).

soil moisture and vegetation. Karst stream hydrology differs in that bedrock derived spring flow is typically perennial, whereas surficial spring flow and runoff may be intermittent. Surface draining water, and even stream baseflow, can be drawn off or even lost completely into cracks in the underlying bedrock, sometimes reappearing down valley. Groundwater inputs and outputs can vary, however, and streams may simply lose or gain a percentage of baseflow depending on the density and size of subterranean fissures and conduits within the underlying bedrock (2).

Although unique locally, the driftless and karst geologies of the region are not unique to the Driftless Area. Large regions of the continental United States, northern Europe and Asia have never been glaciated and have rolling hill and plateau country with silt-dominated loess soils. Karst geology is also common, being found on nearly every continent. What makes the Driftless Area unique is that it is a distinct unglaciated area completely surrounded by glaciated terrain. Other unglaciated areas of the world offer opportunities for comparison of changes in hydrology, erosion, deposition, and channel form caused by human disturbance (1, 4, 5).

Fluvial Geomorphology of Driftless Area Streams

Streams and rivers do work in the form of linear transport of water and sediment. Because of gravity, headwater streams have stored energy that is dissipated as the water moves downhill. In energy systems, there is a tendency to dissipate energy by doing work in the most efficient means possible. In a linear system like a stream or river, energy is dissipated in a sine wave in both plan view, as meanders, and in profile, as steps or riffles and pools. The relationship between work and stream form can be illustrated in the movement of a downhill skier. The efficient downhill skier reduces the slope of her descent by moving in a sine wave pattern. The energy of the skier is dissipated as work in the form of moving snow. At the outside of each turn, snow is moved. In a similar way, streams do work by moving sediment. Sediment is removed from banks where velocities are higher, and then it is deposited in lower velocity (and thus lower energy) areas such as the insides of meander bends. Alluvial streams are those that flow through alluvium, defined as gravel, sand, silt, and clay moved and deposited by streams and rivers. In a classic meandering alluvial channel, erosion from streambanks is deposited mostly within the first few inside bends, or point bars, downstream (Fig. 1). This bar formation creates hydraulic constriction and results in higher velocity on the opposite bank, which also erodes, and so on down the line. If bank erosion and deposition are happening at roughly the same rate, the channel size stays relatively constant, but the channel itself moves within its floodplain. The floodplain is thus destroyed and recreated at the same time. Given enough time, a river could occupy every point in the floodplain. Thus, stable streams and rivers are often described as being in a state of dynamic equilibrium, where the location of the stream in its floodplain may change over time but the channel size, vertical location, and meandering patterns remain the same. As discussed below, channels pushed to disequilibrium by large floods or direct action by humans (i.e., hillslope and gullying sediment inputs, ditching, vegetation changes) tend to move toward a state of equilibrium until a natural or human caused event pushes the system again toward disequilibrium (6–10).

One of the guiding principles of fluvial geomorphology is that channel size and form (cross section geometry or *channel geometry*) can be predicted from the dominant or most frequent precipitation or runoff events and the size and amount of sediment it carries (11). Alluvial systems, or systems whose geomorphology is built with and dependent upon running water, often have a channel size that accommodates flooding that occurs most frequently, for example during spring runoff. These are the floods that shape the channel and transport the bulk of the annual sediment load. The most commonly used stream cross-section measurement is the *bankfull width*, which is a measure of the channel width at the elevation where the flows just start go overbank and onto the floodplain. The bankfull width can be identified using one or a number of field indicators, including: sediment depositional features (e.g., point or midchannel bars), slope breaks, water marks, and vegetation. It should be noted that these are general statements and do not apply to all cases. Depending on the hydrologic characteristics of the watershed in question, bankfull flows may or may not be the most important flow that determines channel characteristics, and there are also systems from which bankfull stage is significantly different

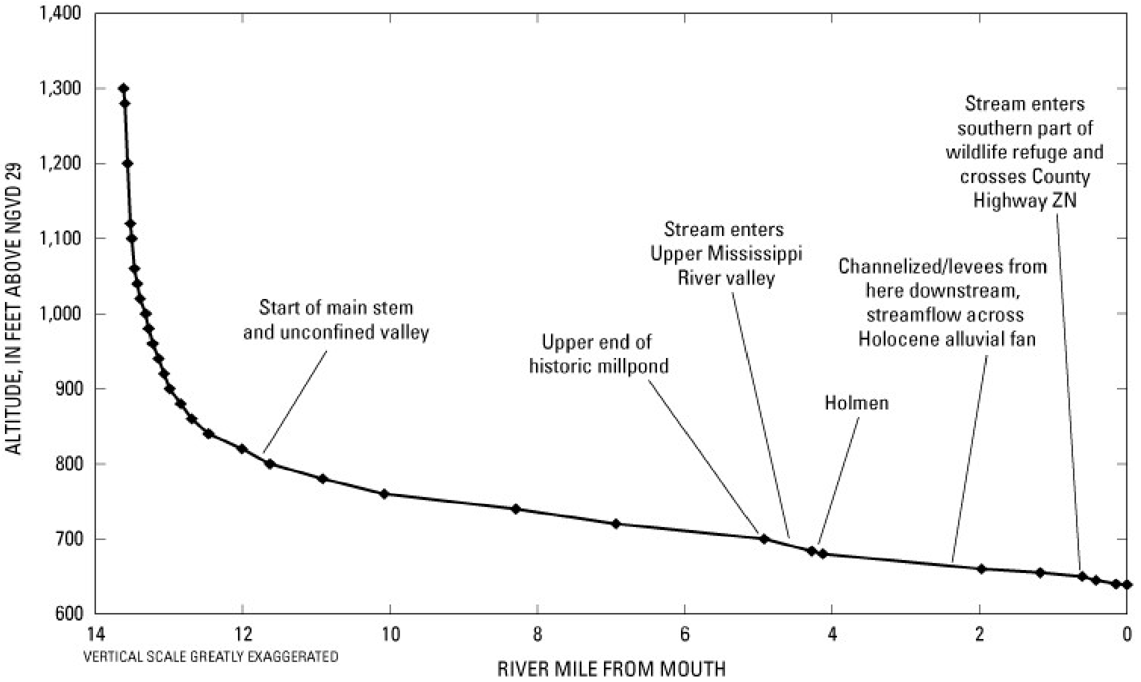

Fig. 3. Longitudinal profile of Halfway Creek, Wisconsin demonstrating the transition from steep headwaters to lower gradient mouth (from Fitzpatrick et al. (14)).

from commonly-referenced 1.5 - 2 year annual flood frequency, such as wetland streams and desert channels. Flood frequency and bankfull channel equilibrium are discussed in further detail in Dauwalter and Mitro (page 55) and Veilleux et al.(12)).

Alluvial channel planform geometry is frequently characterized by three main parameters: meander wavelength, meander amplitude, and radius of curvature (Fig. 2). *Meander wavelength* is the average down valley distance between the apices of meander bends on the same side of the stream, while *meander amplitude* describes the amplitude of meander bends off of the valley center. The average cross-valley distance between meander apices is termed the *radius of curvature*; it is simply the radius of a circle superimposed on a meander bend and is a measure of the tightness or degree of the meander. Planform geometry measurements can be converted into dimensionless ratios comparing bankfull channel width to each parameter. This allows comparisons to be made within or among watersheds. The degree of meandering and the shape of those meanders varies and is highly dependent on channel slope, surficial geologic controls, soils, and hydrology. Headwater streams in steeper, narrow valleys of the Driftless Area or in areas dominated by bedrock outcrops typically have narrow floodplains and low meander amplitude, whereas low gradient segments have higher meander amplitude.

Many streams in the Driftless Area start in steep headwater areas, transition through moderately steep reaches, finally converging with other river systems in lower gradient reaches (Fig. 3). This concave slope profile, or longitudinal profile, is explained by relating channel slope to the relative age of the stream network, and to controls on base level. To better explain this relationship and the current state of Driftless streams, we must first discuss the concept of *channel evolution* (13).

Channel evolution models are helpful in describing how stream and river channels change with age and do so by demonstrating channel form in stages (Fig. 4). Stream channels whose bed and banks are made up of soil, sand, gravel, and cobble respond to increased rate and volume of runoff in a predictable way. The Schumm channel evolution model involves first channel incision – often referred to as downcutting - followed by channel widening, but in areas where channel bed elevation is controlled, as in some streams of the Driftless Area, widening occurs first without incision. Streams are generally thought to be in equilibrium with their hydrology whereby channel size evolves to hold the most frequent floods, which in the Midwest are typically associated with spring and summer rainstorms. As discussed above, as part of the normal geomorphic process of streams, channels erode their outer banks where velocity and erosive power is higher and deposit sediment on the inside of meander bends where velocities are lower. This process thus naturally involves the entrainment and transport of sediment particles, both in suspension (fine silt and clay) and along the bed (sand, gravel, cobble). In a channel stabilized with vigorous vegetation growth on the banks, the increased runoff volume caused by agricultural or urban development first causes the less resistant channel bed to erode downward instead of the channel widening outward.

Downcutting of channel beds can also be caused by a change in base level in the channel or the receiving river. Such base level changes are often caused by channelization (ditching), whereby straightening decreases the stream distance between two points thereby increasing channel slope and erosive power. The erosive power of streams increases with depth. In an incised channel, because flows cannot spill overbank onto the floodplain and are confined in the incised channel, a feedback loop of increasing erosive power ensues, which causes the stream bed to incise further. In this Stage II of the channel evolution model, as the incising channel deepens, the erosive power of the channel continues to increase (Fig. 4). Driftless Area stream reaches that have either never incised or have not incised in many thousands of years occupy Stage III of the channel evolution model, when gravity eventually contributes

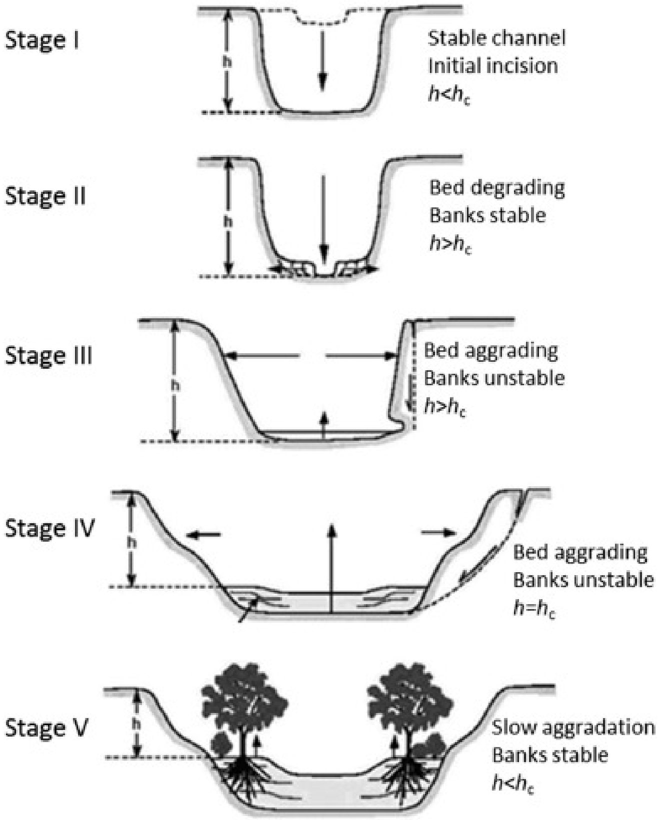

Fig. 4. The incised channel evolution model (from Schumm, et al. (10) and Simon (15)).

to bank failure and the stream begins to widen, or Stage IV when widening slows and the stream begins to stabilize. In Driftless Area streams, channel downcutting is limited in streams that have incised down to the relatively immobile late Holocene alluvial layer. This former streambed or valley bottom is armored with relatively erosion resistant limestone cobble. Channels in Stage III of the model tend to migrate laterally, sometimes dramatically, over this Holocene base layer that has never historically incised (Fig. 5).

Widening continues, which decreases the erosive power of the channel, and this, coupled with a winnowing of fines from the bed (armoring), results in the eventual stabilization of the channel at a new elevation (Stage IV). The channel forms a new floodplain at the lower elevation, whereas the former floodplain becomes what is now called a *terrace*. It should be noted that the model as described is simplistic, and that in reality, there are exceptions at each stage.

This model is more relevant to the headwater portions of Driftless Area streams where incision is an active process, versus in the wider valley bottoms where incision is limited. Larger magnitude flood peaks since settlement have caused erosion that also increased yields of both bedload and suspended sediment. Incision travels upstream, and the bed material eroded is transported downstream where it settles, either in the bed or as overbank or floodplain sedimentation, the latter leading to vertical accretion of floodplain sediments and increased floodplain elevation. The lower reaches on the longitudinal profile represent a relatively older state of the geologic process (Stage IV and V), whereas the actively incising and eroding reaches represent younger processes (Stage II and III; Fig. 4). Post settlement alluvial processes have been well studied in the Driftless Area, with up to 30-ft (9-m) of recorded sediment depths filling valleys near the Mississippi River (16–19). Sediment cores and exposed river banks often clearly show pre-settlement organic-rich floodplain soil buried by the lighter and less cohesive post-settlement sand and fine sediment (Fig. 6).

The channel evolution model is more relatable to geology if we express channel form in terms of geologic age. Headwater streams typically have smaller drainage areas, correspondingly lower water volumes, and armored beds where material is more difficult to entrain. In the Driftless Area, headwater channels can be ephemeral, with spring sources often present along valley sides at lower elevations. Occupying Stage II in the channel evolution model, headwater reaches periodically incise through active gullying during wetter climate periods. These channels are geologically young compared to downstream reaches, which typically have reduced slope and less erosive power.

Transitional reaches between headwaters and mouth tend to erode more sediment due to a combination of more concentrated runoff, moderate slope, erodible bed and banks, and a higher sinuosity than headwater channels (20). Because the erosive power is dependent on the slope and depth (and thus volume) of water moving through a given location, erosion is generally highest in these middle reaches, and these segments are sometimes known as *sediment source* reaches. The laterally eroding channel segments of these middle reaches occupy Stage II and III in the channel evolution model, but in the Driftless Area account for a relatively small percentage of the total sediment load compared to upland sources. Researchers have found that the large majority of sediment in Driftless Area streams comes from upland rill and sheet erosion as compared to tributary or gully erosion (21). Transported sediment historically has deposited in the downstream reaches where stream gradient was lower and the sediment transport capacity of the channel was exceeded; however, even after conservation practices are implemented legacy sediment continues to export from these systems (17).

Many Driftless Area streams have essentially moved a large percentage of their transportable sediment downstream, but most of this sediment remains stored in the system. Trimble (21) reported that nearly 50% of human induced sediment in Coon Creek was stored in downstream floodplains, while only seven percent of the eroded sediment had left the watershed. This has created a situation in which the lower reaches have become *apparently incised*, or have the appearance and character of incised channels, because vertical accretion of floodplain sediments has increased floodplain elevations (aka, floodplain aggradation) despite channel bed elevations remaining largely unchanged. These reaches can now be categorized as Stage III (historically incised and now laterally eroding), and in some cases Stage IV, of the channel evolution model. In both field and laboratory studies, Stage IV channels can continue to erode if there is a continual sediment supply feeding the formation of bars within the Stage IV channels. This means that in the Driftless Area, continued excess sediment supply from upstream can not only add to floodplain aggradation, it can also cause downstream channel bed aggradation and intensify lateral erosion in the post-settlement alluvium reaches.

Woltemade and Potter (22) described how the incised na-

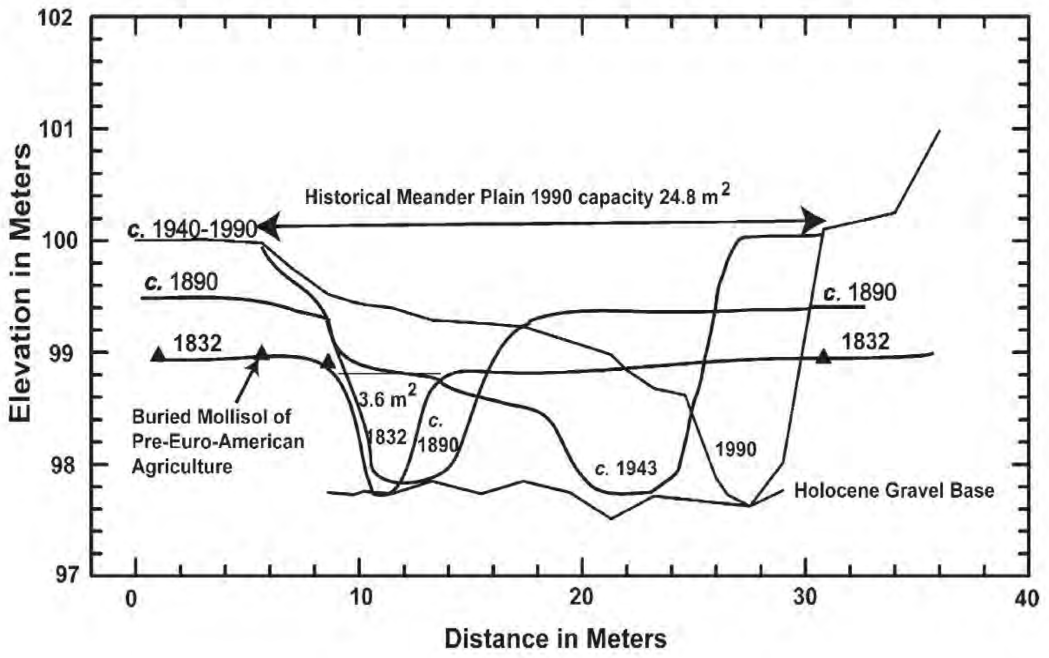

Fig. 5. Lateral channel migration and floodplain aggradation over a vertically stable Holocene gravel layer. The figure demonstrates post-settlement alluvial floodplain aggradation above the pre-settlement 1832 floodplain soils (Fig. 5 from Knox (16)).

ture of lower gradient downstream channel segments causes an increase in peak flood discharge and high shear stress. Under historical conditions, these reaches would have connected floodplains with lower peak floods and, therefore, lower shear stress. Deeply entrenched streams and meander belts in the Driftless Area can result in major channel changes, including avulsion and complete filling of abandoned channels on the scale of years to decades (23).

Channel Stability and Vegetation

The Driftless Area is dissected by extensive V-shaped valleys that formed after the pre-Illinoian glaciation nearly a million or more years ago. It is likely that the geomorphology of these streams changed very little between the end of the last glaciation (15,000 BP) and human settlement, when landuse practices began to change historical vegetation patterns. Stream form adjusts over time in response to dominant hydrologic conditions, foremost being the rate and volume of surface runoff (as opposed to infiltration). Surface runoff during and after rainfall and snowmelt is the principle process determining flood magnitude and the size of stream channels, but upland vegetation changes can drastically change the rate and volume of surface runoff (17, 24).

As stated previously, vegetation changes in the watershed impact hydrology and result in geomorphic instability, and conversely, it is well known that changes in stream geomorphology such as incision and erosion cause river and riparian ecosystem degradation worldwide (25–28). Most of the research on vegetation change in response to changes in channel morphology has focused on the important feedback between fluvial-geomorphic forms and processes and the ability of certain types of vegetation to become established, resist flow, and tolerate inundation (15, 29–31).

Channel stability associations with vegetation are often focused on lateral erosion, or Stage III of the channel evolution process. In reality, changes in stream flow and sediment load are the primary drivers of bank stability. Research has shown that mass failure of cohesive banks often occurs when a critical bank height is reached and can be independent of fluvial entrainment of bank materials (10, 24, 32–34). After a critical height is reached, then banks can slump from block or other failures. Widening is then completed by subsequent fluvial erosion of the failed materials, and once that material is removed, erosive power is reduced because the channel is wider and shallower (35).

Following glaciation up to the period of European settlement, Driftless Area vegetation consisted of tallgrass prairie and bur oak *Quercus macrocarpa*-savanna on ridgetops and drier plateaus, maple-basswood *Acer-Tilia spp.* and oak *Quercus spp.* forest on wetter or north facing slopes, and wet prairies and marshes along rivers and floodplains. Some watersheds, like the Kickapoo River, were more forested than others, and there was generally more prairie and savannah south of the Wisconsin River. At the time of the first government land surveys, the Platte River watershed was approximately 70% forested and 30% prairie, with shrub thicket and forests in narrow divides and higher relief areas. Prairie was restricted primarily to the broader ridge tops or plateaus, which were unfavorable sites for trees due to thin soils and shallow bedrock, rapid drainage, and desiccating winds; all conditions conducive to wildfires. Natural fire is essential for sustaining the ecological processes of prairies, and overall likely created a patchwork of various vegetation successional states within these broad patterns depending on natural landforms and fire breaks such as large rivers (17, 36, 37). In the absence of fire or disturbances such as grazing, succession of riparian vegetation generally follows a grass/forbs to willows/alders *Salix/Alnus spp.* to mature trees (box elder *A. negundo*, etc). Second and old growth trees follow suit, with flood tolerant trees persisting long term, such as silver maple *A. saccharum*, cottonwood *Populus spp.*, black willow *S. nigra*, swamp white oak *Q. bicolor*, bur oak, and others.

Fig. 6. An exposed eroding river bank on Mill Creek in southeastern Minnesota showing a pre-settlement floodplain soil layer overlain by the lighter and less cohesive post-settlement sand and fine alluvium (Credit: M. Melchior).

Post settlement agricultural development after 1850 included widespread conversion of forest cover to pasture, and conversion of plateau prairies to row crop corn (17). Research has shown that undisturbed prairie and forest cover yields very little overland flow (runoff) during precipitation events, particularly under drier conditions when soil infiltration capacity is high. Conversely, row crop agriculture and pasture has been shown to increase runoff, thereby increasing peak flows as much as five times over pre-settlement vegetation conditions (38–41).

Increased hillslope erosion during rainstorms caused by changes in vegetation resulted in significant loss of farmland and in some cases buried settlements or entire towns, as in the infamous case of Beaver, Minnesota (42). In the Platte River system, Knox (18) found that vegetation removal and soil changes caused by agriculture resulted in peak flows three times or more as high as those during pre-settlement. Knox generally found that historically, when vegetation cover was low due to drought or human disturbance, peak runoff and sediment yield increased. As discussed above, these increased flows caused an increase in yield of both bedload and suspended sediment, resulting in varying levels of post-settlement alluvial deposition (18, 19, 43, 44). The shape of the valley also contributes to aggradation levels, with floodplains in wider valleys having more aggradation than narrow valleys due to comparably decreased ability to move sediment particles (4, 22). Using General Land Office notes, sediment coring, and carbon dating of wood in depositional features, paleohydrologists have determined that pre-settlement channels in the Platteville and other Driftless Area stream systems were found to be significantly smaller in the headwater and middle reaches, but larger in the downstream reaches when compared to present-day conditions. The latter is thought to be a result of sediment load overwhelming channels and causing narrowing (17, 18).

Modern Riparian Vegetation Management. There is a common misconception in the Midwest that trees cause erosion and that grasses are better at stabilizing banks. The belief in this generalization has been influenced by a number of factors, including historical riparian management practices that combine habitat improvement with necessary bank clearing to facilitate habitat work, a desire to manage livestock in ways that allow for water access, and recreational fishing, predominantly by fly-casting anglers. The idea that trees cause erosion is partly based on a limited number of published works claiming that forested streams are generally wider and more shallow than streams with grass as the dominant riparian vegetation (45). It should be noted again that historical vegetation mapping suggests that riparian forests in sections of the Driftless Area may have been rare or at least intermittent, and that riparian zones were largely wet prairie or wetland derived. The factors listed above, combined with the desire for historical reference vegetation conditions has resulted in widespread removal of woody riparian vegetation in favor of grasses and forbs.

The scientific truth is that the effect of riparian vegetation on stream stability is much more complex than can be explained with a sweeping generalization. Although it is well understood that vegetation is correlated to geomorphic stability (28, 39, 46), there is limited supporting data to support either the generalization that grass is superior to trees in stabilizing streambanks or that trees and large wood recruited to the stream cause erosion. A few studies have addressed the issue, either directly or indirectly.

Vegetation and Streambank Erosion. It is generally accepted that both grassy and woody vegetation can improve soil and bank stability. Bank stability is influenced by bank height and slope. However, Simon, et al. (24) also demonstrated that soil water pore pressure is one of the most important factors in contributing to cohesion of bank sediments and, thus, to streambank erosion, but this research did not take into account the mitigating effects of vegetation such as interception, tran-

Fig. 7. Tree root mass is concentrated typically within the upper 3-ft (1-m) of soil, but riverine species can form dense root masses parallel to stream flow (Credit: M. Melchior).

spiration, evaporation, and storage. It is extremely important to consider that all vegetation has an upper limit with regard to the amount of stabilization that can be imparted. The majority of stabilizing roots in grass plants, both native and non-native, are within the first 1-ft (0.3-m) of soil, and density decreases below. Thus, in small streams with bank heights less than 1 to 2-ft (0.3 to 0.6-m), grasses can contribute to bank stability.

Tree roots can extend several feet (>1-m) into the soil, but most riparian and flood tolerant trees such as silver maple, red maple *A. rubrum*, and various willow species have their densest roots within 3-ft (1-m) of the ground surface. Grasses do not train their roots along river banks, but woody vegetation, particularly longer-lived trees, will grow roots parallel to shorelines, thus imparting additional bank stability (Fig. 7). Stability is provided by the fibrous roots binding soil and is complemented by the stability imparted by the structure of the roots themselves. When grass lined banks erode, the grass plants fall in and are typically washed away, whereas bank erosion near trees is more noticeable. Falling trees take soil with them and create hydraulic conditions that sometimes result in bank scour near eddies or turbulence caused by the bole in contact with flowing water. When bank heights exceed 3-ft (0.9-m) and beyond the depth of tree roots, undercutting can occur. Conversely, in banks under 3-ft (<0.9-m) in height, the bank stability provided by black willow and other tree willows can withstand extremely high shear stresses, can provide essentially erosion-proof banks, and in small streams can limit channel incision.

It is important to recognize that different types of grasses provide higher root densities and depths than others, as do some tree species. Similarly, primary colonizing trees such as boxelder or black walnut *Juglans nigra* do not provide dense root systems comparable to willow or cottonwood species. The role of canopy shading should also be quantified when considering the stabilizing effects of vegetation. Larger trees have larger root systems, but mature second and old growth forests can have relatively bare understories. Primary growth or early second growth forests can still maintain dense riparian shrub systems, depending on the width of the stream and the amount of sunlight reaching the banks.

Previous Studies. Several studies have compared stream channel characteristics between sites that have forested versus grass riparian vegetation. Zimmerman, et al. (47) reported that vegetative characteristics influenced mean width of riffle-pool and plane bed channels in Vermont, when the drainage area was less than 5-mi^2 (13-km^2), with forested channels being wider than grass-lined channels.

Trimble (45) originally examined the physical attributes of four reach pairs on Coon Creek in southwest Wisconsin. Based on measurements of bankfull width, base-flow width, base-flow cross-sectional area, average base-flow depth, and channel width-to-depth ratios, he concluded that riparian forests significantly affect the channel shape and bank and channel erosion. Trimble indicated that forested reaches are wider and may contribute significant amounts of sediment downstream.

Several items should be noted about the Trimble (45) publication. The author directly related sediment storage to channel cross-sectional area but does not fully explain how. He also assumed that the channels became larger with riparian forestation, rather than the reverse, in which grass-lined streams became narrower after deforestation. Rather than comparing bankfull widths, the author compared base flow width which is not a reliable indicator of geomorphic channel size and can instead be influenced greatly by local sediment deposition and recent flows. The author's analysis correlates base flow width with vegetation type, but then immediately labels forest cover as a causative agent worse than cattle grazing. There is little or no mention of the other possible causative factors, such as increased runoff from agricultural fields. There is also no information given on how the channel measurements were selected or measured, or how parameters such as bankfull width were measured. The author also drew conclusions based on a relatively few measurements (i.e., low sample number). Trimble asserts that this finding should be considered in current stream bank protection and restoration projects and plans, and, like other authors who have reported similar results, inappropriately made the claim that if grassy areas are allowed to return to a woody successional state then the streams would release a large volume of sediment. This is a generalization with many confounding variables that would determine the actual outcome.

In response to Trimble (45), Montgomery (48) pointed out that there are a number of factors that are important in assessing the most appropriate riparian cover for a given stream including: the interplay of sediment supply, size, and lithology; the magnitude and frequency of water discharge; the nature of bank materials; the type of vegetation on the banks; and the effect of obstructions such as large wood. Montgomery acknowledges the salient points that Trimble raises, yet strongly advises putting this information in context, such as considering all interacting factors instead of making gross generalizations, and erring on the side of managing for more rather than fewer forests.

Horwitz, et al. (49) examined forested and unforested riparian zones in Piedmont streams and looked for correlations between riparian vegetation and fish abundance. The authors concluded that the forested reaches were usually wider than unforested reaches, but that there was no significant difference between total numbers of fish per length of stream.

A paper that is frequently cited as justification for favoring grasses over trees is the Lyons, et al. (39) review of published literature addressing the differences in grass versus tree riparian management. It is important to note that this paper does not include empirical data collection or analysis, but is a review paper. Grassed versus forested riparian cover is reviewed in relation to specific stream characteristics including: bank and channel habitat, water quality and quantity, and biota. They conclude that in certain areas of the country, grassed banks may better achieve specific management goals. They caution against removal of existing forests but encourage land managers to carefully investigate all the options before choosing a management strategy. The paper is a good source for citations, but readers should be cautioned that the paper itself makes several generalizations or repeats generalizations made by other authors (not atypical of a review paper).

Murgatroyd and Ternan (50) found afforested British streams to be wider, while Stott (51) the opposite to be true. Anderson, et al. (52) showed larger forested streams were generally narrower than non-forested streams of the same watershed area, while streams in watersheds less than 3.9-mi^2 (10-km^2) showed forested streams being wider than non-forested streams. They include in their analysis previous studies by Davies-Colley (53) and Hession, et al. (54) that showed the same trend in small streams. In similar log-log plots, contrastingly, the Anderson, et al. (52) analysis of Hey and Thorne (55), Soar (56) and Simon and Collison (57) data showed that thickly vegetated forested streams were narrower than thinly forested streams. This study only examined stable stream systems, and the study analysis included a variable amount of potentially controlling variables such as vegetation type, coverage or density, substrate characteristics, and large wood loading. There is not enough detail in the study or base studies to correlate stem density or type of vegetation to channel width or to determine the influence of other geomorphic drivers.

Drawing Management Conclusions. One of the great dangers of applying scientific study results to management is mistaking association for causation. The authors of the above papers all point out the limitations of their data, but those limitations are not fully understood by the general public or are often ignored when discussing conclusions. Clearly, there is variability in the data, and the studies cited do not fully examine the geomorphic drivers or sedimentation history that may be at work in each system. It is thus inappropriate to attribute bank stability simply to the type of vegetation cover grown in the riparian zone within the past 30-50 years. It may be appropriate to say that grass-lined channels with low bank heights may be more stable depending on the slope, planform geometry, hydraulics, hydrology, soil makeup of the channel, and other factors.

Implications for Future Assessment. Generalizations regarding the geomorphic response of forested versus grassed riparian areas are difficult to make for Driftless Area streams that have been managed (habitat improvement, or restoration). This is because most Driftless Area habitat management efforts involve use of hard stabilization of at least the streambank toe to improve stability. In such cases, lateral bank erosion is arrested and no comparisons can be made regarding the effectiveness of established grasses versus trees alone. Future projects that compare riparian vegetation with stream stability need to include appropriate controls and examine confounding variables. Any conclusions made about woody versus grassy riparian areas should consider the actual woody and grassy species of interest, role of erosion in habitat formation, multiple life stages of focal fish species, the many benefits of both grass and wood riparian areas, temperature effects, sediment storage in stream and in floodplains, and most importantly, the actual geomorphic drivers of instability in each particular system.

Driftless Area streambank stabilization and habitat improvement and restoration strategies over the past half century were driven largely by trout stamp dollars and federal and state aid related to erosion reduction. Thus, projects were designed around limited funding, and hard stabilization became a critical element of projects. Large-scale earth-moving projects required to create floodplain connectivity were cost prohibitive, and large-scale upland landuse projects were limited to cooperative landowners. The history and relationship of landuse and ecology are covered in detail in Vondracek (page 8) and Trimble (58).

Conclusions

This section is concluded here with a note about complexity. Fluvial geomorphology is complex even in the most stable systems. Erosion, sediment transport, and depositional characteristics vary greatly with slope, valley shape, local geologic controls, channel capacity, and hydrology. In the Driftless Area, each of these variables can be in flux at any given time, further complicating matters. In order to predict a biological response such as fish abundance, we must first add to this soup the geomorphic influence of vegetation and human landuse, and the influence of climate on vegetation. Despite this complexity, humans have a tendency to look for patterns that explain what we are seeing and help point us toward solutions (59). Bank stability, as demonstrated above, is in itself a complex process dependent on many factors. It is thus inappropriate to attribute bank stability simply to the type of vegetation cover grown in the riparian zone within the past 30-50 years. Each stream system and each locality has its own idiosyncrasies, and geomorphic stability must be analyzed in each situation before applying solutions (see Melchior, page 87).

Thankfully, the geomorphology of the Driftless Area is one of the most well-studied in the world, and we can glean important insights from this body of research. Geomorphology can in this case help to recommend potential solutions. First, it is logical to conclude that improved upland land cover can increase infiltration and reduce peak flows and sediment inputs into tributary channels (60). This assumption comes with the understanding of the complexity of vegetation in the Driftless Area landscape, both past and present, and of geologic constraints. Second, stabilization of sediment source areas such as bank erosion in tributaries and incision in gullies will likely reduce sediment inputs. Last, restoration of floodplain connectivity and the attendant habitat benefits can likely be achieved through removal of stored post-settlement alluvium, but the efficacy of such treatments depends on concurrent reduction in upstream sediment sources.

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Stream Habitat Needs for Brook Trout and Brown Trout in the Driftless Area

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1. Several conceptual frameworks have been proposed to organize and describe fish habitat needs.
2. The five-component framework recognizes that stream trout populations are regulated by hydrology, water quality, physical habitat/geomorphology, connectivity, and biotic interactions and management of only one component will be ineffective if a different component limits the population.
3. The thermal niche of both Brook Trout *Salvelinus fontinalis* and Brown Trout *Salmo trutta* has been well described.
4. Selected physical habitat characteristics such as pool depths and adult cover, have a long history of being manipulated in the Driftless Area leading to increased abundance of adult trout.
5. Most blue-ribbon trout streams in the Driftless Area probably provide sufficient habitat for year-round needs (e.g., spawning, feeding, and disturbance refugia) for most Brook Trout and Brown Trout life stages.

Life History | Age and Growth | Fecundity | Habitat Use and Selection | Biotic Interactions | Scale | Riverscape | Movement

Most streams in the Driftless Area of southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois were degraded by decades of poor land use practices in the late 19th and early 20th centuries (1, 2) (see Vondracek, page 8). Early settlers to the region removed trees from steep hillsides and valley bottoms and plowed upland prairies to promote settlement and agriculture. Loss of protective vegetation led to substantial erosion of hillsides and ravines and subsequent sediment deposition in stream valleys and stream channels. Formerly narrow and deep stream channels with deep pools and gravel riffles were filled with sediment, resulting in wide, shallow channels with few or no pools and riffle areas inundated with fine sand or silt sediments (Melchior, page 20). Originally abundant Brook Trout *Salvelinus fontinalis* were lost from many streams and reduced in abundance in others (1). Subsequent stocking efforts using Brook Trout, Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* were deemed failures because instream habitat was considered insufficient to support them. Many studies were conducted between the 1930s and 1990s to identify important habitat needs of stream trout and to guide early fish habitat management practices (1, 3–5). More recently, public funding for restoring and enhancing these stream resources, principally for the salmonid fisheries they support, has increased. More than $2 million USD annually have been made available through federal (e.g., National Fish Habitat Partnerships) and state (e.g., Minnesota Outdoor Heritage Fund) sources.

To ensure stream restoration and enhancement activities include important habitat features for Brook Trout and Brown Trout, in this section we reviewed the biology of these species, as it pertains to the Driftless Area, and synthesize the habitat needs of both species as revealed from studies conducted in Driftless Area streams. **Our specific objectives were to: (1) summarize information on the basic biology of Brook Trout and Brown Trout in Driftless Area streams, (2) briefly review conceptual frameworks organizing fish habitat needs, (3) trace the historical evolution of studies designed to identify Brook Trout and Brown Trout habitat needs in the context of these conceptual frameworks, (4) review Brook Trout-Brown Trout interactions and (5) discuss lingering uncertainties in habitat management for these species.**

Brook Trout and Brown Trout Biology

Brook Trout. Brook Trout are native to North America, with their native range covering much of the northeastern portion of the continent. The Driftless Area lies at the western edge and a southern edge of their native range, which includes all of Wisconsin, eastern Minnesota, and northeastern Iowa (6). Brook Trout are also known as charr and are distinguished from trout such as Brown Trout and Rainbow Trout by the lack of black spots on their body. Brook Trout are characterized by small red spots surrounded by light blue halos scattered on their lateral sides with larger yellowish spots; yellowish vermiculate patterns on their dorsal surface and fin; and lower fins colored in various shades of orange-red with an anterior black border with a white edge. Their ventral surface can sometimes be a brilliant orange-red, particularly on mature males (Fig. 1).

Although mortality occurs throughout the Brook Trout life cycle, Brook Trout typically live to age 3 in streams and may be uncommon at older ages (7, 8). Brook Trout as old as 6 years have been observed in Driftless Area streams (M. G. Mitro, personal observation), and older ages can be attained in

Statement of Interest

All salmonid species, including Brook Trout and Brown Trout, are only native to the Northern Hemisphere. Brook Trout are the only salmonid native to the Driftless Area since the Pleistocene glaciation. Brown Trout are native to Europe, western Asia and northern Africa but all Brown Trout in North America originated from either Germany or Scotland. Both species provide excellent recreational fisheries in the Driftless Area that generate substantial economic and social benefits to the people of this region. Consequently, management of these species, especially habitat management, has important ecological, sociological, political, and economic implications.

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Fig. 1. A large mature male Brook Trout from a Driftless Area stream. Credit: J. Hoxmeier.

larger water bodies and colder environments. Annual survival rates are typically low and variable. McFadden (8) observed annual September-to-September survival rates of 0.21 (21%; age 0-1), 0.10 (age 1-2), 0.04 (age 2-3), and 0.09 (age 3-4) for Brook Trout in Lawrence Creek, Wisconsin (1953-1956). Hoxmeier, et al. (7) observed annual survival rates of 0.24 to 0.45 across ages 0 to 4 in six streams in southeastern Minnesota (2005-2010). The average October-to-October survival rate of age 1 and older Brook Trout in Ash Creek, Wisconsin was 0.16 (range: 0.10 to 0.28; 2004-2011; WDNR, unpublished data).

Brook Trout size-at-age will vary depending on stream size, productivity, thermal regime, and trout density. Brook Trout typically grow to lengths of 3 to 6-in (75 to 150-mm; all lengths reported as total length) in their first year (age 0), 6 to 10-in (150 to 250-mm) by their second year (age 1), and 8 to 13-in (200 to 330-mm) by their third year (age 2). Larger Brook Trout up to 18-in (460-mm) have been observed in Driftless Area streams but are uncommon.

Brook Trout spawn in autumn when water temperature declines and day length decreases. Spawning typically begins in early October and concludes in December, with peak spawning around mid-November (9)(WDNR, unpublished data). Brook Trout spawn in redds, in which eggs are buried in gravel in a nest-like pit in the stream. The gravel allows for stream flow to provide well-oxygenated water to the protected, developing eggs. If flows are insufficient and stream sediment load is high, redds may become buried by silt leading to egg suffocation and reproductive failure. Brook Trout may detect and spawn in areas with upwelling water, which helps keep eggs well oxygenated.

Male Brook Trout may mature as early as age 0 but typically begin spawning by age 1, whereas female Brook Trout may mature as early as age 1 but typically begin spawning by age 2. The average mature female Brook Trout may produce 300 to 400 eggs, with fecundity a function of size and varying from less than 100 eggs in a 5-in (125-mm) female to 1,200 eggs in a 14-in (350-mm) female (9). In a study in Lawrence Creek, Wisconsin, Brook Trout fecundity ranged from less than 100 eggs to about 700 in trout 4 to 10-in (100 to 250-mm) in length (8). In other Driftless Area streams, Brook Trout fecundity ranged from 130 to 1,645 eggs in trout 6 to 15-in (155 to 386-mm; WDNR, unpublished data).

Brown Trout. Brown Trout exhibit a wide range of colors, shapes, spot patterns and fin markings but most often the species is described as olive brown on its back shading to dark green on its sides and with a dark yellow or white belly (Fig. 2). Numerous red and black spots may be common across the body and on the dorsal and adipose fins.

Brown Trout in Driftless Area streams are short lived with few surviving past age 4 (10, 11). Brown Trout as old as 9 years have been observed in Wisconsin streams (M. G. Mitro, personal observation) and in southeast Minnesota, Brown Trout at least as old as age 7 have been identified (12) (D. J. Dieterman, personal observation). Annual survival rates in the 1980s and 1990s in Minnesota streams were estimated to be 0.59 (59%; age 0-1), 0.50 (age 1-2), 0.27 (age 2-3), 0.29 (age 3-4), 0.18 (age 4-5) (11). In a study in the mid-2000s, Brown Trout survival varied among seasons for age 0 and age 1-2 trout combined but did not vary among different reaches across an inter-connected group of streams. Survival across the three study streams was 0.26 for age 0 trout (September-May) and 0.36 to 0.46 (depending on year) for age 1 and 2 trout combined. Conversely, survival of age 3 and older trout varied by stream reach but not by season and was 0.28 to 0.63 depending on the reach the age 3 and older trout inhabited. Seasonal survival for age 0 and age 1-2 Brown Trout was always highest in winter and lowest during the spring-flood (age 0) or fall-spawning (age 1-2) seasons. The average apparent survival rate for adult Brown Trout in Timber Coulee Creek, Wisconsin, from 2004 to 2011 was 0.39 (M. G. Mitro, personal observation).

Like Brook Trout, Brown Trout size at age varies depending on stream size, productivity, thermal regime, food quantity and quality, and trout density. Brown Trout can grow to lengths of 3 to 7-in (75 to 175-mm) in their first year (age 0), 6 to 10-in (150 to 250-mm) in their second year (age 1), 9 to 13-in (225 to 330-mm) in their third year (age-2) and 11 to 14-in (280 to 350-mm) in their fourth year (age 3). Male Brown Trout may grow slightly faster than females in some streams (10).

Brown Trout spawn in the fall with the female digging a redd, where she will deposit her eggs after being attended by one to several males. Brown Trout in the Driftless Area spawn between the first week of September and the first week of December (13, 14). Both sexes are mature by age 2, thus spawning during their third fall, but a few males may be

Fig. 2. Driftless Area Brown Trout. Credit: R. Binder.

mature and spawn at age 1 (10). In a Norwegian stream, larger male and female Brown Trout attracted and successfully bred with larger mates (15). Bigger males mated with only slightly bigger females but not the reverse. A female only needed to be 5-mm longer than another female to be selected, but males needed to be longer than each other by about 50-mm. Most males and females mated with 1 to 3 partners each year, but some males mated with up to 13 to 15 partners in a single spawning season.

In the Driftless Area in southeast Minnesota, female Brown Trout ovaries can represent up to 15% of their body weight and egg size and number (i.e., fecundity) are a function of female size (10). Fecundity is about 250 eggs in an 8-in (200-mm) female, 400 eggs in a 10-in (250-mm) female, 550 eggs in a 12-in (300-mm) female and 700 in a 14-in (350-mm) female (10). In central Wisconsin streams, fecundity estimates were reported to be higher with a 14-in female estimated to produce 1,200 eggs (16). Females typically bury eggs between 6 and 10-in (15 and 25-cm) below the stream bottom with bigger females burying eggs deeper in the substrate. Brown Trout redds are usually placed in riffles or glides but may be placed in pools and runs if depth, velocity and substrate conditions are adequate. Using the Rosgen (17) classification system, Zimmer and Power (18) found that Brown Trout in the Credit River, Ontario preferred C-channel pools and riffles for redd placement and avoided B-channel runs and glides. Although neither preferred nor avoided, redds were also found in C-channel runs and glides and B-channel pools and riffles.

Following fertilization and deposition, egg development within the redd is strongly influenced by water temperature. In southeast Minnesota streams, eggs can hatch anywhere between mid-December and mid-March (13). After hatching, young trout continue to reside within the redd feeding on their yolk-sac and are termed alevins. After the yolk-sac is used up, young trout emerge from the redd, begin feeding on external foods and are called fry. In the Driftless Area, alevins have been found to emerge from the redd between late February and mid-April (13). Flooding during or shortly after emergence can have a large effect on abundance of that year-class in subsequent time periods.

Fish-Habitat Relationships

Ecology at its most basic level is the study of how organisms relate to each other and to their physical surroundings (i.e., habitat). Thus, assessing habitat needs of a species cannot be fully understood without first considering several conceptual frameworks proposed in ecology. Perhaps the most unifying concept underpinning most other concepts is hierarchical scale, or more specifically spatial, temporal, and organismal scales. Ecological scaling acknowledges that larger-scale items are composed of a number of smaller-scale items nested within each larger-scale item. For example, Adams (19) identified several organismal scales representing the species of interest and three of these are useful for assessing habitat needs of species: population, life stage, and individual (Fig. 3). The larger-scale population is composed of multiple smaller-scale life stages (e.g., eggs, juveniles, adults). Each life stage in turn is composed of several individual fish. To quantify and describe the population-scale, three variables have been proposed: recruitment, growth and mortality (20). To describe fish life stages, several variables have been proposed, but five describe most freshwater, non-migratory salmonids: egg stage (fertilized egg deposited in a redd), alevin stage (hatched egg remaining in a redd), fry stage (individual that has emerged from the redd to early summer, about mid-June), immature juvenile (about mid-June in their first summer to development of mature gonads) and mature adult.

To determine habitat needs or more broadly, that is to describe the ecological niche of species, biologists commonly use statistical procedures to associate habitat features to either individuals representing each life stage or to one of the three population-level variables. These habitat associations mapped in environmental space have been termed the "Hutchinsonian Niche" of a species (21, 22). Important habitat features in a species' niche that are uncommon in a stream are often considered to be limiting factors, an old ecological concept (23). This implies that simply increasing the amount of the

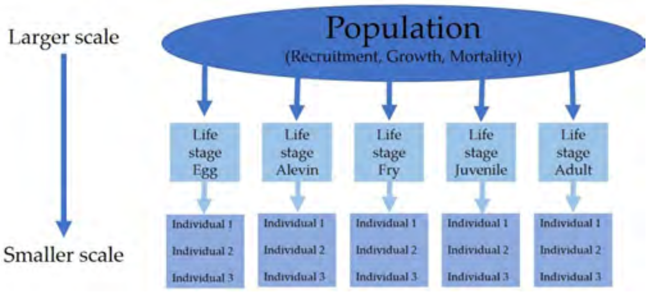

Fig. 3. Selected organismal scales of most freshwater salmonid species of importance to identifying habitat needs. Each larger scale item is composed of multiple smaller-scale items.

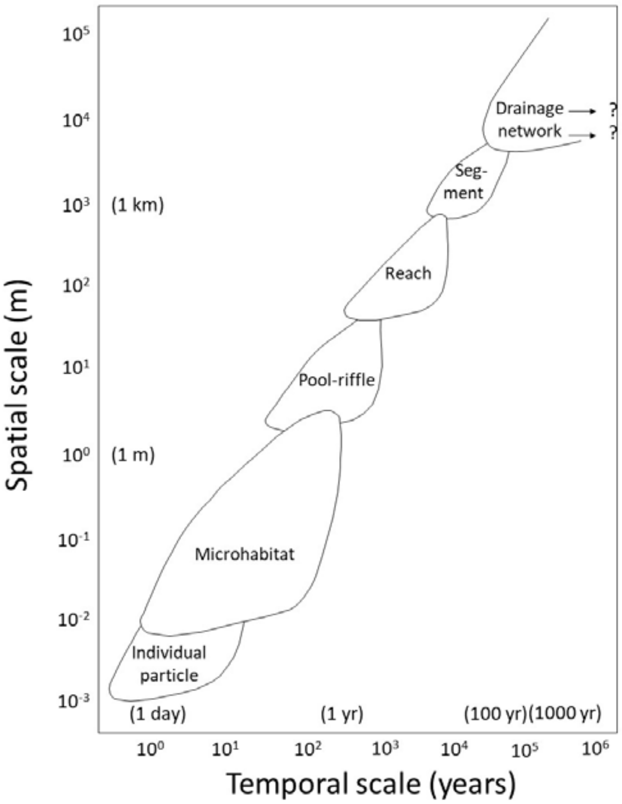

Fig. 4. Approximate spatial and temporal scales over which fish habitat changes in streams and rivers (from Allan (24)). The spatio-temporal linkage implies the time frame (e.g., minutes to hours to days to years) needed to detect meaningful changes at each spatial scale.

limiting factor will result in an increase in population abundance. However, understanding how those habitat features were created in the first place is equally important.

The creation and maintenance of physical habitat that stream fishes use is a result of distinct interactions between water and land over space and time at each habitat scale (24). For example, large spatial-scale features of streams, such as river valleys and floodplains, operate at long temporal scales, taking hundreds of years to form and change. Alternatively, very small-scale habitat features such as sand particles on the stream bed change every second (Fig. 4). In addition, larger spatio-temporal scale processes dictate the form and availability of smaller-scale habitat features that fish use as habitat (25). At very large spatio-temporal scales, processes such as minor glaciation or earthquakes can move entire stream channels at drainage basin or stream segment scales (Fig. 4; Table 1). These stream channel changes may then cause large inputs of sediment from erosion of new uplands or stream channel banks at the reach scale. Excess sediment can then fill pools or interstitial spaces in riffles at the pool-riffle scale. Microhabitats that fish use, such as deep water in pools are then lost at the microhabitat scale. **This illustrates a critical point of stream habitat management: habitat form follows ecological process.** If managers only address the form of habitat at one particular scale (e.g., re-digging out a pool at the pool-riffle scale that has been filled with sediment) without addressing the higher-scale processes that created and maintained that habitat (e.g., sediment movement in the stream channel from bank erosion at the reach-scale) then the habitat feature will return to its former degraded state following restoration actions.

Other scientists noted that the hierarchical scaling of stream habitat focused principally on the physical nature of habitat and failed to explicitly recognize other factors influencing stream biota. An alternative framework of five components was simultaneously proposed to organize the myriad factors influencing overall stream biological integrity: biotic interactions, flow regime, energy sources, water quality, and physical habitat (27). This framework was subsequently adapted to guide overall stream management and management of individual species with slight modifications (28, 29). The new five components were biotic interactions, hydrology, connectivity, water quality, and physical habitat/geomorphology (Fig. 5). Almost all variables regulating or limiting a fish population can be placed within one of these five components. Biotic interactions include predator-prey, competition and disease factors. Hydrology encompasses effects of floods and droughts whereas the water quality component includes dissolved oxygen, turbidity, agricultural chemicals, etc. The physical habitat/geomorphology component incorporates more traditional habitat features such as pool depths, water velocity, and fish cover as well as geomorphic processes that create, maintain or destroy these features. Energy sources, such as sunlight and microbial pathways in the original framework, was replaced by the broader connectivity component. The connectivity component retained the importance of energy movement in stream food webs but also incorporated the emerging importance of fish movements in streams as noted by Gowan, et al. (30). **An important implication of the five-component approach is that management emphasis on only one component, such as restoring physical habitat/geomorphology, may still fail to protect and enhance fish populations if other components, such as water quality or biotic interactions, are also limiting to a population.**

Schlosser and Angermeier (26) blended increasing knowledge of fish movements with landscape ecology and metapopulation concepts and proposed a dynamic landscape model for stream fish populations. Landscape ecology recognized that distinct habitat patches were present on the terrestrial landscape and that habitat patches differed in terms of size, juxtaposition and quality of habitat within them. The concept of metapopulations explicitly incorporated animal movements among these habitat patches. Schlosser and Angermeier (26) proposed that for fishes to complete their annual life cycle they may need to be able to move to different habitat patches in streams to complete critical life stages (Fig. 6). This included movement among habitat patches for spawning, feeding, and refugia from harsh conditions such as winter or drought. **An important implication is that if a single habitat patch does not provide all habitat features needed to complete the life cycle then movement corridors among patches will need to be identified and maintained.** This includes seasonal movements to and from spawning, feeding and winter habitat. **In addition, creation of new habitat features, as is common during instream restoration projects, will need to be cognizant of which part of the life cycle or life stage the**

Table 1. Events and associated processes controlling stream habitat at different spatiotemporal scales in the Driftless Area (adapted from Frissel, et al. (25)). Events in bold text are directly controlled by man.

System level	Linear spatial scale (m)	Evolutionary Events[a]	Developmental processes[b]	Time scale of persistence (years)
Drainage network	10^6-10^4	Glaciation; climatic shifts	Planation; denudation	1,000,000 to 100,000
Segment section	10^4-10^3	Minor glaciation; earthquakes; alluvial or colluvial valley infilling; **watershed land use changes**	Migration of bedrock nickpoints or channel head cuts; development of new first-order channels	10,000 to 1,000 (100 years due to poor landuse practices)
Reach section	10^3-10^2	Channel shifts; cutoffs; **channelization; damming by man; stream restoration activities; riparian land use practices**	Aggradation (from poor land use); degradation (large sediment storing structures (dams)); bank erosion; change in stream slope	100 to 10
Pool/riffle system	10^2-10^0	Bank failure; flood scour or deposition; **stream restoration activities**	Small-scale lateral erosion; elevational change in bed form; minor bedload sorting	10 to 1
Microhabitat	10^{-1}	Annual sediment delivery; organic matter transport; substrate scour	Seasonal depth, velocity changes; accumulation of fines; periphyton growth	1-yr to 1-mo

[a] Evolutionary events are extrinsic forces that create and destroy systems at that scale.

[b] Developmental processes are intrinsic and represent changes following an evolutionary event.

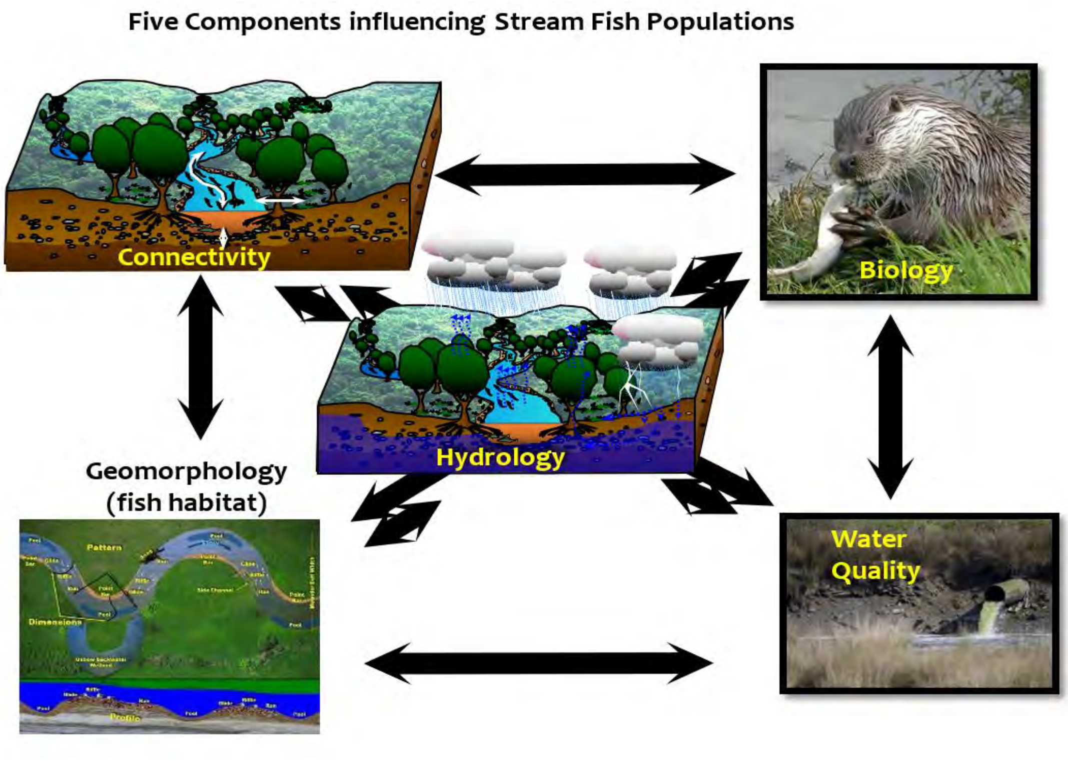

Fig. 5. Five components of streams influencing the health of streams and rivers and their associated fish populations (from L. Aadland, MNDNR).

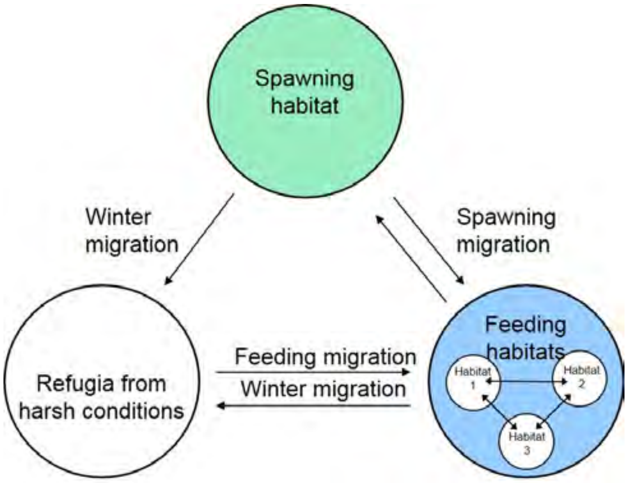

Fig. 6. Dynamic landscape model for stream fishes to complete their life cycle (modified from Schlosser and Angermeier (26) for fall-spawning salmonids).

restored habitat patch is providing habitat for and the distance between that restored habitat patch and other patches necessary for completion of other life stages. However, a corollary to this model is that fishes may not need to move if a single habitat patch fulfills the needs of all life-stages.

Finally, to provide a more holistic framework that incorporated all of the preceding concepts and models, Fausch, et al. (31) proposed the riverscape approach to guide management and conservation efforts for stream fishes. The riverscape approach expanded the dynamic landscape model to note, in part, that management and research efforts need to consider how fish movements among all heterogeneous habitat patches across the full extent of all spatial and temporal scales dictate the persistence and abundance of stream fishes in any particular habitat patch at a particular time. For example, their riverscape approach encouraged assessment of habitat requirements over longer-time scales than traditional within-season assessments (e.g., assessing summer habitat requirements of fishes because most fish sampling occurred during summer) and at much larger spatial scales than the 150 to 1,500-ft (50 to 500-m) sampling stations common to many previous fish-habitat studies. In particular, they noted the need to understand, sample, and manage fish populations at 0.5 to 50-mi (1 to 100-km) stream segment and 5 to 50-year scales. Collectively, each of these conceptual frameworks is important to describing the habitat requirements of stream fishes and incorporating that information in the implementation of stream habitat restoration projects (Table 2).

Brook Trout and Brown Trout Habitat Needs

Brook Trout. Brook Trout are a sportfish uniquely suited for living in Driftless Area streams and many aspects of the Hutchinsonian niche, especially the thermal niche, have been described. Brook Trout are typically associated with cold, clear streams, which are abundant across the karst topography of the Driftless Area (Splinter, page 5). Brook Trout can be found in small headwater streams or larger, higher-order streams with suitable thermal regimes and physical habitat that support the trout life cycle.

Brook Trout share similar thermal tolerance limits with Brown Trout and Rainbow Trout (32). Thermal tolerance limits can be defined by water temperatures in which trout have been observed over a defined duration of time. For example, the maximum 3-day mean temperature for a Wisconsin or Michigan stream in which Brook Trout or Brown Trout were found was 75.6°F (24.2°C) (32). This temperature was found for a stream by taking the highest 3-day moving average for every 3-day interval during the June-August period of record. The maximum n-day daily mean temperature decreased rapidly from 77.5 to 72.5°F (25.3 to 22.5°C) for exposure periods ranging from 1 to 14-days and declined more gradually from 71.8 to 69.8°F (22.1 to 21.0°C) for 21 to 63-day exposure periods (32). Brook Trout can survive short-term spikes in water temperature, such as those associated with surface runoff from precipitation events during summer, provided it does not exceed the upper incipient lethal temperature, which may vary depending on the acclimation temperature for the fish (33). But chronic exposure to elevated water temperatures can be limiting, with the limiting temperature decreasing as exposure time increases.

Within thermal tolerance limits for trout are a series of decreasing temperature ranges preferred for functions such as feeding and growth. Behnke (6) noted that species of the genus *Salvelinus*, which are often referred to as charr and include Brook Trout, can be distinguished from species of *Salmo* such as Brown Trout or species of *Oncorhynchus* such as Rainbow Trout by their adaptation to, and preference for, colder water within thermal tolerance limits. Charr, which also include Lake Trout *S. namaycush*, Bull Trout *S. confluentus*, Arctic Charr *S. alpinus*, and Dolly Varden *S. malma*, have an optimal temperature range of 10 to 14°C versus 14 to 18°C for trout and salmon. However, among the charr, Brook Trout are more tolerant of warmer water and are more comparable to Brown Trout and Rainbow Trout (6). Different studies have reported different thermal preferences for trout, which vary due to acclimation temperatures. In a summary of thermal preference data for fish, the optimum growth temperature was reported as 55, 57, and 61°F (13, 14, and 16.1°C) for Brook Trout and 50, 53.5, 55, and 60°F (10, 12, 12.8, and 15.5°C) for Brown Trout, and the final preference temperature was reported as 52, 57, 64, and 66.5°F (11.3, 14, 18, and 19.2°C) for Brook Trout and 54, 57.7, and 63.7°F (12.2, 14.3, and 17.6°C) for Brown Trout (34). The take-home messages on thermal conditions supporting Brook Trout and Brown Trout may therefore be: (1) acclimation temperature (i.e., prior temperature experience) is important in identifying thermal optima, preference, or tolerance; (2) each species may thrive under similar thermal conditions; and (3) factors other than temperature may be important in determining which species thrives best in a coldwater stream.

As outlined in Schlosser and Angermeier's dynamic landscape model and the broader riverscape approach, Brook Trout require different habitats during the various stages of their life history. These include habitat for spawning, habitat for rearing during early life stages, habitat for adults, and overwintering habitat. Habitat characteristics including physical habitat, water quality, and hydrology have been well described for Brook Trout. Brook Trout usually spawn in gravel riffle areas as described above and eggs develop overwinter until hatching sometime between mid-winter and early spring.

Brook Trout fry may emerge from spawning redds from January through April depending on when spawning occurred and conditions during incubation, such as temperature. Brook Trout fry need rearing habitat with low water velocity and protective cover during their first month or two following emergence from spawning redds. During spring, Brook Trout fry can often be seen along stream margins. Brook Trout are vulnerable during spring flood events that may wash young trout out of streams. Year-class abundance has been positively associated with flows lower than normal and negatively associated with flows higher than normal (35), which can result in regional trends in recruitment (36). Year-class defining flood events can occur any time following emergence through their first summer depending on the magnitude of the flood event. However, stage-based population models also show that Brook Trout population growth rates are sensitive to survival from late in their first growing season (age 0 in autumn) to early in their second growing season (age 1 in spring) (37, 38).

As Brook Trout grow and relocate to other stream areas, they begin to establish and defend territories. Defending a territory allows a fish to sequester resources such as access to food and protection from predators or strong flows. Defending a territory is advantageous to the fish when energy obtained by feeding exceeds energy expenditures in holding and defending the territory. Such habitat for adults becomes limiting in degraded streams, and stream habitat development projects have been used to increase adult trout biomass.

Stream habitat development (aka, habitat improvement, restoration) in Wisconsin streams is predicated on the idea that in some streams adequate spawning and rearing habitat and an abundant food supply would support more trout if more adult habitat were available. Hunt (39) demonstrated how stream habitat development could increase brook trout biomass, numbers, and production in a long-term project on Lawrence Creek, Wisconsin. The development project narrowed and deepened the stream channel, increased pool area and streambank cover for trout, and used paired bank covers and current deflectors to increase stream sinuosity. Stream habitat development today is a widely used approach by state management agencies and conservation organizations like Trout Unlimited to rehabilitate or restore degraded streams and to improve trout fisheries therein.

Overwintering habitat is also very important to Brook Trout and often overlooked in trout habitat evaluations (35). Winter is a dynamic and stressful time for fishes in streams, requiring changes in fish behavior to survive (40). Brook Trout winter habitat typically includes deeper stream areas with slower water velocity and greater overhead cover, with Brook Trout sometimes aggregating in pools near areas of groundwater discharge (41). Age 1 and older trout generally occupy positions in water deeper and faster compared to age 0 trout, the latter of which may use interstitial spaces along stream margins (41, 42).

At the largest spatial scales, such as the drainage network scale, the karst topography of soluble limestone and dolomite in the Driftless Area provide an abundance of coldwater springs feeding the smaller-scale productive coldwater stream segments and reaches that support Brook Trout. The density of Brook

Table 2. Selected conceptual frameworks of ecological importance to describing, organizing, quantifying and managing habitat requirements of stream fishes.

Concept	Key aspects	Implications
Ecological scaling (19, 24, 25)	Ecological scales are hierarchically nested; Populations are composed of distinct life cycle stages each of which are composed of individuals; Larger-scale items and processes influence smaller-scale processes; Space and time interact at each scale	Management of a habitat feature without regard for larger-scale processes creating and maintaining it will be ineffective
Hutchinsonian niche (21, 22)	The needs of any species can be organized and quantified along an axis and there are many axes that describe where and how a species lives; For example, there are axes for habitat needs (e.g., water depth, velocity), prey source needs (prey size, prey type), etc.	Various habitat features (e.g., water depth) can be quantified and plotted along axes to identify a fish's niche or habitat needs that might be created in habitat projects; A fish population may be at low abundance because one or two key axes are missing. These few axes are considered to be limiting the population and increasing those will result in a population increase
Five components of streams (27, 28)	Hydrology, water quality, connectivity, biotic interactions and physical habitat/ geomorphology regulate fish population abundance in streams	Management of only one component will be ineffective if another component limits the population
Dynamic landscape model (26)	Streams provide a heterogeneous mosaic of distinct habitat patches; Fish may need to move among patches to complete critical life cycle stages of recruitment, growth, and survival during harsh environmental conditions	If a single habitat patch doesn't provide all features to complete a life cycle, movement corridors among patches will need to be maintained; Stream restoration projects may need to provide habitat diversity to ensure all life cycle needs are met
Riverscape approach (31)	Synthesized previous conceptual models; Need to understand complete spatial and temporal arrangement of all habitat patches at all scales; Fish life history facets, from genetics to populations, may require 1 to 100-km stream segments and 5 to 50-years to complete	Stream restoration projects may need to be scattered across much larger spatial scales and may need to persist in a functional state for at least 50-years

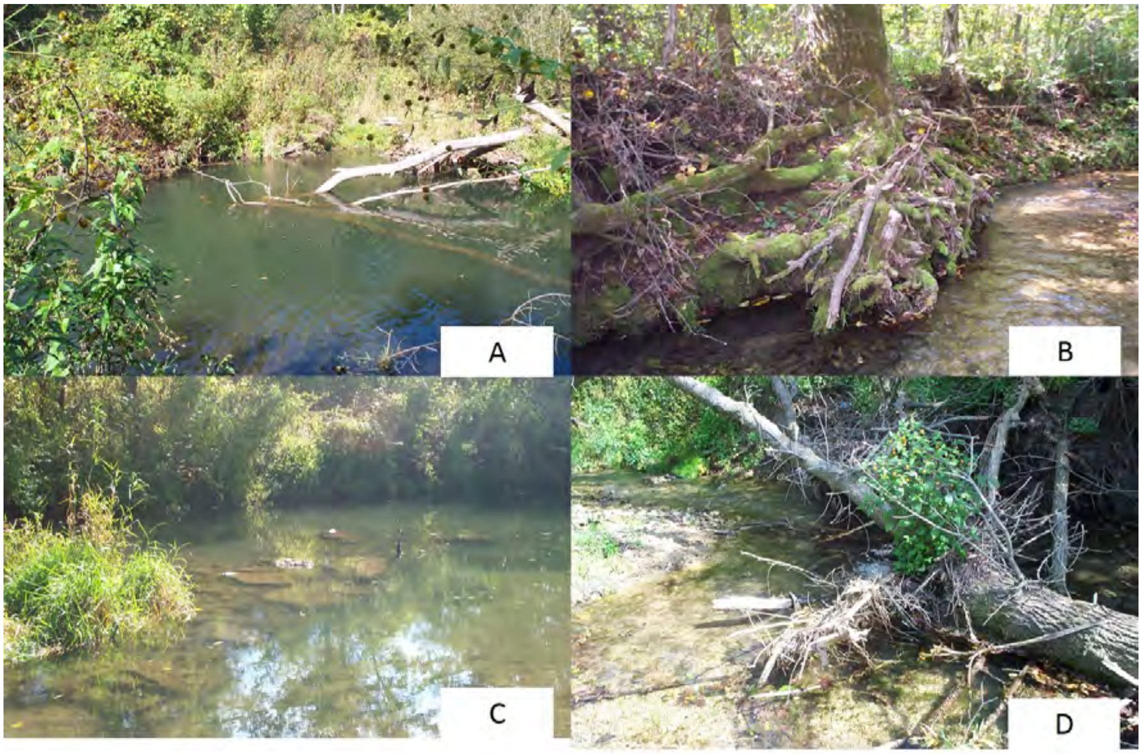

Fig. 7. Important instream cover for large Brown Trout in Driftless Area streams includes pools with depths exceeding 3-ft (A), overhead bank cover such as natural undercut banks with root wads (B), large instream rocks (C) and woody debris (D). Credit: D. Dieterman.

Trout that can be supported in these streams is positively related to stream discharge (7). Higher levels of baseflow support more physical habitat for trout, provided stream conditions have not been degraded. Changes in climate and land management over the past century have led to improvements in Driftless Area stream baseflow, which has coincided with improvements in trout fisheries. Juckem, et al. (43), in a study of the Kickapoo River Watershed in Wisconsin, showed that the timing of an increase in baseflow followed an increase in precipitation after 1970, with higher infiltration rates of precipitation, associated with less intensive agricultural land use, responsible for increasing the magnitude of the change in baseflow. A combination of agricultural lands protected in the Conservation Reserve Program and minimal impervious surfaces in a watershed support groundwater recharge and provide for cold water in Driftless Area streams (44, 45). As recently as the 1970s, Driftless Area streams in Wisconsin were largely devoid of wild trout populations (9, 46). Today, Driftless Area streams boast some of the most productive trout fisheries in the world (47), which can be attributed to a combination of improved land use, a favorable climate, a dedicated stream habitat development program, and improved genetics of trout stocked to restore extirpated populations (48).

Brown Trout. Although native to Europe, and extreme western Asia and northern Africa, Brown Trout have been introduced around the world and the subsequent literature on this species is vast. Because of this, many aspects of the Hutchinsonian niche of Brown Trout have been described previously but most by studies conducted outside of the Driftless Area. Much of this literature has been summarized in several review papers (33, 49–51). Most reviews presented niche information for selected Brown Trout life stages at microhabitat and pool/riffle spatio-temporal scales. These niche axes can be organized into four of the five stream components (Table 3). The oxy-thermal niche axes have been the most studied (33, 52) but other water quality and physical habitat/geomorphology parameters have been studied as well.

Because of the preponderance of information from other areas, relatively few niche axes have been directly examined in the Driftless Area. Wehrly, et al. (32) examined the thermal niche in upper Midwestern streams that included several Driftless Area streams. They developed thermal tolerance criteria for Brown Trout based on field observations. Most observations indicated a weekly thermal tolerance limit of about 75.2 to 77.9°F (24.0 to 25.5°C) and a daily maximum of 81.7°F (27.6°C). Grant (53) quantified the microhabitat feeding niche in one stream on the northern extent of the Driftless Area. Drift-feeding sites for 6 to 12-in (150 to 300-mm) Brown Trout were from 1 to 3-ft (30 to 100-cm) deep with column velocities from 0.6 to 0.9-ft/s (0.2 to 0.3-m/s). For larger Brown Trout (>12-in, or 300-mm) drift-feeding sites were 2 to 3-ft (60 to 100-cm) deep with velocities from 0.46 to 0.88-ft/s (0.15 to 0.29-m/s). Although not specifically quantifying Brown Trout niche axes, several other studies have examined Brown Trout associations with other parameters in the Driftless Area. These include biotic interactions of predation, diet and intra- and inter-specific interactions (54–57) (see later section in this review); water quality parameters including stream productivity (47), sediment (58), dissolved oxygen (13); and hydrology, principally flooding effects (13, 59). However, the physical habitat component has been perhaps the most studied aspect of the Brown Trout's niche in southeast Minnesota.

Many Driftless Area studies examined Brown Trout associations with physical habitat features at multiple spatial scales in large part because this component has been amenable to stream habitat management programs. Most studies quan-

Table 3. Summary of selected aspects of the Brown Trout niche at microhabitat and pool/riffle spatio-temporal scales based on published information outside of the Driftless Area. Data are organized by life stage for each of the five components of streams. Overall maximum-minimum values, representing niche boundaries, are presented here. See references in text for more detailed information.

		Life Stage				
Component	Parameter	Egg[1]	Alevin	Fry	Juvenile	Adult
Hydrology	Flooding	No winter floods, variously defined (e.g., >75th-percentile flows)	No flooding during spring emergence (flooding variously defined)	Intermediate flows best (variously defined)	undefined	Intermediate flows best (variously defined)
Water quality	Oxygen	≥7.0 mg/L	≥7.0 mg/L, ≥80% saturation	≥3 mg/L		
	Temperature (survival)	0-8°C	0-22°C	0-25°C	0-29°C	0-29°C
	Temperature (growth)			7-19°C		4-19.5°C
	pH			5.0-9.5	5.0-9.5	5.0-9.5
	Suspended sediment				≤59,800 mg/L (1 hr) ≤400 mg/L (1 week)	≤59,800 mg/L (1 hr) ≤400 mg/L (1 week)
Physical habitat	Depth	6-82 cm	6-82 cm	5-35 cm	14-122 cm (50-65 cm preferred)	≥60 cm
	Column velocity	11-80 cm/s		0-20 cm/s	0-70 cm/s	
	Focal velocity	0.03 cm/s		0.1-4 cm/s	<20 cm/s	<27 cm/s
	Substrate	8-128 mm	8-128 mm	10-90 mm	8-128 mm	
	Cover	Woody debris		≥15% stream surface area composed of small branches, cobble substrate, instream vegetation	≥15% stream surface area composed of small branches, cobble substrate, instream vegetation	Woody debris, instream rocks, instream vegetation, undercut banks, overhanging vegetation
Biotic interactions	Intra-cohort Brown Trout density			≤10 fry/m^2	≤1.5 juveniles/m^2	≤0.50/m^2

[1] Physical habitat for the egg stage describes characteristics associated with locations of spawning redds where eggs were deposited.

tified Brown Trout population responses, usually changes in abundance or biomass, following manipulation of fish cover, at pool/riffle and stream-reach scales (3, 4, 60, 61). Such manipulations have variously been termed instream habitat improvement, enhancement, or restoration. These studies showed positive increases in Brown Trout abundance or biomass following addition of overhead bank cover, current deflectors, instream rocks, or large wood (1, 3, 5). Many projects also observed increasing Brown Trout abundance in association with increasing pool depths (generally depths >2-ft, or 60-cm) following stream narrowing (1, 3). Authors speculated that abundance increases were due to increased natural recruitment and higher adult survival. Collectively, these studies demonstrated that adult cover was a primary factor limiting adult Brown Trout abundance in Driftless Area streams as concluded by Thorn, et al. (1). Based on these studies, Thorn, et al. (1) provided a table of recommended amounts of cover to be maintained or added in stream habitat projects at pool-riffle and stream reach scales (Table 4).

Several early studies (1970s-1990s) found that abundances of larger Brown Trout, those 14-in or longer (≥356-mm), did not respond to management actions, such as more restrictive angling regulations or instream habitat improvement. This led to recommendations to investigate habitat requirements of these larger individuals (62, 63). Studies were subsequently conducted that investigated summer and winter habitat needs of larger Brown Trout, but again at stream reach and pool/riffle scales (12, 59, 64). Important reach-scale features were larger streams (summer baseflows >15.2-ft^3/s, or 0.43-m^3/s) with abundant cover in pools. Important cover types were water depths >35.4-in (>90-cm), overhead bank cover, instream rocks and woody debris (Fig. 7). Cumulatively, all four cover types should be present in a pool and the latter three, (overhead bank cover, instream rocks, and woody debris) should exceed 10-m^2 of pool surface area. Dieterman, et al. (64) investigated the microhabitat niche of wintering large Brown Trout during daylight and found selection for depths from 23.9 to 46.9-in (60 to 119-cm) near woody debris and with water column velocities ≤4-in/s (≤10-cm/s). They also concluded that artificially placed habitat structures were used similarly to natural cover, such as undercut banks, in streams that had been rehabilitated.

At larger stream segment and drainage network scales, Brown Trout populations in Driftless Area streams have been associated with land use patterns, soil types and underlying geology. For example, higher Brown Trout abundance and improved trout growth have been associated with larger drainage basins with increasing percentages of forested lands and bedrock with greater porosity (65–70). More specifically, Blann (66) found that adult Brown Trout abundance was positively associated with the Jordan sandstone geologic layer, a layer known for its many springs. Conversely, stream segments with fewer adult Brown Trout have upstream drainage basins with more urban (>11%) or agricultural (69% on average)

Table 4. Recommended amounts (percent of total stream area except as indicated) of instream habitat in pools and stream reaches for juvenile and adult Brown Trout in the Driftless Area (adapted from Thorn (1))

Variable	Abbreviation	Recommended amount or range
Overhead bank cover (%)[a]	OBC	2-12
Instream rock cover (%)	IR	2-3
Debris cover (%)[b]	DEB	5
Total cover (%)[c]	TC	20
Length of OBC/thalweg length (%)	LOBC/T	20
Area of water deeper than 60 cm (%)	D60	25
Pool bank shade (%)	PBS	75
Pool length / reach length (%)	PL	75
Gradient (m/km)	GRAD	5-7
Velocity (cm/s)	VEL	15-25

[a] Includes undercut banks, artificial structures, overhanging grass. [b] Usually woody debris but can be other debris items (e.g., old farm machinery in the stream). [c] Sum of OBC, IR, DEB.

landscapes with soils with high runoff potential (45, 66). However, most Driftless Area studies have noted that large-scale drainage basin features usually explained only modest amounts of variation (<40%) for specific Brown Trout variables, that is, land use is only part of the picture. This is probably because the trout are responding to proximate instream habitat features, such as pool depth and cover (60, 66), rather than the larger-scale drainage basin features directly. However, as noted previously, larger-scale drainage network and stream segment processes are important regulators of proximate instream habitat features, patterns confirmed for Driftless Area watersheds in southeast Minnesota (69).

Almost all Driftless Area studies on Brown Trout habitat needs focused on physical habitat components with identification of cover as a primary limiting factor for adult life stages and at pool/riffle and stream-reach scales. However, individual pools and stream reaches only represent single habitat patches scattered across the entire stream system. Earlier we discussed the importance of also considering all the other habitat patches that exist throughout a riverscape and potential importance of fish movements among those patches to complete seasonal life cycle needs (e.g., seasonal movements to/from summer-feeding areas and overwintering habitats) or critical life stages (e.g., juvenile feeding areas in summer or fall spawning areas in headwater reaches). Although, no studies have examined the importance of a complete Driftless Area riverscape to Brown Trout populations, one study examined the importance of 3.5 or more mi (>6-km) of riverscape to juvenile and adult life stages in southeast Minnesota (59, 71). In that study, six geomorphically similar reaches were identified and represented six habitat patches differing in terms of habitat features. Three were shallow reaches with abundant riffle habitat for spawning and two of these reaches were headwater sites near spring inputs with colder summer water temperatures (59). The other three patches had more deep-water pool habitat with adult cover that could provide winter and spring-flood refugia. One of the tenets of the dynamic landscape model is that fishes may need to move seasonally among spawning, feeding, and refugia habitat patches to complete critical life stage needs. However, no large-scale seasonal movement patterns among these habitat patches were documented for either juvenile or adult Brown Trout suggesting that each habitat patch had adequate habitat to fulfill annual life cycle needs (i.e., each patch had habitat to support spawning, rearing, wintering and adequate growth). The primary pattern observed was an ontogenetic shift of smaller and younger trout in shallow habitat patches transitioning to adjacent patches with more deep pools as they grew into larger adults. In particular, one stream reach with extensive instream habitat improvement did not conform to earlier predictions that habitat improvement project areas produce excess individual trout that emigrate into adjacent reaches (i.e., increased fish production in adjacent reaches). Instead, smaller and younger Brown Trout (ages-0, -1, and -2) immigrated into the reach with habitat improvement as they grew older and increased trout abundance there. The authors speculated that as the trout grew in size, they sought deeper pool habitat with good cover, stream features provided by the habitat improvement project. More deep-water pool habitat and instream cover likely increased Brown Trout immigration and subsequent survival.

Brook Trout and Brown Trout Interactions

Competition. Biotic interactions is one of the five components that regulate the abundance of stream fishes and several studies have examined the interactions between Brook Trout and Brown Trout. The only salmonid to historically populate Driftless Area streams was the native Brook Trout. Following the 19th century introduction of nonnative Brown Trout to midwestern streams, the distribution of Brown Trout has increased and distribution of Brook Trout has decreased. It should be noted that Brown Trout were not simply added to streams populated by Brook Trout. Poor land use during the late 19th and early 20th centuries led to extirpation of trout from many Driftless Area streams (9, 46), and late 20th century improvements in land use and stream conditions were often followed by stocking of Brown Trout rather than Brook trout. The native ranges of Brook Trout and Brown Trout do not overlap, and these species do not naturally co-occur. Plots of Brown Trout versus Brook Trout catch per effort for adult trout surveyed in Wisconsin streams show that while co-occurring populations of Brook Trout and Brown Trout now exist, rarely do these species occur together at or near equal abundances (Fig. 8). Rather, streams tend to be dominated by one species or the other.

The mechanisms for change in species dominance are varied and may have included, following introduction of Brown Trout, biotic interactions that favored reproductive success or stage-specific survival of one trout species over another and net immigration or emigration (72). Such interactions between individuals of the same or different species, in which one or more individuals experience a net loss and none experience a net gain, is termed competition. For salmonid species that do not naturally co-occur, there is a greater likelihood that interspecific competition will affect one of the species (73). Stream habitat and environmental conditions also may affect the outcome of biotic interactions of Brook Trout and Brown Trout such that different trout species succeed in some streams and not in others (Johnson, page 70).

The evidence for interspecific competition between Brook Trout and Brown Trout is varied. The segregation of Brook

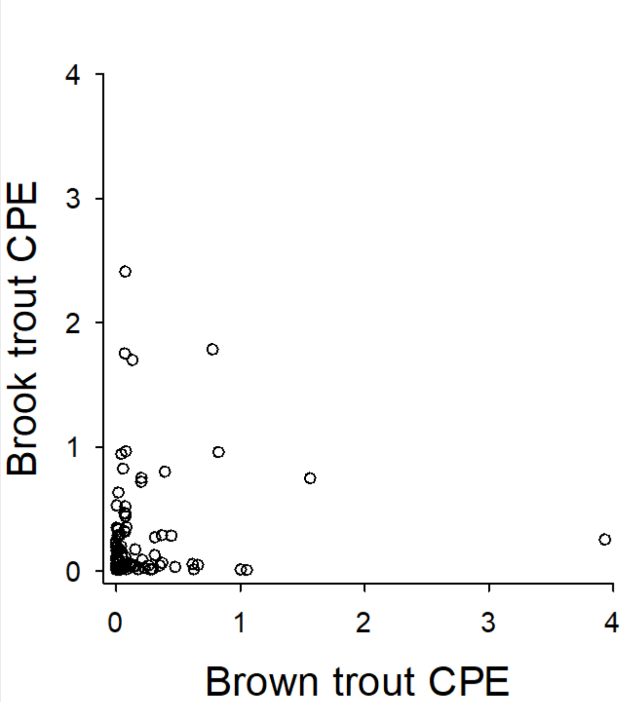

Fig. 8. Catch per effort (CPE) of Brown Trout versus Brook Trout in 345 Wisconsin streams in which only Brown Trout (n=126), only Brook Trout (n=134), or both Brown Trout and Brook Trout are present (n=85). Data from WDNR.

Trout and Brown Trout observed in streams (74) may be selective or interactive, with interactive segregation a result of interference competition. Interference competition may be observed when co-occurring species differ in resource use, in contrast to similar resource use when they are not co-occurring. Interference competition may occur when behavior of one individual interferes with the ability of another to acquire a resource. A good example is the territorial behavior by trout in streams that may result in interference competition in which the superior competitor occupies the most profitable stream habitat measured in terms of net energy gain while drift feeding (e.g., growth).

Observations of changes in abundance of one species following introduction of another can also serve as evidence of interspecific competition (75). A limitation of such observations, however, is the potential confounding of other factors such as predation of one species on another. Controlled experiments have been used to separate such factors and have provided evidence to show that Brown Trout can be competitively superior to Brook Trout. For example, Fausch and White (76) conducted field experiments in a Michigan stream to show that introduced Brown Trout can aggressively exclude Brook Trout from preferred resting places. Following release of competition from Brown Trout, Brook Trout shifted resting positions. Fausch and White (76) also noted that declines in Brook Trout populations while Brown Trout populations expanded may have been attributable to the combined effects of interspecific competition, predation on juvenile Brook Trout by Brown Trout, and a differential response to environmental factors. In laboratory studies of native Brook Trout and hatchery Brown Trout, DeWald and Wilzbach (77) found that Brown Trout presence resulted in changes in Brook Trout behavior. Brook Trout shifted location, initiated fewer aggressive interactions towards other Brook Trout, lost weight, and were more susceptible to disease in the presence of Brown Trout. The authors suggested that if these changes in behavior and growth rates extended to co-occurring populations in streams, they may help explain observed declines in native Brook Trout populations.

Fig. 9. A Brook Trout x Brown Trout hybrid from a Driftless Area stream often called a Tiger Trout.

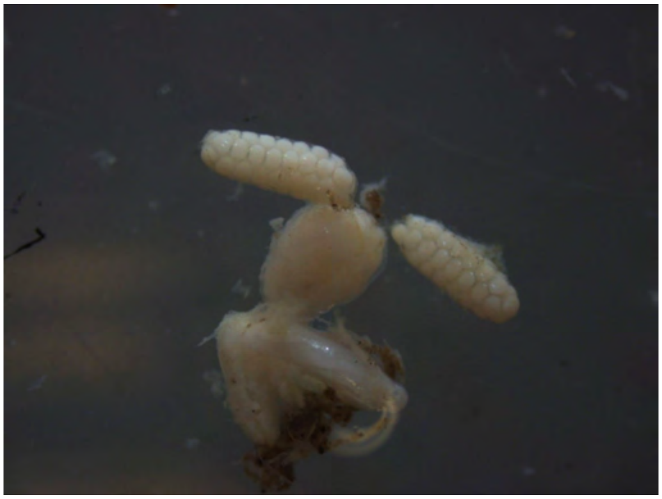

Fig. 10. A gill louse *Salmincola edwardsii* from a Brook Trout captured in Maple Creek, Fillmore County, Minnesota in 2008. Credit: J. Hoxmeier.

Competition for spawning habitat in streams may also be important in displacement of Brook Trout by Brown Trout. Brook Trout and Brown Trout spawning seasons consistently overlapped by two to four weeks in Valley Creek, a small Minnesota stream, during a three-year study in which Sorensen, et al. (78) observed attempts at hybridization (Fig. 9) and superimposition of spawning redds (i.e., building a new redd on top of an existing redd). About 10% of sexually active females were courted by males of both species. There was evidence of redd superimposition, particularly by later-spawning and larger Brown Trout. The authors concluded that reproductive interactions may be partially responsible for displacement of Brook Trout by Brown Trout because Brook Trout spawn earlier in the season, are smaller in size, and rarely survive long enough to spawn in subsequent years. A subsequent study by

Essington, et al. (79) found that frequency of superimposition of redds was greater than expected by chance, with females exhibiting a behavioral preference to spawn on existing redds. Grant, et al. (80) also showed that reproductive interactions between Brook Trout and Brown Trout may play a role in displacement of native Brook Trout by introduced Brown Trout.

Life history differences between Brook Trout and Brown Trout favor Brown Trout population growth. Although female Brown Trout begin to mature at age 2 (versus age 1 in Brook Trout), they live longer, grow larger and become more fecund than Brook Trout. Brown Trout commonly live to age 4 or 5 in streams and may live to age 9 or older (M. G. Mitro, personal observation) and commonly grow to 12 to 20-in (300 to 500-mm) in length (16). A 14-in (350-mm) Brown Trout can produce about 1,200 eggs, a 16-in (400-mm) Brown Trout can produce 1,500 eggs, and a 20-in (500-mm) Brown Trout can produce over 2,700 eggs. Over time, these demographic differences will favor population growth rates in Brown Trout over Brook Trout.

The infection of Brook Trout with the gill louse *Salmincola edwardsii* (Fig. 10) also favors Brown Trout in streams where the two trout species co-occur (56). *S. edwardsii* is an ectoparasitic copepod that infects the gills of Brook Trout but not Brown Trout. Brown Trout in Wisconsin have been observed to not have any parasites typically found in Brown Trout where they are native (R. White, personal communication). An epizootic of the *S. edwardsii* in Ash Creek, Wisconsin in 2012-2014, for example, led to a 77 to 89% decline in age 0 Brook Trout recruitment. Brown Trout are also present in Ash Creek and did not experience such a decline in age 0 recruitment. The inspection of Brook Trout for *S. edwardsii* in 283 streams across Wisconsin in 2013-2017 showed that the epizootic that occurred in Ash Creek was not common. However, *S. edwardsii* were found to be present in 79% of streams inspected with prevalence of infection (percent of fish infected) ranging from 0.4 to 100%, and maximum intensity of infection was 15 or more *S. edwardsii* in a Brook Trout for 34% of streams where the parasite was present. In the Driftless Area of southeast Minnesota, *S. edwardsii* were present on Brook Trout in 24 of 60 streams (40%) examined from 2006 to 2009 (81). Changing environmental conditions such as warming stream temperatures and drought conditions may favor the *S. edwardsii* life cycle and potentially lead to further epizootics and the potential extirpation of Brook Trout where Brown Trout co-occur (56).

Trout Habitat Needs in the Driftless Area: Lingering Uncertainties

For Brook Trout, there is a continuing need to determine if there are habitat features that could be incorporated into habitat development projects that may favor Brook Trout over Brown Trout when those species co-exist in the same stream. Although Hunt (39) documented an increase in Brook Trout following common stream habitat development techniques, such as narrowing and deepening a stream, Brown Trout were not present in his study stream, Lawrence Creek, Wisconsin (though some Rainbow Trout were present). Do habitats used by Brook Trout differ when they are the only salmonid species present versus when co-occurring with Brown Trout? Several studies have suggested that when co-occurring with Brown Trout, Brook Trout prefer headwater areas (74), but Hoxmeier and Dieterman (82) demonstrated that when Brown Trout are removed from larger downstream areas, Brook Trout from headwaters will emigrate and reproduce in the downstream reaches. In another study, Hoxmeier and Dieterman (83) documented a natural decrease in Brown Trout abundance coincident with an increase in Brook Trout in East Indian Creek, Minnesota. This suggests that some natural environmental changes may enhance Brook Trout abundance at the expense of Brown Trout. Identification of these environmental factors may help promote management efforts that benefit Brook Trout. Limited data from East Indian Creek suggested that baseflows increased and summer water temperatures decreased from the 1970s to the mid-2010s, but a more rigorous testing of these and other factors, including changing habitat features, is needed.

Although much is known about the habitat needs of Brook Trout and Brown Trout based mostly on studies outside the

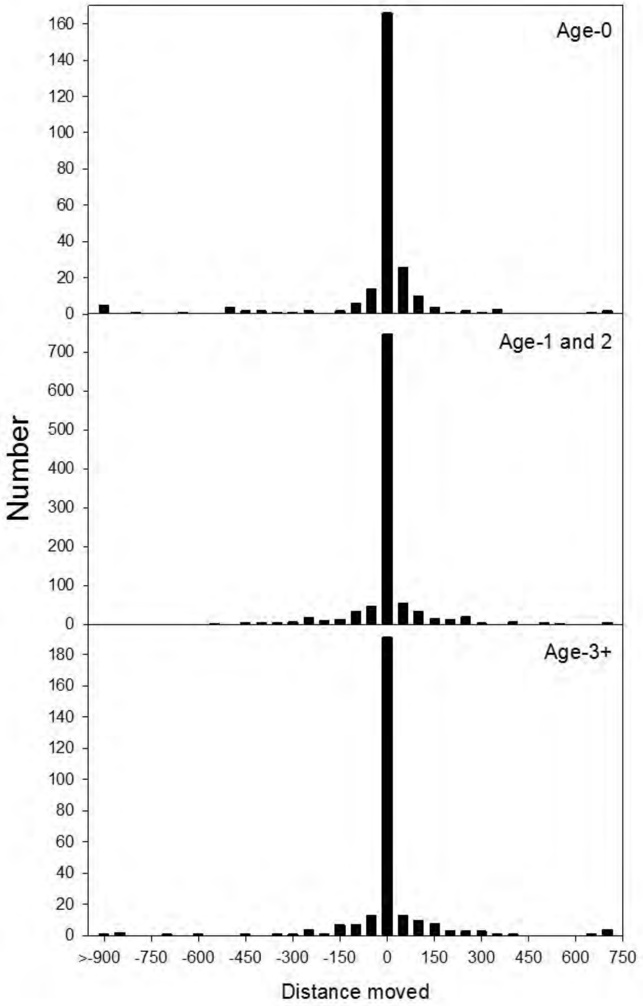

Fig. 11. Frequency of distance moved (in meters) by individual Brown Trout of three age groups in nine consecutive sampling events spaced three months apart from September 2006 to September 2008 in three inter-connected southeast Minnesota streams. Negative numbers are downstream movements. Similar movements were observed for Brook Trout (84).

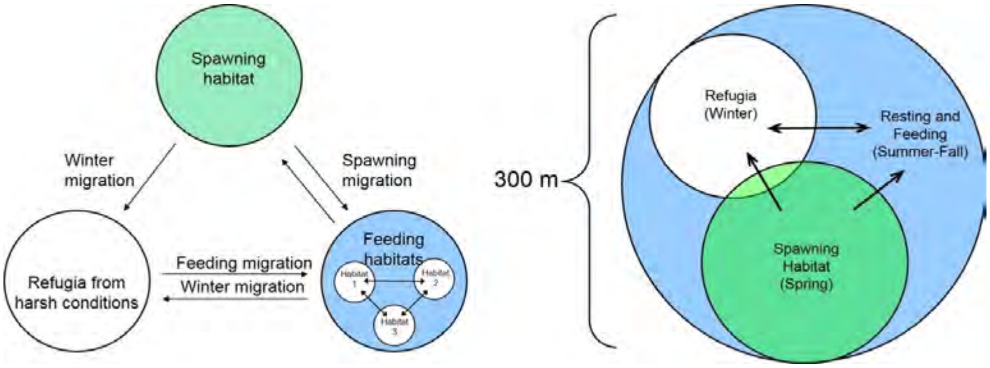

Fig. 12. Riverscape conceptual figures contrasting the need for fish movement in differing stream systems. The figure on the left is the traditional riverscape concept, emblematic of northeastern Wisconsin trout fisheries, where trout need to move to different stream reaches to fulfill key life history needs (e.g., spawning or overwintering habitat). The figure on the right likely exemplifies most Driftless Area streams where trout are able to fulfill all their habitat needs within a short stretch of stream (e.g., within one or two pool/riffle sequences).

Driftless Area, there are still several lingering questions that could influence the prioritization, placement, design and management of instream habitat. In particular, how does the full riverscape approach apply to trout management and research in the Driftless Area? Past management and research have confirmed that cover is often a limiting physical habitat feature in Driftless Area streams and Dieterman and Hoxmeier (59) demonstrated that improvement of such habitat in typical "blue ribbon" trout streams (i.e., streams with existing optimal water temperatures and dissolved oxygen levels for supporting wild trout) will fulfill most of the niche needs of juvenile and adult Brown Trout life stages. This is probably due to the abundance of groundwater springs to most streams which provide ample water flows with moderate, almost ideal thermal regimes for trout. Thus, when physical habitat conditions that fulfill the year-round needs of trout are present or enhanced in habitat improvement projects (e.g., deep pools with log jams for overwintering, gravel riffles for spawning, etc.), Driftless Area trout probably do not need to move much. Dieterman and Hoxmeier (59) and Hoxmeier and Dieterman (84) found that most juvenile and adult Brown Trout and Brook Trout stayed within one or two pool/riffle sequences (<900-ft, or <300-m) in Driftless Area streams in southeast Minnesota (Fig. 11). In contrast, trout in other stream systems, such as in northeastern Wisconsin, may need to move greater distances to find appropriate habitat conditions to fulfill life cycle needs (Fig. 12).

Less certain are other applications of the riverscape concept including application to some stream reaches with seasonally-poor habitat and importance for early life history stages and genetics. Some Driftless Area stream reaches have excellent trout fisheries at certain times of the year. Most often these reaches are at the most downstream end of streams with an abundance of sand and silt substrate and are believed to become thermally stressful during summer months (Fig. 13). Such reaches are also believed to provide a variety of abundant fish prey such as Creek Chub *Semotilus atromaculatus* and White Sucker *Catostomus commersonii*. Large adult trout are known to inhabit these reaches because angling for them can be excellent during some seasons and years. Knowing where, when and how long these larger adult trout inhabit these areas (and their movements to and from them) is less well known, making justification for, and design of, instream habitat projects less certain for these areas.

Fig. 13. A downstream reach of a Driftless Area stream in southeast Minnesota. These reaches often have abundant sand and silt substrate limiting trout spawning and often become thermally stressful during warm summers, yet can still provide excellent recreational fisheries in some seasons and years. The inset picture shows a 14-in Brown Trout caught at this site. Credit: D. Dieterman.

Dieterman and Hoxmeier (59) were unable to examine other aspects of a complete Driftless Area riverscape including dispersal of younger Brown Trout life stages (eggs, alevins, fry) and the larger spatial (>3.7-mi, or >6-km, they studied) and longer time periods (5 to 50-years; Dieterman and Hoxmeier's study was three years) recommended by Fausch, et al. (31). In particular, the importance of even a small number of fish moving throughout a riverscape may be important to aiding population recovery following disturbance or to maintaining genetic diversity (85). Although most Brook Trout and Brown Trout appeared to move little in the Driftless Area streams examined by Dieterman and Hoxmeier (59) (Fig. 11), a few individuals did move longer distances (>2,700-ft, or 900-m) and some disappeared entirely indicating that they either died or moved completely out of the 3.7-mi (6-km) study area. These few individual dispersers may play an important role in maintaining the genetic integrity of the broader trout population in the riverscape. Thus barriers, such as improperly designed road crossings or perched culverts (Fig. 14), could still be problematic.

Examination of habitat needs over longer time periods are important for identifying other key factors, such as hydrology, water quality, and biotic interactions, that may be limiting Brook Trout and Brown Trout in Driftless Area streams. For example, Mundahl (86), used a 25-year dataset for Brown Trout in a 610-ft (200-m) section of Gilmore Creek, a Driftless Area stream in Minnesota, to document that Brown Trout population dynamics were related to hydrology and biotic

Fig. 14. Perched culverts, such as this culvert on Trout Brook in Dakota County, Minnesota, may prohibit trout movements during most stream flow conditions, except large floods. Credit: D. Dieterman.

interactions, such as intraspecific competition. Implementation of such long-term studies is imperative but requires long-term commitments in resources (staff time and money) to maintain study integrity. Such long-term monitoring programs can help evaluate system resistance and resilience to rare events (e.g., floods, fish kills), time lagged responses, true changes in highly variable systems, and effects of management actions (87).

There is also lingering debate about the appropriateness of various stream restoration designs for bolstering Driftless Area trout populations and how long those artificially placed habitat structures will persist (or should persist). Much of the lingering debate is fueled by a poor understanding of stream restoration terminology and lack of robust long-term data to assess persistence of artificially-placed structures. In overly simple terms, the debate contrasts the use of traditional techniques of using rock to narrow streams and "stabilize" them in a permanent position versus using less rock and more geomorphic principles to design a geomorphically-stable stream channel (i.e., a channel that may move but that retains its width, depth, gradient, and meander pattern (Fig. 15; Melchior, page 20). The geomorphic approach is sometimes call natural channel design (NCD) and may include instream wood for additional fish cover. Even though several studies reviewed in this chapter noted the importance of instream wood as habitat for Brook Trout and Brown Trout, there continues to be debate about the importance of wood as fish cover in Driftless Area streams. In addition, many traditional habitat projects that used wood have been incorrectly labeled NCD, leading to suggestions that NCD projects do not provide cover for trout. The paucity of true NCD projects and the fact that this is a relatively new approach means that there have not been many comprehensive, long-term evaluations completed and certainly none that have simultaneously contrasted NCD with more traditional designs. Thus, the debate over these two broad approaches will likely continue until more data are collected.

Finally, there is a lack of verification of the importance of selected habitat features for large Brook Trout and Brown Trout. For example, several studies documented in this review identified important physical habitat aspects of the niche of large Brown Trout including the importance of deeper pools (>25-in, or >90-cm) with woody debris, instream rocks, and overhead bank cover. However, very few instream habitat projects have specifically incorporated these items in projects with a stated goal to increase large Brown Trout abundance. Implementation of a number of such projects is needed, in conjunction with adequate long-term monitoring, to verify the importance of these features to bolstering large trout abundance for anglers as has been documented for adult trout in several agency review reports (3).

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Fig. 15. Examples of two broad approaches to enhancing or restoring stream habitat. The figure on the left is a more traditional approach that uses a lot of rock to stabilize a stream channel and provide fish habitat (note the substantial amount of rock on both sides of the stream). The figure on the right represents a natural channel design approach that constructs a stable stream channel using geomorphology principles. Some natural channel design projects use woody debris, in addition to limited amounts of rock, for channel stabilization and fish cover (note the presence of root wads along the left bank in the photograph).

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Non-Game Species and Their Habitat Needs in the Driftless Area

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1. The Driftless Area has some of the richest species diversity of the Midwest...not combining habitat for other species utilizing the riparian corridor (than trout) is a missed opportunity.
2. Consider using the Nongame Wildlife Habitat Guide "Decision Matrix" to determine under what conditions the major non-game habitat features are most likely to provide benefits for various non-game species.
3. Incorporating non-game habitat at the same time that construction equipment is being used for trout/stream restoration projects is efficient and cost-effective.
4. The Nongame Wildlife Habitat Guide contains a detailed Monitoring Section. We strongly encourage you to monitor your projects to determine if adding these non-game habitat features is producing the desired results.
5. The Nongame Wildlife Habitat Guide contains more than 20 habitat features to consider for your project, and they are all ready to go in an NRCS practice design format.

Amphibians | Reptiles | Birds | Hibernaculum | Vertical Nesting Bank | Instream Structures | Riparian | Restoration

Fig. 1. The Driftless Area is a dissected landscape with ridges and valleys, farmed uplands and floodplains, and forested slopes. There is an active stream restoration community in the region.

The Driftless Area, located in the heart of the Upper Mississippi River basin, is a geographically distinct 24,000-mi^2 area primarily in southwestern Wisconsin and includes areas of southeastern Minnesota, northeastern Iowa and extreme northwestern Illinois. This area is interlaced with more than 1,200 streams (more than 6,000 river miles) that spring from the underlying limestone bedrock. This area includes very steep topography with elevations ranging from 603 to 1,719-ft. The peculiar terrain is due to its having escaped glaciation during the last glacial period (approximately 10,000 years ago).

The streams and riparian habitats of the Driftless Area suffer from a history of human disturbances. Land use practices have led to extensive erosion and subsequent sedimentation of the watersheds in this region. The steep topography of the region has exacerbated these human influences. Across the region, hundreds of miles of spring creeks have been inundated with soils and fine sediment, resulting in degraded water quality, increased stream temperatures, damage to aquatic habitat, and altered watershed hydrology (1–3). For over fifty years conservationist and conservation organizations have been working to improve Driftless Area streams by stabilizing streambanks and incorporating habitat for trout (4). Each year federal, state and county conservation agencies spend millions of dollars to stabilize streambanks and create habitat for trout (Fig. 1). However, past stream restoration projects in the upper Midwest have often failed to incorporate habitat for non-game species such as amphibians, birds, invertebrates, mammals and reptiles, primarily because of a lack of knowledge about those species' habitat needs. Developing habitat for other non-game species while construction equipment is being used for stream restoration projects is efficient and cost-effective. Not combining habitat for these species is a missed opportunity.

Having a better understanding of what kinds of nongame wildlife live in your project area and a basic understanding of their life history is necessary to create a better project. A good place to start gathering information on what nongame species would benefit from additional or improved habitats is by reviewing your states Wildlife Action Plan. All of the states in the Midwest have developed Wildlife Action Plans identifying natural communities and their associated Species of Greatest Conservation Need (SGCN) (low and/or declining populations that are in need of conservation action). From this you can generate a target species list for your region to help you refine your species list. Trout Unlimited has also

Statement of Interest

Incorporating habitat elements for non-game species into stream restoration projects can increase the reach of a project by benefiting a wider variety of species and, therefore, opening the doors to additional sources of project funding. We have found additional funding sources and partners for our projects by addressing the needs of other riparian critters early on in the project design.

This chapter was reviewed by Anonymous.

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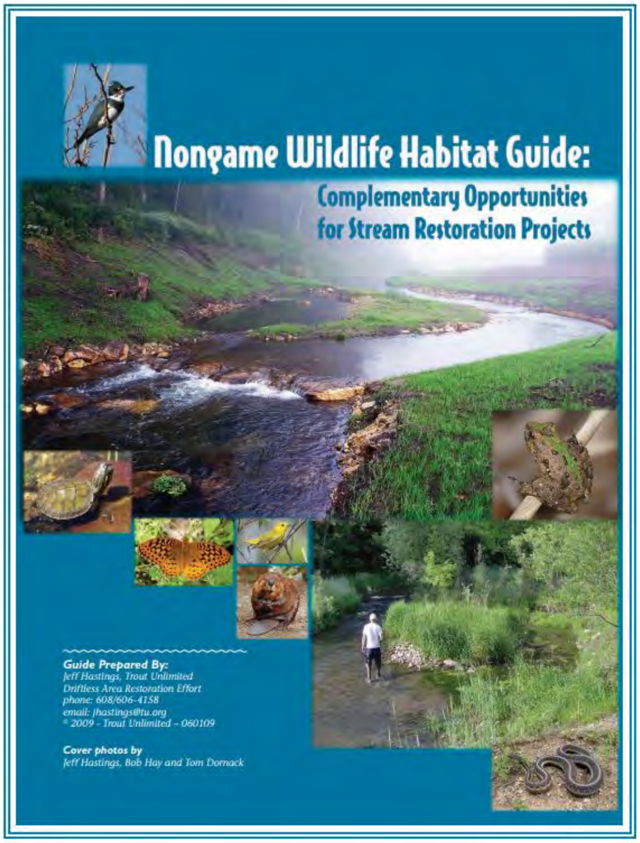
Nongame Wildlife Habitat Guide:
Complementary Opportunities
for Stream Restoration Projects

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Cover photos by
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Fig. 2. Nongame Wildlife Habitat Guide: Complementary Opportunities for Stream Restoration Projects.

Fig. 3. Backwater wetland with basking logs.

created a generalized target species list in their Nongame Wildlife Habitat Guide: Complementary Opportunities for Stream Restoration Projects (5) (Fig. 2). Another great resource produced by Partners in Amphibian and Reptile Conservation (PARC) in their Habitat Management Guidelines for Amphibians and Reptiles of the Midwestern United States, Technical Publication HMG-1, 2nd Edition (6). It will be helpful to then obtain a more precise list of species that are likely to exist in your more immediate area by contacting local species experts in your area, such as biology departments at local colleges and universities and Department of Natural Resources (DNR) staff. These folks may also be able to put you in touch with local non-agency species experts.

NOTE: Your target species list should also include common wetland, riparian or aquatic nongame species.

The Trout Unlimited publication provides information about the habitat needs of a variety of upland, riparian and wetland/aquatic non-game species and describes a number of management practices that can benefit them. By integrating some of these practices into your project, where appropriate, you may be able to make a positive contribution toward increasing the carrying capacity of instream, wetland, riparian and upland habitats for nongame birds, herptiles, invertebrates, mammals and possibly nongame fish. This is Trout Unlimited's second edition of this Nongame Wildlife Habitat Guide and has been modified to help project proponents better determine whether any habitat feature is more likely to accomplish it intended purpose within the immediate habitats and within the surrounding landscapes. A habitat, species, and landscape matrix is also provided in the guide to help you determine which habitat features are most likely to benefit species on your target list. For example, adding wetland scrapes within an intact riparian corridor is likely to benefit population of common amphibian species in your area and may also improve populations of SGCN species like the Northern Cricket Frog *Acris crepitans* and the Pickerel Frog *Lithobates palustris* (Fig. 3). On the other hand, adding wetlands scrapes within an active pasture may have more limited benefits for amphibians. Wetland scrapes in a pasture may be even less likely to succeed if the surrounding landscape is comprised primarily of row crops. This improvement to the guide will help project proponents develop plans that only incorporate habitat features that are likely to succeed and should allow state and federal agency staff to make better informed decisions within the project reviews and approval process.

Nongame Wildlife Life History Consideration

Invertebrates (*protozoa, annelids, mollusks, arthropods, crustaceans, arachnids and insects*). This exceedingly diverse group of species is the backbone or base of the animal food chain and is perhaps the most important as a result. Providing for the life history of such a broad range of species may be best accomplished by attempting to provide many of the recognizable macro- and micro-habitats that naturally occur within an intact natural riparian community that is similar to the desired outcome of your project restoration area. Providing standing and flowing water habitats with varied depths, temperatures, substrates and structures may be the best way to maximize aquatic invertebrate biodiversity. The rest of the fine habitat features are likely to be naturally provided over time. Riparian and upland habitats should have varied vegetative structure and be planted with a diverse mix of species. To achieve this, we are suggesting seed mixes that contain both native and exotic species (grasses and forbs) that have the greatest likelihood of achieving a varied herbaceous vegetation layer once established. We are purposefully including some exotic plant species because it is understood that most of these properties will not receive management. The establishment and maintenance of a diverse native planting typically requires significant management, especially in the early years, if a diverse plant diversity and structure is to be achieved. Where a project is attempting to improve conditions for one or more of the SGCN target invertebrates, such as a butterfly, seed mixes can include host plant seed as appropriate. Having knowledge about these species and their specific habitat requirements, host plants and soil types needed must be known to determine if you can accommodate these species within your project area. Other terrestrial microhabitat structures for invertebrates include flat rocks on the surface, embedded rocks and varying types and sizes of down woody debris.

Amphibians (Class: *Amphibia*). Amphibians, such as frogs and salamanders are cold-blooded animals, most of which metamorphose from a larval form to an adult form, leading double lives – one in water and one on land (7, 8). Most species lay their eggs in standing water but have varied habitat preferences on land, ranging from open canopy grasslands to dense forests. Suitable breeding habitat is critical to their long-term survival. Amphibians in this region generally breed during three peak phenology windows, although overlaps often occur between these windows. The early spring breeding frogs mostly rely on ephemeral wetlands or ponds that do not support predatory fish. Successful recruitment for amphibians occurs in ponds that support water at least 4-5 months during spring and summer. Most of the Driftless Area's terrestrial salamanders breed in water in April and their larvae transform from mid-July through early September. They require longer water persistence than the early breeding frogs. The middle breeding frogs, peaking from late April through early June, also prefer fishless environments. Because they breed later in the season, they also require water presence well into August. Recruitment for these frogs is best in fishless waters. The third phenology involves three frogs that breed from late May through early-August. Of these, two species have overwintering larvae (tadpoles) and require permanent waters. The third species, the endangered northern cricket frog, breeds in semi-permanent and permanent water but the larvae transforms in the same season. All three of these species have developed chemical or behavioral means by which to reduce predation rates by fish.

Frogs and salamanders have thin, semi-permeable skin that needs to remain moist. Therefore, upland habitats must provide microhabitats that allow them to avoid damaging water loss. Downed woody debris or healthy duff layers often supply this microhabitat. Adult salamanders often live underground or under large woody debris on land outside of the breeding period.

Vernal pools and ponds were not historically abundant in the Driftless Area due to steep topography and narrow valleys. The impacts of over-grazing and early agricultural practices have significantly altered most stream drainages in this area, often resulting in broader floodplains. These floodplains provide managers with the opportunity to create and restore wetlands adjacent to these streams.

Amphibians overwinter in a variety of ways, some overwinter underwater to avoid freezing. Others burrow below the frost line to avoid freezing. The endangered northern cricket frog is unique in it overwintering requirements. They cannot withstand freezing nor can they withstand being underwater for days. Because they cannot effectively burrow to escape freezing, they require specialized microhabitats where they can avoid freezing, yet still retain moisture. Cracks in damp unfrozen soils near the shoreline or near seeps, crayfish burrows and other microhabitats are essential to this species' persistence. Research is needed to determine how to manage these critical microhabitats and to create and maintain them. The lack or loss of these microhabitats may be major limiting factors for cricket frogs (Fig. 4).

Fig. 4. Northern cricket frog in overwintering crack. Credit: A. Badje.

Reptiles (Class: *Reptilia*). Reptiles for this guide include turtles and snakes (Fig. 5). They are cold-blooded animals with scales covering most or all their skin as opposed to having smooth moist skin like amphibians. Terrestrial and most aquatic reptiles lack the ability to internally regulate their body temperatures but instead rely on external influences to establish their body temperatures. As such, they rely on ambient air and ground temperatures and sun and shade to thermally regulate their body temperatures. Of all cold-blooded species, reptiles have some of the highest thermal preferences. As a result, habitat conditions must provide reptiles with opportunities to adequately thermo-regulate. Varied habitat structure that offers a range of canopy conditions and that favors open canopy conditions is important for reptiles. Reptiles also require overwintering microhabitats underground or underwater to avoid freezing during the winter.

Aquatic turtles require basking surfaces to increase body temperature. This helps them digest food, acquire Vitamin D and maintain shell health. Gravid females bask in spring to elevate their temperatures to allow for timely egg develop. Adult turtles will commonly emerge from overwintering habitats as soon as the ice melts (9). Turtles that overwinter in riverine settings often migrate in early spring to adjacent wetlands and shallow ponds. These habitats warm up more quickly in spring, providing better conditions for foraging on invertebrates and aquatic vegetation. Shallow standing water is important in this region by helping turtles complete their annual life cycle (10).

Snakes are primarily terrestrial animals (Fig. 6). They have relatively high thermal preferences and prefer open canopy habitats. The most commonly encountered snake along streams in the Driftless Area is the Northern Watersnake *Nero-*

Fig. 5. Blanding's Turtle. Credit: Dan Nedrelo.

Fig. 6. Snakes are cold-blooded and rely on air and ground temperatures to regulate body temperatures. Credit: Dan Nedrelo.

dia sipedon. It feeds on a combination of amphibians, crayfish and fish. Gartersnakes *Thamnophis spp.* are often common in streamside riparian habitats and amphibians are their primary prey. Several other snake species are found in streamside communities in this area but are less dependent on it. Many of these snakes are communal denning, meaning that they congregate to overwinter (9). In areas where natural den sites are limited or absent, artificial structures can be created to meet their overwintering needs.

Birds (Class: *Aves*). Birds are warm-blooded species that maintain stable internal body temperatures regardless of external influence. Because winters in the Midwest impact food availability for many birds, they migrate south to take advantage of warmer climates where access to food resources is not limited by cold temperatures, ice or frozen soils. This includes many of the riverine and wetland associated birds. Most water-associated nongame bird species fall into the category of being insectovores (small birds that eat invertebrates including insects), are piscivores (eat primarily fish) or are more general predators, eating a wide variety of prey including insects, fish, amphibians, reptiles and small mammals along with wetland/aquatic vegetation and seeds. A wide variety of birds can be found along stream corridors, but are not dependent on these habitats alone.

Shallow wetlands, low gradient shoreline of ponds, and mud flats and backwater areas along streams provide excellent foraging areas for wading birds. Perches over the water are important for a variety of insect eating birds such as Eastern Kingbirds *Tyrannus tyrannus* and for fish eaters like the Belted Kingfisher *Megaceryle alcyon*. Dead trees provide perching areas for hawks and other birds and can provide structure for nesting and foraging. Vertical banks can be important nesting habitats for Bank Swallows *Riparia riparia* and kingfishers (11). Varied habitat structure (trees, brush and grasslands) in riparian habitats can provide a variety of nesting opportunities.

Mammals (Class: *Mammalia*). Mammals are warm-blooded animals with varying degrees of cold temperature tolerance. Mammals of the Midwest do not migrate seasonally. Many remain active year-round by growing a denser coat of fur while others hibernate underground or in protective structures (e.g. hollow trees). A few mammals are highly associated with riverine environments, such as Muskrats *Ondatra zibethicus*, American Beaver *Castor canadensis*, North American River Otter *Lontra canadensis*, American Mink *Neovison vison*, and Short-Tailed Weasels *Mustela erminea*. Many other mammals from shrews to bears utilize riverine habitats.

Beavers are unique among all of the animals found in riverine communities because they create habitat to improve access to their food supply (12). Beavers provide extremely valuable shallow water habitats for a wide variety of amphibians, birds, invertebrates, mammals and reptiles. However, beavers also create problems for streams by impounding water that warms the stream, blocks upstream migration of fish and can impacts instream habitats. As a result, they are often controlled on cool and cold-water streams to minimize their damage to fish and instream habitats (13). However, stream restoration specialist can create habitats that provide similar conditions for the many nongame species that benefit from shallow impoundments and they can do this without having negative impacts on the stream itself. These alternative habitats can help stabilize and improve local biodiversity and add to the carrying capacity of the area.

Riparian and Upland Area Habitat Feature that Benefit Nongame Wildlife

The following habitat features are designed to improve conditions for amphibians, reptiles, birds, invertebrates and mammals:

Wetland Scrapes and ponds.

- Create where soils have low permeability or where the water table is close to the surface. Placement in an existing wetland must be pre-approved by your state's natural resources agency. These are typically only approved where the wetland is dominated by monotypic exotic vegetation or where other disturbances have grossly simplified wetland functions.

- Ephemeral ponds and scrapes should hold water for at least 4-5 months (early spring through mid-summer) and be less than 30-in (76-cm) deep (Fig. 7).

- Permanent ponds should have varying depths. Ponds should be 6-ft (1.8-m) in the deepest spot to allow for overwintering by amphibians, invertebrates and turtles. Note. These ponds could support fish populations.

- Design scrapes and ponds with irregular shorelines to increase shoreline to area ratios (not bowl shaped)

- Scrapes and ponds should have varied but generally low gradient slopes (6-8 to 1).

- If more than one pond is constructed, vary their distance to the stream. Ephemeral scrapes are best placed where they will flood only during high water events or surface water runoff.

- Isolate ponds from unwanted sources of pollution such as runoff from roads or sloped pastures.

- Add brush and large woody debris to ponds for egg deposition, basking and cover: 1) Basking logs should extend at least 5-ft (1.5-m) out from shore to minimize ambush by terrestrial predators. Include trees with branches above the water for birds, 2) Logs can vary in diameter from 6-in (15-cm) and up and should be anchored into the bank to keep them positioned so turtles and other species can easily access then from the water, 3) Use logs that have been dead for at least one year as green logs are heavy and tend to sink.

Terrestrial Cover Objects.

- Place large woody debris and large rocks adjacent to ponds and along travel corridors for cover and as elevated basking spots. Over time, large woody debris often supports abundant invertebrate life that is valuable to a wide variety of species.

Vegetation and Buffer Strips.

- Plant mixes of short grasses and low growing forbs around ponds and scrapes and in riparian habitats as buffer strips (minimum of 200-ft, or 60-m) to improve thermal conditions for herptiles while providing habitat for a variety of other nongame wildlife and their prey and to protect water.

- Connect buffer strips to suitable upland habitats to improve/restore habitat connectivity with breeding sites.

Snake Hibernacula.

- Several species of snakes in the Driftless Area overwinter communally. These include the common gartersnake, Decay's brownsnake, eastern milksnake, northern red-bellied snake, northern watersnake, prairie ring-necked snake, timber rattlesnake and the western foxsnake. These species may all overwinter together, in some combination or separately as a species depending on the surrounding habitats and the availability of suitable hibernacula. Snakes are known to migrate up to two miles (3.2-km) from their summer range to their hibernation site, but the migration is often shorter. Species may have different overwintering microhabitat preferences even when they use the same hibernaculum, so designing a one-size-fits-all hibernaculum is easier said than done. Two key elements are critical for snakes to overwinter successfully; conditions must prevent snakes from freezing and sufficient moisture is required to prevent damaging water loss during the long period they remain underground. Many studies have shown the lack of adequate hibernacula to be a limiting factor in the success of snake populations (14). The hibernaculum design and specifications below were developed by gaining experience with the design of several old and abandoned dug wells that support several of the communal denning snakes (Figs. 8, 9).

Vertical Bird Nesting Banks.

- Reconstruct vertical nesting banks away from the streambank but in close proximity to it (Figs. 10, 11). This can be done by shaving back existing banks or by creating soil mounds that have a vertical face on the streamward side. Stabilize the rest of the mound with cool season grasses such as Kentucky blue grass.

- **NOTE**: Place netting over eroding banks where bank nesting is known or expected to occur prior to the nesting season in the year that the restoration will occur.

Riparian Trees.

- Leave some trees along the riparian corridor but not at the immediate shoreline for bird use. Where trees only occur at the shoreline and must be removed due to threats to streambank stabilization, replant native trees back from the bank to restore nesting and perching sites.

Instream Habitat Features that Benefit Nongame Wildlife

Turtle Hibernacula.

- The structures used for overwintering by many cold-blooded species are called *hibernacula*. Silts are often deposited on the downstream side of trees that have lodged adjacent to the streambank. The large trunk or roots of a tree slow the water down and allow silt to settle and accumulate immediately downstream, usually against the bank. Turtles locate these deposited fine silts and bury themselves in for the winter. Unfortunately, some of the worst streambank erosion occurs adjacent to these unstable trees and roots. As discussed earlier, an unanchored tree may be good for a year or more but eventually moves downstream during flood events. A more permanent artificial overwintering structure has been developed to create similar sediment traps and can be found in the Nongame Wildlife Habitat Guide. These structures are strategically placed under the bank immediately downstream of flow deflectors placed on the upper inside end of bends. These structures are specifically designed for Common Snapping Turtles *Chelydra serpentina* but may occasionally be used by other turtles. The turtle hibernacula, made of a hard wood, will be virtually rot resistant once it is placed under water and not exposed to air. The current design uses 2-in (5-cm) thick rough oak, 8-ft (2.4-m) long, which is what we typically use for building our habitat structures.

Fig. 7. Off-channel ponds with basking log. Credit: D. Dauwalter.

Fig. 8. Construction of a hibernaculum as part of a stream restoration project.

Fig. 9. Post-construction hibernaculum.

Large Cover Rock or Woody Debris.

- Adding large boulders, or anchored woody debris will create pockets of slack water immediately downstream of these structures in deep pools, providing slack water microhabitats which can be used by turtles for overwintering. These features can also benefit trout by creating areas of lower flows thereby reducing the amount of energy needed by trout to feed. Vortex weirs are often created utilizing rocks, however in smaller streams wood can be used as well.

Cross Channel Logs.

- Cross channel logs can also be used to create deep pools (Fig. 13). Care must be taken to keep water from undermining the log and losing the plunging effect. Packing rock of different sized on the upstream side of the log will help reduce the chance of undermining.

Basking Logs.

- Basking helps turtles regulate their body temperature and aids in digestion. Vitamin D is important for the uptake of calcium from their food and is important for shell development and maintenance. Basking allows the shell to dry, inhibiting bacterial and fungal growth and assists some species with the shedding of scutes (the keratin plates overlaying the shell bones)(14). Creating permanent basking logs, or escape logs, is a simple task with an excavator (Fig. 14). Logs can be anchored into the bank and placed so that they sit just above the water surface during normal flows where they would not significantly obstruct water flow.

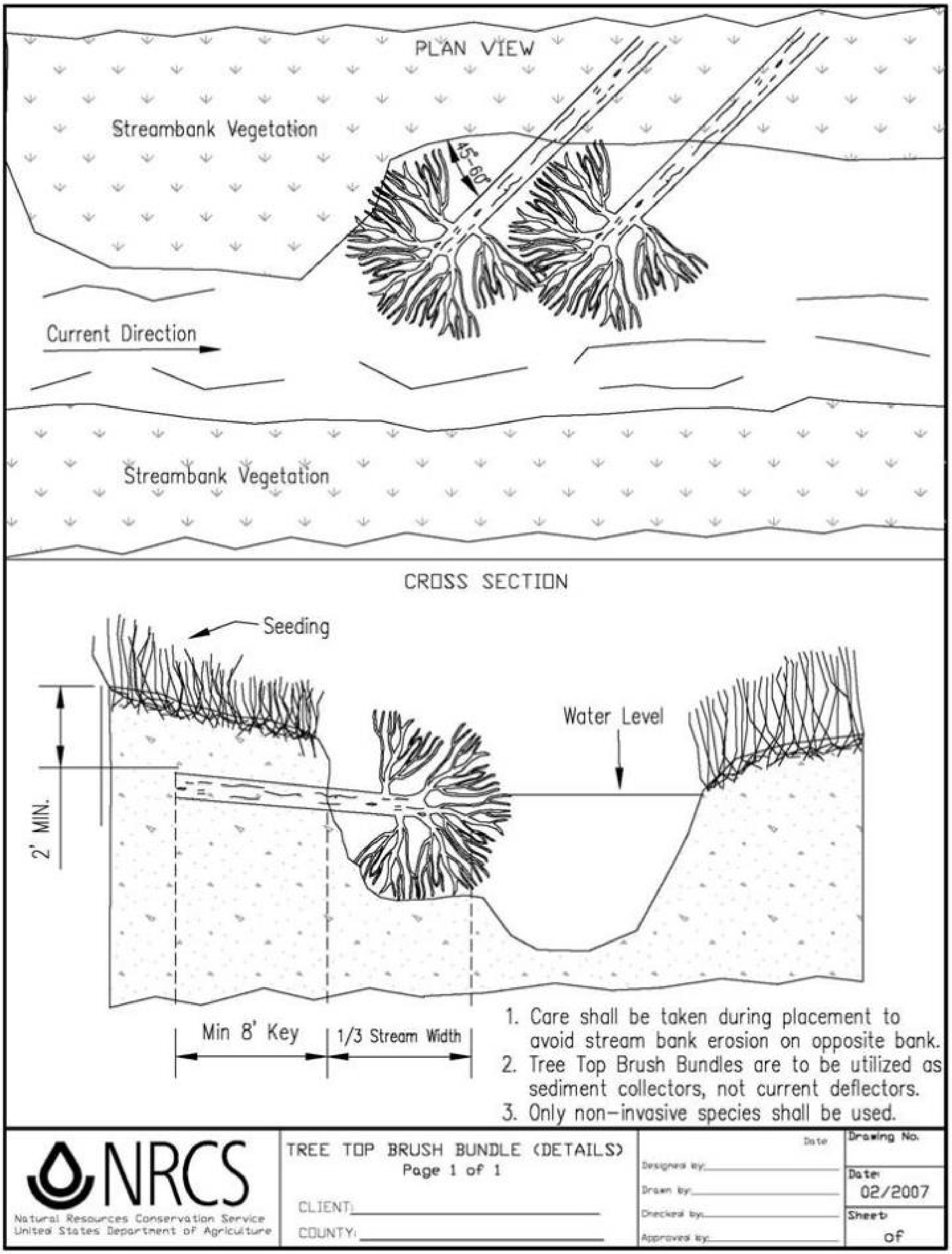
Fig. 10. Recently completed vertical nesting bank constructed as part of a stream restoration project.

Fig. 11. Vertical nesting bank in background. Note its location set back from the stream channel.

Large Cover Rocks/Boulders.

- Another practice often used to create additional habitat for trout is placing large boulders in deep water on straight stretches of stream. Eddies behind the large boulders in the center of the channel will also provide microhabitats for over wintering turtles.

Rock Deflectors.



1. Care shall be taken during placement to avoid stream bank erosion on opposite bank.
2. Tree Top Brush Bundles are to be utilized as sediment collectors, not current deflectors.
3. Only non-invasive species shall be used.

Fig. 12. Northern Water Snakes forage along stream and river banks. Providing in-stream habitat such as Tree Top Brush Bundles could provide valuable habitat. This design, and many more have been formatted on NRCS standards and designs and approved for Environmental Quality Incentives Program dollars, and can be found in the Nongame Wildlife Habitat Guide.

Fig. 13. Crosslog used to create pool habitat as part of a stream restoration project.

Fig. 14. Basking log at backwater confluence on Coon Creek, Wisconsin. Credit: D. Dauwalter.

- Rock deflectors typically installed to kick water flow from one bank to the other in-time will also provide shallow sediment flats on the downstream side. These provide habitat for burrowing invertebrates and foraging habitats for small wading birds. Add rocks to riffles that sit just above normal stream flow. These can serve as insect foraging sites for the Louisiana Waterthrush *Parkesia motacilla*.

Brush Bundles and Root Wads.

- This woody material can provide bank stabilization, overhead cover for trout and substrate for invertebrates (Fig. 12).

Oxbows.

- Connecting and even enlarging old oxbows to the stream will support tadpoles, frogs, turtles and forage fish. An oxbow lake is a U-shaped lake water body formed when a wide meander from the mainstem of a river is cut off to create a lake. Coldwater predatory fish will usually avoid these refuge areas because of the higher temperatures created by their shallow water and little or no flow.

Fig. 15. Side channel (left) on Trout Run, Minnesota. Note also the basking log. Credit: D. Dauwalter.

Vortex Weirs.

- A "Vortex Weir", constructed by placing large rocks in the shape of a "V", with the point of the "V" pointed upstream with large boulders in the pool will provide microhabitats for over wintering turtles and trout. As water flows over the rock it is directed to the center of the stream and the action of the water falling over the rock scours out a deep permanent pool.

Side Channels.

- Side Channels (Fig. 15) connect to the stream but are slightly warmer in temperature and will provide additional microhabitats for frogs, forage fish and invertebrates, which in turn provide foraging habitat for streamside community snakes, turtles and wading birds.

Point Bars.

- Point bars allow for the deposition of sediment, creating shallow flats of mud or sand. These shallow sediments typically support low and sparse vegetation and are ideal for many frogs and shore land birds. This habitat feature is particularly important for Wisconsin's only endangered amphibian the northern cricket frog.

In order to maximize the likelihood of success of these additional habitat features, it will be important to eliminate, or restrict access to ponds and streams by livestock. Cattle crossing have been effective in stabilizing bottom substrates and reducing erosion and turbidity.

Monitoring Non-Game Habitat

A suite of monitoring protocols to assess nongame wildlife on larger projects that incorporate several to many of the habitat features listed in this guide can be found in the Nongame Wildlife Habitat Guide. The purpose of monitoring is to determine if the added nongame habitat features accomplish their intended purpose, to improve nongame diversity and relative abundances. For monitoring to have value, pre- and post-monitoring is necessary. Pre-monitoring provides a baseline of species and relative abundance that can be compared to post-project results. Monitoring for pre- and post-construction must be done similarly, following the same methods and level of effort. While this will not provide definitive results for all species, it will help managers and funding agencies make decisions about what habitat features are most beneficial. Over time, monitoring results should help refine what practices to continue promoting and which to drop. We strongly encourage you to monitor your projects to determine if adding these nongame habitat features is producing the desired effect (see Johnson, page 70).

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Climate Change, Recent Floods, and an Uncertain Future

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1. The Driftless Area is expected to experience higher temperatures and more intense and frequent rainfall events as climate changes (high certainty).
2. Soil moisture is expected to decline, especially when droughts occur, but effects may be offset by increases in precipitation.
3. Trout distributions are predicted to decline with warming stream temperatures, and the way species interact (e.g., Brook Trout *Salvelinus fontinalis* and Brown Trout *Salmo trutta*) will change in complex ways, such as being externally influenced by changing parasite-host relationships (e.g., gill lice *Salmincola edwardsii*).
4. Changes in precipitation frequency and intensity will change water:sediment balances in streams, altering stream stability and habitat for aquatic biota. These changes, such as flooding frequency, have been shown to influence trout population dynamics at a regional scale.

Climate Change | Precipitation | Flooding | Species Distributions | Species Interactions

Fig. 1. Flooding in Vernon County, Wisconsin in August, 2018. Over 20 inches of rain fell in some areas. Credit: M. Hoffman, Milwaukee Journal Sentinel.

The Earth's climate is changing, with observed changes since the 1950s being unprecedented over decades to millennia (1). The Driftless Area has experienced heavy rainfall events and large-scale flooding in recent years, and such events are perceived to be occurring with greater frequency. For example, torrential rains upon already saturated soils in June 2008 caused severe flooding in southern Wisconsin (2). More than 12-in (30-cm) of rain fell within seven days in June 2008 (up to 2-in, or 5-cm, per hour), which was preceded by over 100-in (250-cm) of snow during winter 2007-08 and heavy rains in late summer 2007. Thus, saturated soils inhibited infiltration, resulting in a high proportion of runoff. Record gage heights were observed at 21 USGS stream gages across southern Wisconsin, and extensive flooding damaged several communities. This included the Kickapoo River and other portions of the Driftless Area. In 2007, 15-in (38-cm) of rain fell in 24 hours in the Whitewater River drainage in southeastern Minnesota, which resulted in catastrophic flooding that re-arranged stream channels, flooded towns, caused millions of dollars of damage to state parks, and killed seven people (Pioneer Press, 19 April 2015). In 2013, over 36-in (91-cm) of rain fell over three days in the Root River drainage (southeast Minnesota), again resulting in large floods. Heavy rainfalls have caused flooding in northeastern Iowa, southeastern Minnesota, and southwestern Wisconsin in 2004, 2007, 2008, 2013, 2014, 2017, and 2018 (See Preface; Fig. 1); some 2018 events are reviewed by the National Weather Service). The perceived uptick in heavy rainfalls and subsequent large-scale flooding is consistent with expected changes in climate and has led to concern that more heavy rainfall events can be expected in the future.

The Climate is Changing

Climate is defined as long-term patterns in daily weather observations (1). Global annual average surface temperatures have increased 1.8°F (1.0°C) from 1885 to 2016 with greater increases in northern latitudes, and we are currently in the warmest period in the history of modern civilization (3). The last three years (2015 to 2017) have been the warmest on record, and warm temperatures have been accompanied by numerous record-breaking weather extremes, such as prolonged drought and heavy rainfall events. The Fourth National Climate Assessment (NCA4) was released in late 2017 by the

Statement of Interest

Attribution is the action of ascribing one thing as being caused by another. Advances in the science of attribution have led to an increased acceptance based on evidence by both the public and scientists that global warming is human caused (termed anthropogenic global warming). In a review of nearly 12,000 studies on climate change, only 0.7% rejected the attribution of warming to human activities (but see (4)), and 97% of scientists involved in those studies were in consensus that climate warming is attributable to humans (5). Previous polls of a separate set of climate scientists have also shown that 97% concluded climate change is caused by humans (6).

This chapter was reviewed by B. Vondracek, K. Potter, and J. Williams.

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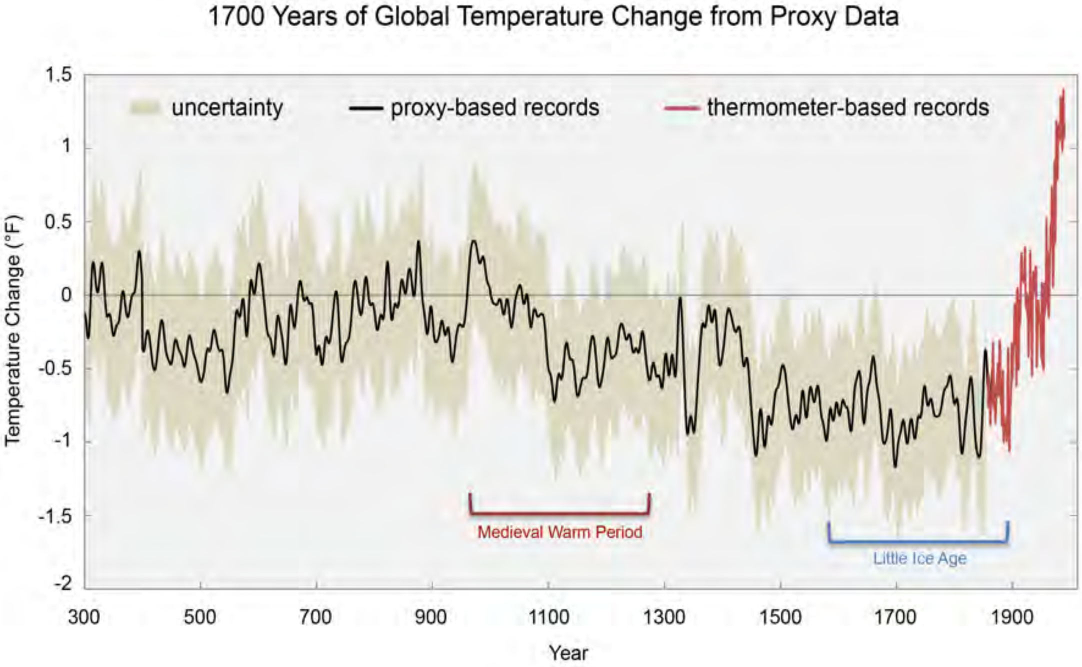

Fig. 2. Global temperature anomalies for past 1700 years from the observational and proxy records. Figure from USGCRP (1).

U.S. Global Change Research Program (1). The report used extensive evidence to conclude that human activities are the dominant cause of climate warming since the 1950s.

The NCA4 is the authoritative source for climate change-related information for the U.S., as is the Intergovernmental Panel on Climate Change (IPCC) (1, 7). Where do those data come from? Recent climatic changes from historical reference periods are typically based on observational records from instrumentation, whereas future changes are projected using climate models that are developed using observational data. For example, four independent estimates of global air surface temperatures are made by the National Aeronautics and Space Administration (NASA; GISTEMP estimate), the National Oceanic and Atmospheric Administration (NOAA; MLOST estimate), the Japanese Meteorological Society (JMS estimate), and the University of East Anglia and United Kingdom (UK) Met Centre (HadCRUT4 estimate). These estimates are obtained from analysis of data collected from 5,000 to 7,000 ground stations, and the estimates are congruent in that they all show global surface temperatures to be increasing (1). Proxy methods are used to reconstruct historical climates, such as in the use of fossil pollen and ocean or lake sediments, and they allow climate reconstruction for over 1700 years (Fig. 2) (8). In addition, the Mauna Loa Observatory run by NOAA has one of the longest running observations of atmospheric CO_2, and it has shown steady increases in CO_2 since the late 1950's that surpassed 400 parts per million (ppm) for the first time in recorded human history in 2015. CO_2 plays a large role in the greenhouse gas effect that absorbs infrared radiation reflected from the Earth's surface leading to surface and atmospheric warming, therefore creating a link between anthropogenic industrial carbon emissions and climate warming (termed anthropogenic forcing). Precipitation, drought, and other climate-related information is similarly monitored and modeled, including in the Driftless Area (9).

Some of the debate associated with climate change is focused on the link between global warming and human activities – a process termed 'attribution.' The ability to attribute changes in climate to human factors has advanced significantly in the last decade, and especially so in the last five years (10, 11). Research has now shown that only increases in anthropogenic-induced greenhouse gases, especially CO_2, can explain the level of observed global warming, particularly since the mid-20th Century (11, 12).

Here we review the main patterns of climate (i.e., temperature, precipitation, drought, floods) as reported from the observational record to present, as well as what climate models are projecting for the future, drawing largely on the NCA4 results for the Midwest (1) as well as Wisconsin-specific analyses (9). We then summarize climate-related research conducted in states representing the Driftless Area, which includes stream temperature modeling using future climate scenarios, how projected changes to stream temperature are predicted to influence stream fish distributions and population dynamics, and how stream temperature warming has and is predicted to change interactions between native and non-native sport fishes and their co-evolved parasites. We end by discussing the uncertainty with some aspects of climate change and how it relates to Driftless Area stream habitat projects and fisheries.

Climate: Past Trends and Projected Futures

Air Temperature. The entire U.S. experienced an increase in average surface temperature from the first half of the last century (1901 to 1960) to the present day (1986 to 2016; Fig. 3). The Midwest experienced a 1.26°F (0.70°C) increase in annual average surface temperature overall, with a higher 1.75°F (0.97°C) increase in annual average minimum temperature (winter minimum) versus a 0.77°F (0.43°C) increase in the annual average maximum in summer (3). That is, winters are warming faster than summers, which is reflected in later

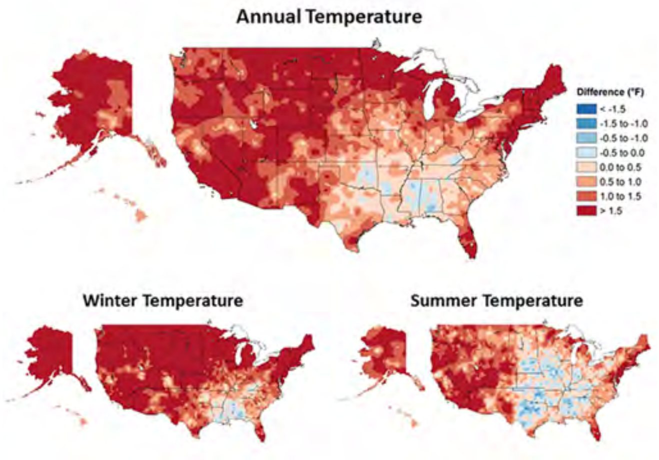

Fig. 3. Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawaii). Estimates are derived from the nClimDiv dataset. Figure source: NOAA/NCEI and (1, 14, 15)

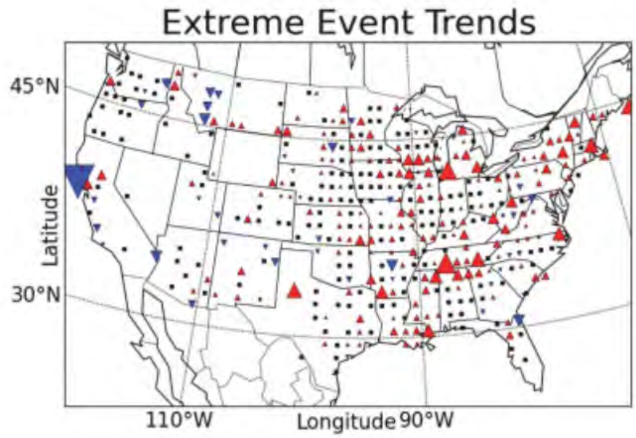

Fig. 4. Significant (95%) trends in an Extreme Precipitation Index (EPI) from 1901 to 2012 for a 2-day precipitation duration and 5-year return interval. Red triangles indicate significant increases, with triangle size indicating trend magnitude. Blue triangles indicate significant decreases, also with triangle size indicating trend magnitude. Figure from Janssen, et al. (17)

formation and earlier breakup of lake ice exemplified by a decrease in days of ice cover of 12.6 days per decade from 1980 to 2002 (13). Analyses of patterns of climate change across the state of Wisconsin also show increases in air temperature metrics from 1950 to 2006, with greater warming during winter and spring (9). However, there were also diurnal differences in warming with nighttime low temperatures warming faster than daytime high temperatures. Annual average nighttime low temperatures increased by 1.1 to 3.9°F (0.6 to 2.2°C) from 1950 to 2006 whereas annual average daytime high temperatures increased by 0.5 to 1.1°F (0.3 to 0.6°C) (9). Wintertime daily average temperatures increased by 1.8 to 6.3°F (1.0 to 3.5°C) across Wisconsin. One notable exception to increases in daytime high temperatures was that daytime highs decreased slightly in portions of the Driftless Area in Wisconsin (-1.1 to -0.5°F, or -0.6 to -0.3°C, decrease).

Precipitation and Streamflows. Climate science is also focused on changes in precipitation (both rain and snow), especially the frequency and magnitude of heavy rainfall events. **Heavy rainfall is commonly defined as 2 or more inches (or >5-cm) of rain in a 24-hour period** (16). The frequency of heavy rainfall events has increased in the continental U.S. over the last half century (Fig. 4)(17). Heavy rainfalls have increased in frequency most in the Northeast but also in the Midwest, and those heavy rainfall events are predicted to become even more frequent according to future climate projections (17, 18). In Wisconsin, average annual precipitation (rain and snow) has increased 2.0 to 3.9-in (50 to 100-mm) from 1950 to 2006, with higher increases in west-central and south-central portions of the state (9). Within that same time period, south and southwestern Wisconsin observed increases in precipitation across all seasons (0.4 to 0.8-in, or 10 to 20-mm), with slightly higher increases in fall (0.4 to 3.1-in, or 10 to 80-mm) and patchy increases in spring and summer (0.8 to 2.4-in, or 20 to 60-mm) with the highest increases in Dane and Sauk counties (to near 3.1-in [80-mm]; Fig. 5) (9).

There is evidence that heavy rainfall events have become more prevalent, but some of the details are dependent on the statistical methods used to assess and detect trends over time. Kucharik, et al. (9), used data from six airport weather stations to explore increases in frequency of heavy rainfall events in the southern and central portions of Wisconsin (Eau Claire, Green Bay, La Crosse, Madison, and Wausau). Using a simple linear regression approach, they detected an increase in frequency of 1, 2, and 3-in (25.4, 50.8, and 76.2-mm) rainfall events from 1950 to 2008 (9). Using a more conservative Mann-Kendall statistical method, they found the frequency of 1-in (25.4-mm) rainfalls to have increased, including near La Crosse, Wisconsin, but no increases in the frequency of 2 or 3-in (50.8 or 76.2-mm) rainfall events were detected.

Regional differences in heavy rainfalls across the United States suggests that there might also be regional differences in the frequency of flooding. However, according to a study by the U.S. Geological Survey there is generally not a cohesive geographic pattern of changes in flood frequency and magnitude; however, the study did detect a decreasing frequency of small floods (0.5 to 1-yr) in some areas such as southern Wisconsin (19). The study also found only weak correlations between changes in flooding and climate indices, suggesting that changes in climate played a small role, if any, in changes to flood characteristics. Several studies have shown that Driftless Area streamflows exhibit decreasing trends in flood frequency when compared to historical records (19). Gyawali, et al. (20) analyzed stream gages in three reference (least disturbed) watersheds and found annual flow volumes to increase from 1951-1980 vs. 1981-2010, minimum flows increased, and maximum peak flows decreased (Fig. 6). Splinter, et al. (21) noted similar findings for Driftless Area streamflows. In addition to long-term trends, there is also a notable step-change (increase) in flows around 1970 and 2005 (21, 22), the earlier of which has been attributed to higher total precipitation but also higher infiltration rates due to less intensive agricultural land practices (improved tillage on fields and grazing cessation on hillslopes) in the Driftless Area (23). Gyawali, et al. (20) approximated that only 60% of the increase in annual flows can be attributed to changes in climate (increased annual precipitation), as changing land use practices were also

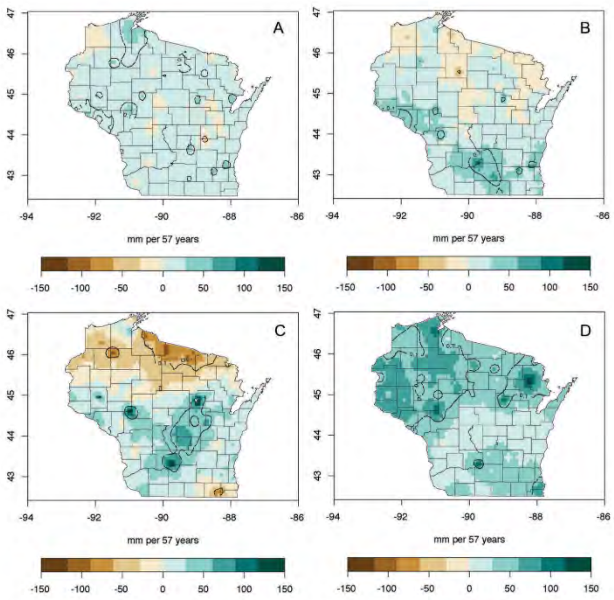

Fig. 5. Trends in total precipitation from 1950 to 2006 for (A) winter (Dec–Jan–Feb), (B) spring (Mar–Apr–May), (C) summer (Jun–Jul–Aug), and (D) fall (Sep–Oct–Nov). Regions that had statistically significant (P > 0.1) trends are enclosed or bounded by dark dashed lines. Figure from Kucharik, et al. (9).

influential.

Drought. Recent droughts and heat waves have increased in intensity in some but not all U.S. regions, but the Dust Bowl era is still the benchmark drought in the historical record (24). In other regions increased precipitation is associated with drought decreases but neither have been attributed to anthropogenic forcing (i.e., attributing observed changes to human activities), which is difficult to detect due to observation uncertainty and decadal-scale climate variability. The 2012 drought was the most extreme recent drought for the Midwest and Great Plains and was driven by an uncharacteristic pattern of natural climate variability whereby typical slow-soaking rains from evening thunderstorms from May to August were absent, but there was little evidence for human influence on that pattern (25). Soil surface moisture is projected to decrease with future warming, but it may be offset by increased precipitation. Although there is some uncertainty, increased future temperatures are likely to exacerbate soil moisture loss when droughts occur (24).

Stream Temperature. Climate and geology interact to provide an abundance of coldwater streams that support trout throughout the Driftless Area. Water temperatures in Driftless Area streams are influenced by many factors, including climate and geology, interacting at different spatial and temporal scales (27). Air temperature is an important climatic factor that affects water temperature, yet stream temperatures may be highly heterogeneous across small spatial scales within streams and among streams within and among watersheds. Groundwater, for example, may cool stream temperatures during summer while surface water, particularly runoff following rain events, may warm streams (Potter, page 15). In winter, the opposite occurs: groundwater helps maintain seasonably warm stream temperatures (e.g., 41°F [5°C]) and surface runoff following snow melt may cool streams to near-freezing temperatures. Precipitation is therefore another important climatic factor that can warm or cool streams depending on the season, and precipitation can interact with land use to recharge groundwater and influence stream baseflows.

Stream temperature models based on monitoring data collected during the June to August summer period show a high concentration of cold and cold transition streams in the Driftless Area of Wisconsin and Minnesota (Fig. 7)(26, 27). Lyons, et al. (28) defined thermal classes for Wisconsin streams based on water temperature during summer and species of fish present. Thermal classes based on the mean water temperature during the month of July are defined as coldwater (<63.5°F [<17.5°C]), cold transition (63.5-67.1°F [17.5-19.5°C]), warm transition (67.1-69.8°F [19.5-21°C]), and warmwater (>69.8°F [>21°C]). Thermal classes based on June-August mean water temperature are coldwater (<62.6°F [<17°C]), cold transition (62.6-65.7°F [17-18.7°C]), warm transition (65.7-68.9°F [18.7-20.5°C]), and warmwater (>68.9°F [>20.5°C]).

Coldwater streams are characterized by the presence of few species, typically salmonids such as Brook Trout *Salvelinus fontinalis* and Brown Trout *Salmo trutta* and cottids such as Mottled Sculpin *Cottus bairdii*, and warmwater streams are characterized by greater species richness including cyprinid (minnows), catostomid (suckers), ictalurid (catfishes), centrarchid (sunfishes), and percid (perches) fishes (28). Warmwater species can survive cold temperatures typical of northern winters but need warmer temperatures to complete their life cycles (29). Transition streams as a thermal class represent thermal regimes intermediate between coldwater and warmwater. Cold transition streams are dominated by coldwater species, but some warmwater species may be present in sparse numbers; warm transition streams are dominated by warmwater species, but some coldwater species maybe present in sparse numbers (28). High quality trout fisheries can be found in both coldwater and cold transition streams in the Driftless Area.

Stewart, et al. (27) used statistically downscaled air temperature and precipitation projections from 10 General Circulation Models (GCMs) to project future stream temperatures for the mid-21st century (2046-2065) for Wisconsin streams. Model projections show what could occur under the assumptions of the GCMs and stream temperature model. Mid-21st century projections of stream temperatures for Wisconsin show the Driftless Area to be more resilient to changes in climate compared to other regions of the state, likely owing to groundwater-dominated flows (Fig. 8)(Potter, page 15). Statewide, the stream temperature model predicts 57% of Wisconsin stream miles as coldwater or cold transition streams thermally suitable to support trout and mid-21st century projections suggest a decrease to 39% (average of 10 GCMs), with a best-case scenario of 47% and worst-case scenario of 26% (27). As streams warm in response to changing climate conditions, water thermally suitable for supporting trout may contract within streams towards headwaters or other groundwater sources of stream water.

Direct Effects on Fishes. Fish are cold-blooded ectotherms and, in some cases, stenotherms, the latter meaning that they can only survive in a narrow range of temperatures. As such, increasing air temperatures leading to increasing stream, river, and lake temperatures are expected to influence the distribution of fishes (30–32). Fishes in the Midwest have been catego-

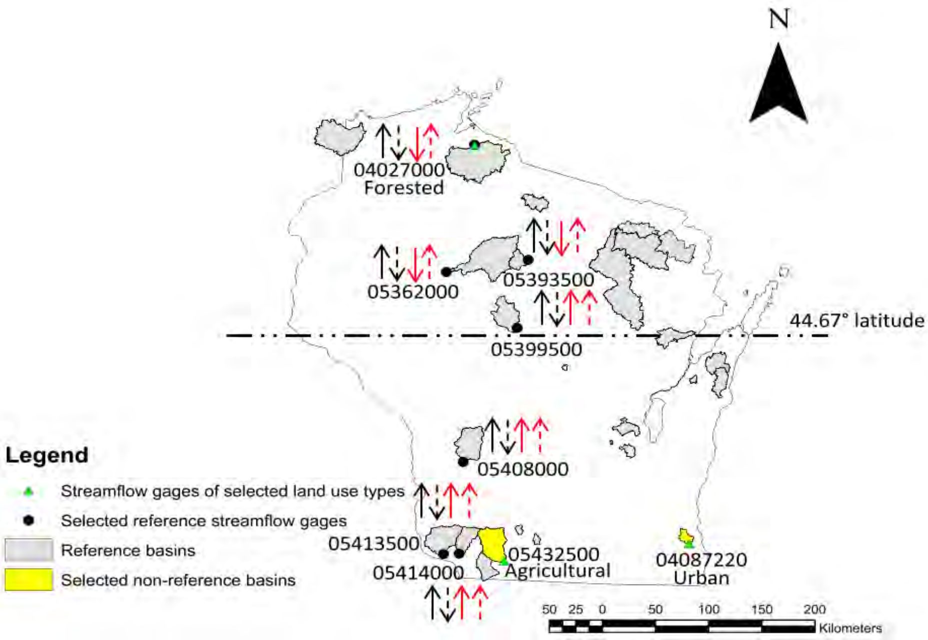

Fig. 6. Seasonal increases and decreases in streamflows at stream gages in Wisconsin between 1951-1980 versus 1981 to 2010. Arrows from left to right indicate winter (solid black), spring (dashed black), summer (solid red), and fall (dashed red) seasons. Figure from Gyawali, et al. (20).

rized generally as cold, cool, and warm-water species (28) and, therefore, can be expected to have differential responses to projected climate warming. Lyons, et al. (33) modeled changes in the distribution of 50 common fish species in nearly 54,050-mi (87,000-km) of Wisconsin streams under current conditions, limited climate warming (1.4°F [0.8°C] increase in water temperature), moderate warming (4.3°F [2.4°C] increase), and major warming (7.1°F [4°C]). Twenty-three species were projected to experience declines in distribution, 4 were projected to be unchanged, and 23 were projected to increase in distribution. Cold-water species were projected to lose the largest amount of habitat, and lose more habitat than warmwater species gain because they exist in small headwater streams that represent a disproportionately high number of all streams. For example, Brook Trout were projected to decline in distribution across Wisconsin by 94% and Brown Trout by 33% under a moderate warming scenario (34). This is similar to other projections made for changes in the distribution of cold-water salmonids given future climate projections (35, 36). Brook Trout and Brown Trout projected distributions for the mid-21st century were updated for the A1B emissions scenario using the stream temperature model described in Stewart, et al. (27) and the fish distribution model in FishVis (26). Models projected a decline of 68% in stream habitat for Brook Trout and a decline of 32% for Brown Trout in Wisconsin (37).

Indirect Effects on Fishes. Although stenothermic fishes like salmonids would appear to be most susceptible to increasing stream temperatures for physiological reasons, in a review of climate-related extinctions Cahill, et al. (38) found that only 7 of 136 extinction cases across various taxa were due to a direct physiological response to increased temperatures. Rather, many extinction cases were a result of changes to prey base or biotic interactions related to climate change. In Ash Creek, Wisconsin, Mitro (39), for example, observed an epizootic of gill lice *Salmincola edwardsii* infecting Brook Trout coincident with anomalously high stream temperatures and low stream flow in 2012. Gill lice are an ectoparasitic copepod indigenous to Wisconsin that co-evolved with Brook Trout, also native to Wisconsin. Multi-year stock-recruitment data indicated that poor Brook Trout recruitment in Ash Creek in 2012-2014 was attributable to gill lice infecting age 0 Brook Trout (39). Gill lice complete their life cycle faster in warmer waters, thus tipping the co-evolved relationship to a point detrimental to Brook Trout and favoring gill lice when more gill lice life cycles are completed during warmer years. With Brown Trout present in Ash Creek and the species not susceptible to infection by *Salmincola edwardsii*, a climate-related decline in Brook Trout recruitment may hasten their extirpation and replacement by Brown Trout. This illustrates that temperature warming may be an indirect rather than proximal cause of species extirpations in a changing climate, and that the effects of climate change may manifest itself in different ways for different organisms. Other researchers have shown that changes in climate-related changes to streamflows and water quality will change benthic macroinvertebrate communities (40), which has important implications for the prey base of stream salmonids.

A Complex and Uncertain Future

The climate has changed over the last 50-60 years compared to conditions in the 1800s and early 1900s, including in the Driftless Area. Climate models are projecting these changes to continue, and climate change studies have predicted undesirable consequences for salmonids that comprise important Driftless Area fisheries (Druschke, page 63). While there is evidence that heavy rainfall events have recently increased in frequency, the streamflow record shows that flood magnitude and flood frequency have decreased or remain unchanged. What drives this discrepancy between the climate and hydrological science?

1. First, changes in land management to incorporate more conservation practices has been attributed to decreased runoff and increased infiltration (20, 23). Changes in land management is likely to dampen the frequency and magnitude of small, 1 to 2-yr floods associated with spring

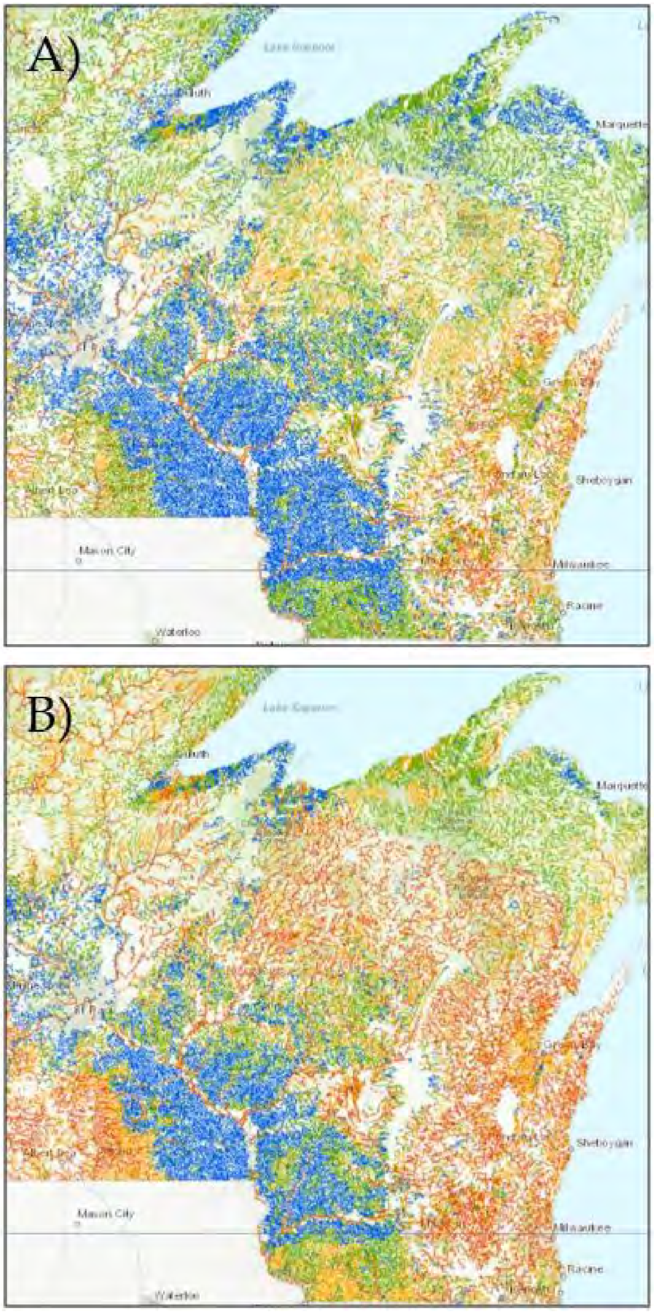

Fig. 7. Current (A: 1990-2006) predicted stream thermal classes and future (B: 2046-2065) projected stream thermal classes. Coldwater streams (July mean water temperature <63.5°F, or <17.5°C) are blue, cold transition streams (63.5-67.1°F, or 17.5-19.5°C) are green, warm transition streams (67.1-69.8°F, or 19.5-21°C) are yellow, and warmwater streams (>69.8°F, or >21°C) are red. Figures created from FishVis Version 1 (26).

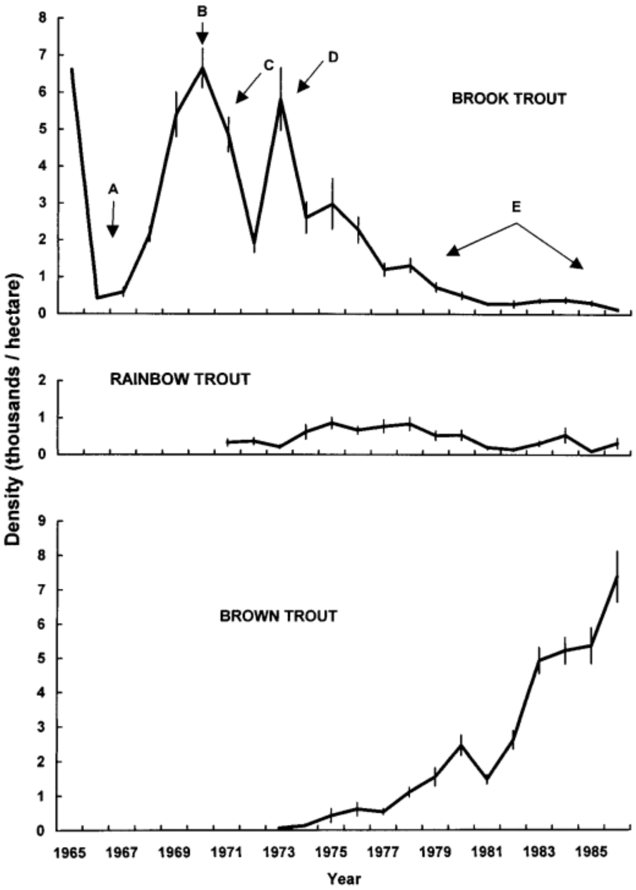

Fig. 8. Density of Brook Trout, Rainbow Trout, and Brown Trout in Valley Creek, Minnesota showing decreases in Brook Trout abundance due to floods (1965-6; A), high sedimentation events (C), and increase in Brown Trout abundance (E). Figure from Waters (41).

runoff or moderate-intensity rainfall events, but it is unlikely to decouple the link between heavy rainfall events and record floods.

2. Second, there could also be a spatial mismatch between weather stations used to evaluate trends in heavy rainfall events and where changes in streamflow have been studied. Rigorous evaluation of both require stations with long-term records (>50 years) with an absence of confounding factors such as urbanization for weather stations or lack of dams for streamflow gages. Different watersheds also integrate precipitation over variable-sized land areas and heavy rainfalls can occur in localized areas, further complicating the issue.

3. Third, most existing studies have relied on statistical methods to detect trends, and these methods often require long time series or very large rates of change to detect patterns in streamflow with a high level of confidence. Studies of extreme events have to be very selective in the weather or streamflow gage stations they use to evaluate changes over time (9), and this further reduces the number of watersheds with both weather and streamflow gaging stations for such analyses (multiple watersheds are needed to make strong generalizations from such data).

4. Last, many of these studies were conducted over a decade ago, and the analyses need to be revisited because there have been numerous heavy rainfall and record flooding events over the last decade, including in late summer of 2018.

Additional well-designed studies, including repeats of old studies with the most recent data, could help to resolve the uncertainties arising from this decoupling to better understand precipitation changes to hydrology in future climates and how they might influence stream habitat and fisheries.

Should heavy rainfall events continue to become more frequent and of higher magnitude as predicted, Driftless Area streams can be expected to adjust to new water:sediment balances. Stream morphology (sinuosity, channel dimensions, etc) reflects sediment and water transport processes that interact with local streambank sediments and vegetation (Melchior, page 20). While no studies of climate change impacts to stream geomorphology have been conducted, historical changes in climate have been linked to changes in hydrology in Driftless Area streams. Knox (42) used relict Holocene stream channels preserved in the sedimentological record to study the influences of past climatic changes on channel-forming flood magnitudes in the Driftless Area of Wisconsin. He found that the magnitude of historical floods as far back as 8,000 years before present ranged from -40 to +30% of present day floods due to fluctuations in climate, and increases in flood magnitudes were accompanied by coarser stream sediments and accelerated lateral channel migration. Any future increases in heavy precipitation events (increase in high-intensity rainfalls), and increases in total precipitation overall (increases in annual precipitation), are likely to cause streams to adjust to new water and sediment transport loads. This includes accounting for the increased flood energy and high shear stress in stream channels that are incised from vertical accretion of floodplain sediments (43). Most stream restoration and habitat enhancement projects are designed for or assume stream stability, which at a minimum suggests stream design standards would need to account for projected changes in flood frequency and magnitude. Design elements focused on dissipating excess stream energy, such as reconnecting floodplains, sloping streambanks, increasing sinuosity, and increasing channel roughness (bed morphology, wood), may also be necessary to promote resiliency of stream channels and restoration projects to floods of large magnitude in the future.

Many studies of climate change impacts on fishes and salmonids in particular have focused on changes in fish distribution in response to projected temperature changes (33, 36). Some studies have also focused on how changes in air and stream temperature and precipitation might influence fish population dynamics and bioenergetics. For example, Driftless Area specific studies have shown floods to influence Brook Trout population dynamics (Fig. 8)(41), Brown Trout growth rates and survival to differ across seasons with different thermal regimes (44, 45), interactions between Brook Trout and Brown Trout influence both species' population dynamics (46, 47), and trout population dynamics to change in response to species interactions and seasonal variation in stream temperature and flow (39). Other midwestern studies have shown Brook Trout and Brown Trout populations to be regionally synchronized due to the negative impacts of high flows during periods when redds may be susceptible to scour and emerging fry may experience high mortality or displacement (48). Research on changes in fish abundance, growth rates, and bioenergetics in response to climate change in the Driftless Area remains an important science need for future trout fisheries management given an uncertain climate future.

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The Importance of Human Dimensions Research in Stream Restoration

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1. Stream restoration success depends not only on ecological outcomes, but also on manager learning and public support.
2. Restoration managers, practitioners, and researchers in the Driftless region have huge amounts of knowledge about the human dimensions of stream restoration.
3. Some attempts have been made to synthesize angler perspectives on restoration practices and the major economic impacts of restored trout streams.
4. There is a need for more peer reviewed research into the human dimensions of stream restoration in the region.
5. Collaboration across states, with tribal nations, and between disciplines will be central to learning more about how to engage public stakeholders to support stream restoration outcomes.

Restoration | Social Science | Stakeholders | Economics | Human Dimensions

In their landmark paper defining standards for ecologically successful restoration, Palmer, et al. (1) distinguished between three axes for evaluation of river restoration projects: ecological; learning; and stakeholder successes. Ecological success featured five characteristics: basis on a guiding image; measurable ecological improvement; improved resilience; absence of lasting harm; and publicly available pre- and post-assessment data. Meanwhile, learning success involved "advances in scientific knowledge and management practices that will benefit future restoration action," and stakeholder success referred to "human satisfaction with restoration outcome" (1). The most effective river restoration projects, they argued, meet all three axes of success.

These three axes are central to stream and river restoration in the Driftless Area, and such science reviews as presented in this Special Publication of the 11th Annual Driftless Area Symposium are attempts to meet at least two of these goals: gathering and synthesizing the best available science for restoration work in the Driftless (i.e., ecological success) and sharing that research among managers, researchers, and practitioners in the region (i.e., learning success). But the third axis—stakeholder success—may well be just as critical to Driftless Area restoration project outcomes and is largely understudied across stream restoration literature in the Driftless, nationally, and internationally.

Bernhardt, et al. (2) found a positive correlation between community involvement and ecological success in a nationwide study, while Druschke and Hychka (3) found that long-term public engagement played a central role in achieving aquatic restoration project successes in New England—even for projects that were focused primarily on ecological indicators of success. But, as Druschke and Hychka (3) detailed, "little research explores how to cultivate the sorts of quality public engagement experiences that might contribute to restoration success." And so, while natural resource agencies and organizations (e.g., Wisconsin Department of Natural Resources, Trout Unlimited, Natural Resources Conservation Service) work to restore Driftless Area streams for trout, and increasingly for non-game species, it is humans who conceive of projects, fund them, enact them, monitor them, and decide whether or not to support them. Likewise, it is humans who have an outsized impact on trout stream quality across the region based on fishing practices, land management practices, and agricultural practices. But, again, these human impacts, perspectives, and values are largely understudied.

Fig. 1. Paul Hayes educates participants on the 2018 TUDARE bus tour about the ongoing restoration project on Wisconsin's Weister Creek.

The bulk of this Special Publication is understandably and necessarily focused on physical and biological attributes of Driftless watersheds and science-based restoration practices that might support the restoration of dynamic streams in the Driftless in the face of climate change. But future projects will face major implementation challenges without better understanding of the human dimensions of stream restoration in our

Statement of Interest

Trout angling offers major economic benefits to communities throughout the Driftless Area region, and there is evidence to suggest that degraded streams negatively impact both trout and trout anglers. More work is needed to consider the wider impacts of stream restoration, and to consider how fish, streams, and communities can benefit from these projects.

This chapter was reviewed by Anonymous.

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Driftless context, in terms of both learning and stakeholder successes, focused on managers in the case of the former, and public stakeholders in the case of the latter. The remainder of this section, then, will focus on what we currently know about the human dimensions of stream restoration in the Driftless, and then point to directions for necessary further research.

What We Know: Human Dimensions Research in the Driftless

Generally speaking, Driftless researchers, managers, and practitioners have huge amounts of knowledge about the human dimensions of stream restoration in the region (Fig. 1). The Wisconsin and Minnesota Departments of Natural Resources are well known for their deep history of trout stream habitat management, dating back a century. Work in the region was guided in large part by Ray White and Oscar Brynildson's (4) "Guidelines for Management of Trout Stream Habitat in Wisconsin," a groundbreaking text that contributed to learning successes by offering technical advice based in a philosophy of encouraging a river's natural processes. The history of recreational trout fishing in the Driftless, coupled with an early management orientation in the region, means that managers have been thinking—both explicitly and implicitly—about human aspects of stream restoration for decades.

Referring to work in the Driftless' Pecatonica Watershed, Steve Richter, director of conservation programs for The Nature Conservancy in Wisconsin, recently explained the importance of looking beyond the streambanks to human actors: "You can't just do stream restoration projects without looking at the practices in the adjacent fields. And you can't implement new practices in the field without having strong relationships with farmers and landowners. We took the time to develop strong relationships. That time spent in building relationships leads to bigger outcomes" (5). As Dieterman and Merten (6) recently suggested in their comprehensive history of trout management in southeastern Minnesota, "Effective and successful fisheries management requires information on the three primary components of a fishery: the biota (primarily fish), their habitat, and the benefits they provide to society (7)" (p. 16).

And yet, mirroring a national and international trend, there is a lack of published research into the human dimensions of stream restoration in the Driftless. As Dieterman and Snook (8) emphasized, while the Driftless region was an early leader in the biological evaluation of stream habitat projects and needs to continue that close biological evaluation with new habitat practices, "Perhaps more importantly, direct tangible benefits of habitat projects for anglers have been less frequently investigated" (8). They urged more specific, measurable project objectives, on both the biological and sociodemographic fronts. In the spirit of this Special Publication—which intends to offer "a review of the scopes of programs, projects, activities, and the underlying assumptions regarding scientific objectives to determine whether they are valid and credible," and to make explicit the links between restoration practices and science—I begin by reviewing the existing state of the science.

While, as mentioned above, there is a general lack of peer reviewed literature into the human dimensions of stream restoration in the Driftless, there are two clusters of research—angler preferences and economic impacts—that offer a good foundation for building a more robust archive of social science and social-ecological science in this realm. Both clusters are primarily driven by state managers and researchers in the Minnesota, Wisconsin, and Iowa Departments of Natural Resources, with contributions from Trout Unlimited and graduate students in the region.

Fig. 2. Trout lover Emma Lundberg shows off a brook trout in a Driftless stream. Credit: M. Mitro.

Trout Angler Preferences in the Driftless. Statewide surveys of angler preferences offer important insight into the possibilities for stream restoration (Fig. 2). While the Wisconsin Department of Natural Resources does not consistently survey anglers in the state, they have conducted several statewide surveys. Schroeder and Fulton (9) indicated that the Minnesota Department of Natural Resources conducts annual social surveys of angler attitudes; some data from those surveys are included in a variety of reports and manuscripts. Every five years, the Iowa Department of Natural Resources surveys 10,000 trout privilege purchasers, though results from those surveys do not seem to be publicly available.

In Minnesota statewide, anglers have consistently placed importance on habitat protection and restoration. A statewide survey of anglers who purchased licenses for the 2003 fishing season found "Over three-fourths of respondents felt that improving lake and stream habitat (91.3%) and protecting the land surrounding lakes and streams were important activities (83.2%)" (10). In southeastern Minnesota specifically, trout anglers linked stream health with agricultural induced erosion, with a majority of anglers indicating that livestock fencing, riparian vegetation, and rip-rap would be at least "very effective" (11). A decade later, a statewide survey of 2014 Minnesota fishing license holders ages 18 and over showed similar interest, with respondents rating "protecting the habitat in lakes and streams" as the most important management activity, and "restoring the habitat in lakes and streams also rating above "important" (4.2 out of 5) (12).

Protection and restoration of trout streams seems to play an important role in supporting and maintaining a strong population of trout anglers (Fig. 3). A recent Wisconsin survey of lapsed trout anglers (anglers who didn't purchase a trout stamp for three years after five consecutive years of purchase) found that quality of the trout fishery was an important factor in the trout angling lapse, and recognized that, coupled with

Fig. 3. A fly fisher enjoys a newly restored section of a Driftless stream.

external factors, habitat improvement projects can contribute to angler satisfaction (13). These findings are not divided by region, however, to get a sense of Driftless-specific responses. A statewide survey of active Wisconsin trout anglers showed that, statewide, 56% of trout anglers indicated a preference or requirement for a stream with restored habitat, while 74% would prefer not to or would never fish a degraded stream (14). Petchenik (14) hypothesized, "the imbalance between these two measures may be one of perception: anglers are more likely able to perceive poor stream habitat but may have more difficulty perceiving stream restoration, particularly if it is an angler's first experience at a stream" (p. 54). Use of live bait and years of angling experience were found to impact responses. A statewide survey of anglers who purchased Minnesota trout stamps and indicated they fished in southeastern Minnesota found that stream improvement projects most positively affected satisfaction with trout fishing in southeast Minnesota, with anglers supportive of trout stream easements, and fly anglers significantly more supportive of trout stream easements than lure and bait anglers (15). Anglers were supportive of trout stream easements newly in place, again with fly anglers more supportive (15). A recent comprehensive study of the economic impact of trout angling in the Driftless showed that 88.5% of respondents reported being aware of trout stream preservation and restoration efforts in the region, with almost 80% of that group reporting that past efforts prompted them to be more likely fish in the region and 72.7% indicating that future trout stream restoration efforts would make them more likely to fish in the region (16).

Minnesota anglers also seem fairly satisfied with state managers' work on habitat protection and restoration. Statewide respondents holding 2003 licenses indicated that the Minnesota Department of Natural Resources "performed well at improving lake and stream habitat (68.1%) and protecting the land surrounding lakes and streams (70.1%)" (10). A decade later, Schroeder (12) reported that "Respondents felt that the Minnesota Department of Natural Resources was doing well at protecting habitat in lakes and streams, protecting land surrounding lakes and streams, and educating people on how they can help protect lakes and streams" (12). Schroeder (12) recommended activities for future focus related to habitat management, including, "managing shoreline to protect fish spawning sites, restoring the habitat in lakes and streams, restoring land surrounding lakes and streams that have been damaged/developed, and educating people about lake and stream ecology/habitat" (p. v). Schroeder and Fulton's (9) recent work, based on a survey of Minnesota fishing license holders, reminded readers that management outcomes depend in large part on angler perceptions about those management decisions. Importantly, they found that acceptance of management decisions depended largely on impressions of voice and procedural fairness.

Managing increased fishing pressure—generally and in the wake of habitat restoration projects—will continue to be an issue for state managers. In Wisconsin's Kickapoo River Valley, a two-stage survey (intercept with mail follow-up) and series of focus group interviews conducted with trout anglers in 1994/1995 demonstrated respondent interest in improving fisheries management via management of future fishing pressure and the provision of larger fish, more fish, and greater species diversity on Valley streams (17). A 1999 follow-up to that survey showed that respondents were generally very satisfied with fisheries and river management practices in southwestern Wisconsin, though there continued to be concern about future crowding (18). In southeast Minnesota, creel surveys were conducted during the 2013 season on 11 southeast Minnesota streams; habitat enhancement projects had occurred on three stream sites within the past eight years to allow for initial pre- and post-project evaluations, with a fourth site offering a control (8). Pre- and post-project comparisons revealed few differences in demographics, catch rates, participation, or satisfaction pre- and post-project, with the exception of Trout Run Creek, which saw a 200% increase in angler pressure post-project (8).

In terms of preferred habitat, statewide in Minnesota, respondents indicated a preference for dense forest adjacent to streams and rivers, natural rocky banks, and rocky stream/river beds (12). This result may not hold true for the Driftless region, however. An earlier survey of trout angling in southeastern Minnesota detailed angler opinions regarding desired stream characteristics. Respondents preferred partial canopy cover and low brush on banks, with views of hills or bluffs, and respondents had a neutral response to the impact of pasture with animals (11). Respondents preferred "medium streams that are 10 – 25 feet wide, with a mix of both fast and slow water that is usually clear, even in times of high water" (11). In Wisconsin, data from the Department of Natural Resources' Driftless Area Master Plan survey indicated a preference for grass-lined banks over forested or pastured banks, but the survey was targeted only to individuals who signed up to receive updates about the Master Plan (19). A 2014 Wisconsin Department of Natural Resources Trout Angler Survey, meanwhile, indicated a preference for forested banks across the state. Approximately three respondents in ten statewide indicated they would never or would prefer not to fish a stream that was pastured or mowed (29%) or to fish a stream with an overgrown bank (30%) (14). Statewide, a thin majority of trout anglers needed or preferred forested stream banks (51%) and an equal percentage (51%) preferred not to or would never fish a stream where trees have been removed along the bank (14). Driftless-specific responses, however, offered directly by Petchenik indicated that while Driftless-specific sample size was limited, Driftless respondents to the statewide survey, unlike counterparts in the Master Plan survey, had more of a preference to fish on pastured or mowed stream banks and more indifference to forested stream banks compared with respondents from other parts of the state (14).

While the research was not specifically focused on stream management, a recent study of angler preferences for the Minnesota winter fishery showed that fly anglers tended to be specialized on a small group of streams, including branches of the Whitewater River, and that easy access was one of the common reasons driving angler preference (20). This point about angler access might influence future restoration design.

Much of what we know about trout angler preferences in the region comes from reports of state surveys of anglers. A notable methodological exception to that trend is work that emerged from five focus groups conducted in southeastern Minnesota to explore factors influencing riparian and watershed management among landowners in the area (21). Though the groups varied somewhat based on location and cultural aspects and concerns, emergent themes included strong interests in multi-generational stewardship, coupled with concerns about flooding, erosion, failed agricultural policy, corporatization of agriculture, chemical and livestock pollution, and increasing development (21). These interests suggest directions for future research in the region.

Another methodological exception is a pre- and post-project survey-based assessment of a conservation intervention in southeastern Minnesota's Wells Creek Watershed (22). While not angling-specific, a 1994 landowner survey gathered baseline data from southeastern Minnesota counties, allowing for comparison between the Wells Creek Watershed, other bluffland counties (Goodhue, Wabasha, Olmstead, Winona, Fillmore, and Houston), and other southeastern Minnesota counties (Rice, Steele, Dodge, Freeborn, and Mower). Conservation actions, including social and educational activities related to conservation actions, were introduced in the Wells Creek Watershed, and a 1999 survey was used to determine whether any noticeable differences emerged between the Wells Creek Watershed, neighboring counties, and other southeastern Minnesota counties. Results demonstrated very few changes in the perceptions and behaviors of landowners over the five-year span. The study noted that, "Changes that did occur tended to bring the responses of landowners in the bluffland and other southeastern Minnesota counties closer to those in Wells Creek—homogenizing views and actions," but respondents demonstrated some increasing concerns about increasing development (22). Concern with "quality of fish habitat" did not show significant change (22).

A final methodological outlier comes from Epton and Fulton (23) related to controversial trout management efforts in southeastern Minnesota in the late 1990s. Concerns from the Minnesota Trout Association (MTA) and Trout Unlimited (TU) about results from a 1997 survey related to proposed trout regulation changes in southeastern Minnesota (24) led to the 1998 formation of a stakeholder committee facilitated by Minnesota Department of Natural Resources and the beginning of a public comment process. Participatory decision-making in the process was assessed according to sense of need, agreement on technical boundaries, perceptions of one's own power, and sense of urgency (23). While all stakeholders agreed on the need for the process, and all but one agreed on the technical boundaries, there was a great deal of disagreement about the perception of one's own power and sense of urgency(23). Participants reported mixed responses about their satisfaction with the process, including satisfaction with outcomes, personal commitment, and willingness to participate again (23). In terms of procedural justice, respondents mostly agreed that they had a high level of perception of voice and influence, but were much more mixed in terms of fairness of outcomes and procedural fairness (23). Responses about trust in authority, neutrality of authority, respect, pride in participation, and legitimacy of authority were mixed, as well (23). Epton and Fulton (23) recommended the development of future, meaningful opportunities for stakeholders to provide input into decision-making processes in ways that build trust and offer longer-term follow-through.

Economic Impacts of Trout and Trout Restoration Efforts in the Driftless

There is a small but relatively thorough body of knowledge about the economic impacts of trout angling in the Driftless.

Over twenty years ago, Anderson and Marcouiller (17) noted the importance of trout angling as a rural economic engine in the Driftless region, including both direct and indirect impacts, with research focused specifically on the Kickapoo River Valley. Through a two-stage intercept and mail survey and focus groups, mentioned above, the study found that half of trout anglers surveyed were nonlocal, and that visiting anglers spent almost $220,000 during the 1994 season, and contributed almost $500,000 to total gross output (17). The study pointed to past investments of nearly $330,000 (in 1994 dollars) on the Timber Coulee system and to the impacts of those restoration efforts on supporting increasing spending by out-of-town anglers in the area (17). A 1999 follow-up to that 1994 survey in the Kickapoo Valley demonstrated rapid growth in angling, with double the numbers of trout anglers from 1994 to 1999, including a three-to-one increase in nonlocal anglers, and an increase in total expenditures, including a 360% increase in nonlocal angler expenditures (18). Nonlocal anglers spent just over $1,000,000 in the region in 1999, with a total economic impact of $1.5 million.

In Minnesota, a 2000 statewide mail survey of Minnesota trout stamp holders focused on the economic and social benefits of coldwater angling. It demonstrated that the southeastern portion of the state accounted for 33.1% of all coldwater angling trips and 75% of stream fishing trips (25). Total direct sales due to stream anglers amounted to over $30 million for the year, with another $18 million in direct income, supporting over 632 full- and part-time jobs (25).

A comprehensive survey of Driftless-wide economic impacts of trout angling was conducted in 2016. 2,000 surveys were mailed to a representative sample of Wisconsin, Minnesota, and Iowa trout stamp holders who did not reside in a county fully contained in the Driftless (1.5% of the total population of estimated trout stamp holders in Wisconsin, Minnesota, and Iowa living outside the Driftless), as well as being made available online for mail survey recipients to encourage others to respond online. This yielded 310 useable responses, with Trout Unlimited Driftless Area Restoration Effort (TUDARE) providing expenditure information on restoration projects to complete the analyses. The study estimated the total economic impact of fishing to the Driftless Area in 2015 at $703,676,674.50, supporting 6,597 jobs in the region (16). The total effect of fishing in the Driftless Area in 2015, including both Driftless Area and non-Driftless Area angler spending is $1,627,186,794.79 (16).

What We Need to Know: Recommendations for Future Research into the Human Dimensions of Stream Restoration in the Driftless

While the existing research detailed above focuses on angler perspectives and economic impacts, this work is not nearly as robust as it could be. Presumably, states have a plethora of long-term data from angler surveys that could be analyzed by researchers, and there are a variety of new questions that could be asked about angler perspectives and economic impacts across the region. Further, there are a variety of other questions to be asked of Driftless stream restoration projects and a variety of methodologies that could be adopted beyond angler surveys and valuation studies. This section closes with suggestions for future human dimensions research in the Driftless that could support Special Publication's goal to "contribute to providing increased resilience for stream ecosystems in a changing climate."

Fig. 4. Angler fishing a Driftless Area stream flowing through a working pasture. Credit: D. Welter.

A. Keep doing what we're doing....

- Continue research that explores angler perspectives on trout angling in the region.
- Continue research into economic impacts.

B. And extend existing work....

- Consider the diverse uses of Driftless Area streams, with special focus on the intersecting needs and impacts of trout angling and livestock grazing.
- Improve access to state data that already exists, offering important new possibilities for analysis.
- Existing state surveys and experiential knowledge offer great insights into useful and productive questions that deserve follow-up. Research questions can and should flow from this existing pool of expertise: including state surveys and master plans, public comments, and grounded expertise. Dieterman and Merten (6), for instance, catalogued historical southeastern Minnesota creel surveys that could be mined for information. A 2013 roving-roving creel survey of 24 southeastern Minnesota trout stream areas urged additional human dimension surveys to identify factors contributing to retention and recruitment of new anglers, young anglers (<16 years old), female anglers, and bait anglers (8), while a comprehensive comparison of pre- and post-habitat improvement project creel surveys concluded with a recommendation for future creel surveys focused on a smaller number of stream sites, suggesting, "the compilation of existing data in this report should thus serve to provide more robust data for evaluations of future habitat projects implemented at the other seven stream sites" (8).
- Increase the amount of research focused on the impacts of specific restoration projects following the example of Dieterman and Snook (8), which noted the funding and sample size challenges of assessing sociodemographic and fishery-related benefits on particular streams, but offered

a comprehensive study design for approaching quantitative research related to angler perceptions pre- and post-habitat project implementation.

- Consider using existing public comments from management plans and meetings as a source of data for management related research, as well as to guide future research questions. A 1996 survey of southeastern Minnesota trout anglers related to a proposed change in fishing regulations, for instance, includes 15 pages of colorful narrative feedback about trout management that raises issues about access, philosophies of stocking, and elitism, among other issues (24).

- There is great potential for mixed methods and qualitative explorations into the human dimensions of stream restoration in the Driftless. Existing research remains in the realm of numbers: with basic survey data and economic calculations. Those quantitative data are important—and can be especially useful for supporting arguments (politically and fiscally) for stream restoration projects. But, given the deep history and passion of anglers, land managers, and restoration practitioners—and the often-contentious nature of managing this singular and multifunctional landscape—those passions and controversies don't always translate well to quantitative data.

- Likewise, there is a need to build human dimensions explorations of stream restoration in the region in conversation with the vast font of science-based knowledge about Driftless hydrology, geomorphology, and biology. This integrative, social-ecological approach will be essential to managing these streams into an increasingly uncertain future.

C. Focus on adaptive management....

- Consider how human dimensions research and public engagement can support learning successes in adaptive management. There is a need for research that focuses on management expertise and practice.

D. Increase the amount of peer reviewed literature....

- There is a need for an increase in peer reviewed literature about all aspects of the human dimensions of stream restoration in the Driftless. Driftless managers have a huge amount of knowledge about the social and managerial aspects of restoration, in addition to their physical and biological knowledge. Extending the peer review process outside of state agencies would add to the robustness and availability of those data.

E. Build collaborations for richer human dimensions research....

- While much is understood about Trout Unlimited member perspectives on trout angling and stream restoration, there is a need to engage with and study populations outside the Trout Unlimited umbrella.

- Continued collaborations with staff from tribal nations, including the Ho-Chunk Nation, could contribute to a multifacted understanding of the past, present, and future of stream ecosystems in the Driftless.

- Engaged, participatory research methods can yield important data, while also serving to engage broad communities in stream restoration and management. Statewide surveys offer useful insights, but understanding the human dimensions of stream restoration in the Driftless poses two paired challenges: 1) Driftless-specific data are not always available in state surveys; and 2) state surveys only provide insights in state-specific areas of the Driftless. Coordinating survey efforts across states to provide a multi-state understanding of the region would be especially useful.

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Evaluating Stream Response to Restoration

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1. Stream restoration is an important element of trout stream management in the Driftless Area, generally involving the re-establishment of aquatic functions and related physical, chemical, and biological characteristics of streams that would have occurred prior to anthropogenic disturbance.
2. Each year, private entities, county, state, and federal governments, and non-governmental organizations like Trout Unlimited spend millions of dollars on stream restoration projects in the Driftless Area, for the primary purpose of improving coldwater streams for Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, and Rainbow Trout *Oncorhynchus mykiss*.
3. Planning a monitoring program in conjunction with a restoration project facilitates the development of realistic, measurable project goals and objectives and the use of suitable protocols to assess project outcomes. In addition to documenting intended beneficial effects, consistent and systematic monitoring may also highlight inadvertent effects of restoration on target ecosystems.
4. The information obtained through monitoring provides critical feedback to project participants, grantors, and the public, and also helps restoration professionals decipher the reasons behind project successes and failures and apply those lessons to their practice.
5. When project outcomes and the resulting lessons are presented and shared, they help increase the overall knowledge of stream ecosystems and shape the growing science of stream and watershed restoration.

Effectiveness Monitoring | Response | Metrics | Stream Habitat | Stream Temperature | Trout Populations

Introduction

On a national scale, stream restoration is a big business, with steadily increasing popularity. Since 1990, more than a billion dollars have been spent annually on stream restoration (1).

Coldwater fishes are an integral part of the Driftless Area's natural legacy, and coldwater fisheries are a core part of the region's culture and identity. The restoration of wild and native fisheries to Driftless Area waters is a stated goal of multiple agencies entrusted to manage these resources. Anglers also make a significant contribution to local and state economies in their pursuit of trout and other coldwater fishes (2). As such, stream restoration is an important element of trout stream management in the Driftless Area (Fig. 1). Stream restoration generally involves the re-establishment of aquatic functions and related physical, chemical, and biological characteristics of streams that would have occurred prior to anthropogenic disturbance.

Each year, private entities, county, state, and federal governments, and non-governmental organizations like Trout Unlimited spend millions of dollars on stream restoration projects in the Driftless Area (Fig. 2), for the primary purpose of improving the Driftless Area's coldwater streams for Brook Trout *Salvelinus fontinalis*, Brown Trout *Salmo trutta*, and

Fig. 1. Pine Creek, Pierce County, Wisconsin. Credit: J. Johnson.

Statement of Interest

All parties involved with stream restoration projects, including natural resource professionals, grantors, practitioners, land managers, and the public, are vested in the outcomes of these projects and therefore benefit from feedback on project successes, failures, and unintended consequences. Such feedback is critical for expanding the collective knowledge of the relatively young science of stream and watershed restoration, fine tuning techniques, and enhancing maintenance regimes. Stream restoration monitoring is the systematic collection and analysis of data that provides information useful for measuring project performance, determining when modification of efforts is necessary, and building long-term public support for habitat protection and restoration.

This chapter was reviewed by D. Dauwalter.

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Fig. 2. A restored trout stream reach at Pine Creek, in Pierce County, Wisconsin. Photo courtesy of Jeanne Kosfeld, Pine Creek Artist in Residence, 2009.

Fig. 3. A degraded Driftless Area stream, with a wide, shallow channel, slow current velocity, and eroded bank.

Fig. 4. A restored Driftless Area stream (same location as Fig. 3), with a narrow, deep channel, rapid current velocity, and sloped bank.

Rainbow Trout *Oncorhynchus mykiss*. Past fisheries surveys have demonstrated that stream restoration projects improve trout numbers and often allow streams to sustain populations of wild trout via natural reproduction. Hunt (3) and Avery (4) have summarized evaluations of 103 trout stream habitat improvement projects conducted by the Wisconsin Department of Natural Resources (WDNR) during the 1953-2000 period. Restoration project outcomes were generally favorable, producing increases in total trout abundance, size, and biomass. Due to stream restoration efforts, the WDNR has upgraded the classification status of many miles of coldwater streams during the past several years.

Stream restoration may take different forms, many of which can protect streams from the impacts of climate change. For example, degraded streams may exhibit wide and shallow channels, with relatively slow current velocities (Fig. 3). Restoration efforts typically narrow and deepen the stream channel and increase current velocity, thereby helping to maintain or further cool stream temperatures during the summer. Stream banks are often sloped back to open the stream channel to the flood plain, thereby dissipating flood energy into the flood plain rather than eroding stream banks (Fig. 4). In-stream structures (Fig. 5) may be installed, providing overhead cover and shade for fish (5). These structures mimic undercut banks, and are often placed on the south side of a stream, away from direct sunlight (6).

Stream restoration will continue to play a major role in trout stream management, and will help lessen any effects of climate change on coldwater streams, including warming and flooding related to changes in precipitation patterns. The Wisconsin Initiative on Climate Change Impacts) (WICCI) Coldwater Fish and Fisheries Working Group (6) recommends using restoration techniques that promote colder water temperatures (e.g., narrowing and deepening stream channels) and targeting restoration efforts to streams most likely to realize these benefits under a changing climate. Stream temperature and stream fisheries models can be used to aid in site selection for future stream restoration projects (see Dauwalter and Mitro, page 55).

In 2017, Trout Unlimited's Driftless Area Restoration Effort (TUDARE), in collaboration with numerous local, state, and federal partners, completed nearly 20 miles of coldwater stream restoration via 50 projects, adding to more than 1,200 miles of public stream access that support coldwater fisheries and angling across the region (7). Overall, close to $5 million was raised for this project work, including funding from the Natural Resource Conservation Service (NRCS) Regional Conservation Partnership Program (RCPP), the Lessard-Sams Outdoor Heritage Program, trout stamp revenues in Minnesota and Wisconsin, the U.S. Fish and Wildlife Service, foundations, and Trout Unlimited chapters across the four Driftless Area states (Iowa, Illinois, Minnesota, and Wisconsin).

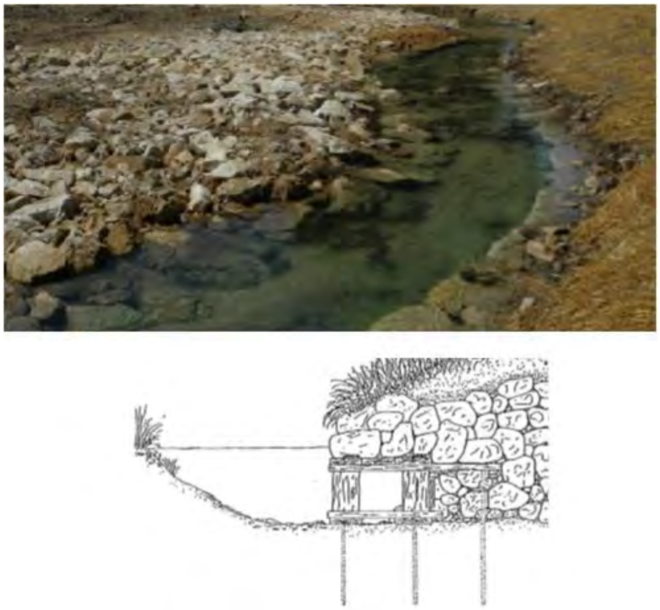

Fig. 5. Typical installation of trout habitat LUNKER structures in a Driftless Area stream.

On the Need for Stream Restoration Monitoring. All parties involved with stream restoration projects, from grantor to practitioner to land manager, are vested in the outcomes of these projects and therefore benefit from feedback on project successes, failures, and unintended consequences. Such feedback is critical in expanding the collective knowledge of the relatively young science of stream and watershed restoration, fine tuning techniques, and enhancing maintenance regimes. Also, by directing the maintenance of existing projects and improving the design of future projects, such evaluation may increase the credibility of restoration efforts in the eyes of participating landowners. More formally, grant administrators are requiring an increased level of accountability from grantees, including documentation that financial resources were used for the purposes requested and that they produced the desired results (8).

The effectiveness of common stream and watershed restoration techniques at improving or restoring physical conditions and water quality and ultimately increasing production of fish and other biota has been the subject of research and discussion for more than 75 years (9). As early as the 1930s, scientists were calling for improved and rigorous monitoring and evaluation of stream restoration programs (10). Although this call for more comprehensive physical, biological, and chemical monitoring has been steadily increasing (11–15), only a small fraction of the money spent on restoration is dedicated to evaluating project success. For example, Bernhardt, et al. (12) estimated that only 10% of the money spent on restoration in the USA is dedicated to any type of monitoring and evaluation, and that little of this money is dedicated to effectiveness monitoring.

A Definition of Stream Restoration Monitoring. Stream Restoration Monitoring: The systematic collection and analysis of data that provides information useful for measuring project performance, determining when modification of efforts is necessary, and building long-term public support for habitat protection and restoration (16).

Developing a Monitoring Program

Project Goals and Objectives. Ecological success in a restoration project cannot be declared in the absence of clear project objectives from the start and subsequent evaluation of their achievement (17). Monitoring objectives are directly connected to the goals and objectives of the restoration project and the two should be integrated starting from the project design stage (18). Understanding this connection and integrating the project's expected outcomes with monitoring will increase the ability to use monitoring effectively as a management tool.

The clarity and direction of project goals and objectives can be improved by ensuring that they are specific, measurable, achievable, relevant, and time-based (19). **Project goals and objectives should clearly state desired outcomes that are measurable through monitoring**. These anticipated outcomes (such as improvements to habitat or water quality) provide the rationale for monitoring components. They also direct the selection of metrics (or attributes) to measure. Project goals and objectives determine monitoring goals and objectives (20). Local, state, and federal natural resource professionals can provide excellent support for development of project goals and objectives and the monitoring methods that can be used to determine whether these goals and objectives are met.

Project Funding and Resources. Confirming the amount and duration of funding needed to implement a monitoring effort is a critical and practical step in setting monitoring objectives that are realistic and achievable. Many grantors mandate that some level of funding be included in the project budget to ensure that monitoring is implemented. Plan a monitoring budget prior to submitting a project proposal by reviewing suitable methods and estimating the cost of staff time, training, and materials needed to monitor each site for each desired stage of monitoring (i.e., pre-restoration, post-restoration, effectiveness). The percent of the project budget dedicated to monitoring must coincide with the unique terms outlined by the grantor (20).

Most contract periods allow for a minimum of one pre-restoration and one post-restoration monitoring visit to each site. At least one effectiveness monitoring survey of each site should be conducted before the close of the contract period whenever possible. Grantors with longer contract periods may support repeat monitoring visits over multiple years. These longer-term monitoring programs generally yield the most definitive confirmation of project outcomes (20).

Understanding and Selecting Types of Monitoring. It is important to have a good understanding of monitoring types as they relate to restoration monitoring (21, 22) before developing and implementing a monitoring program. Determining which of four principal questions are applicable will provide direction for which monitoring types will be used in a monitoring program. These four monitoring types include (20):

1. *Pre-Project Assessment Monitoring*: Documentation of current site conditions and how they support project selection and design. **Principal Monitoring Question: What are the existing site conditions and the reasons for implementing a project at the site?**

2. *Implementation Monitoring*: Monitoring to confirm that the project was implemented according to the approved designs, plans, and permits. In other words, was the work completed as planned? This is also a critical moment to identify any potential threats to project success so they can be addressed in a timely manner. **Principal Monitoring Question: Was the project installed according to design specifications, permits, and landowner agreements?**

3. *Effectiveness Monitoring*: Monitoring to assess post-project site conditions and document changes resulting from the implemented project. This is done through comparison with pre-project conditions to establish trends in the condition of resources at the site. Accordingly, effectiveness monitoring needs to occur over a sufficient period of time for conditions to change as a result of the project. Similar to implementation monitoring, effectiveness monitoring is a critical moment in the project timeline to identify and address threats to project success. **Principal Monitoring Question: Did attributes and components at the project site change in magnitude as expected over the appropriate time frame?**

4. *Validation Monitoring*: Monitoring used to confirm the cause and effect relationship between the project and biotic and/or physical (water quality) response. For example, this may include the change in use, presence, or abundance of desired aquatic flora and/or fauna at the project site. Similar to effectiveness monitoring, validation monitoring needs to occur over a sufficient period of time for biotic assemblages and/or water quality to change as a result of the project. **Principal Monitoring Question: Did biotic assemblages and/or water quality respond to the changes in physical or biological attributes/components brought about by the restoration project?**

It is often the case that multiple questions and monitoring types are of interest.

Qualitative and Quantitative Monitoring Approaches. Each monitoring type can be conducted in a qualitative or a quantitative manner. Qualitative and quantitative monitoring approaches each have their place and purpose and can be complementary to each other (20).

Qualitative monitoring provides subjective observations of implementation, effectiveness, and validation outcomes. These observations may include a broad assessment of project site conditions with questions pertaining to multiple project objectives. Although qualitative monitoring can include some quantitative measurements, it is generally not necessary to identify specific attributes when conducting a qualitative evaluation. Photopoint monitoring is a very useful qualitative technique, achieved through a series of photographs taken to document site conditions before and after project implementation and over time as changes occur at the restoration site. Quantitative monitoring is data driven and assesses changes in project site characteristics as a means of objectively measuring project outcomes.

The choice to use qualitative methods, quantitative methods, or both will depend upon funding availability and duration as well as the level of detail required to meet needs for feedback on project outcomes. Determining which principal questions should be answered through monitoring and the choice to use qualitative or quantitative methods will influence the time, effort, and resources required to conduct monitoring. It may not be realistic in all cases, but where resources allow, qualitative monitoring should be conducted in conjunction with quantitative monitoring. Qualitative monitoring is able to identify a broad range of concerns with the project that might not be detected by a more narrowly focused quantitative approach. On the other hand, quantitative monitoring provides objective data that are less subject to varying interpretations of project outcomes.

Key Elements of Stream Restoration Monitoring. Stream restoration monitoring should focus on a number of key physical, water quality, and biological elements that are critical for determining restoration project outcomes. Physical elements include stream temperature (including resilience to climate change), hydrology, sediment dynamics, and habitat characteristics. Water quality elements include turbidity, suspended sediment, nutrients, pathogens, and other pollutants that may be affected by watershed or local land uses. Biological elements include periphyton, macrophytes, macroinvertebrates, trout and non-game fish. Riparian areas targeted for restoration as a part of the stream restoration project can also be monitored to evaluate changes in terrestrial vegetation types and the presence of non-game species such as mammals, birds, reptiles, amphibians, and invertebrates. As noted above, monitoring of these key physical, water quality, and biological elements should be aligned with project goals and objectives, funding, and resources.

Monitoring Techniques

Qualitative Monitoring Methods. The California Department of Fish and Game's (CDFG) Coastal Monitoring and Evaluation Program provides an example of qualitative monitoring protocols that were developed to standardize stream restoration monitoring statewide (23, 24). These qualitative protocols, which are currently being used to assess projects funded through the CDFG Fisheries Restoration Grant Program, could be used as guidance for establishing qualitative monitoring protocols in the Driftless Area.

Quantitative Monitoring Elements and Methods. To conduct quantitative monitoring, one needs to determine, on a site-by-site basis, which elements are appropriate indicators of change in site conditions as a result of the restoration project. First and foremost, selection of elements to be monitored and determination of the timing and frequency of monitoring should be driven by project goals and objectives (20). It may be beneficial to create a list of common elements that could be expected to change over time as a result of stream restoration, and also identify the preferred methods for monitoring change in those elements.

Keep in mind that the identified protocols may be modified to suit unique project needs. However, using standardized methods rather than customized techniques will allow direct comparisons and analyses with other restoration projects. This offers the ability to quantify performance of multiple projects within a region and evaluate restoration technique effectiveness (20).

Fig. 6. Measuring flow velocity at a stream restoration monitoring site.

While it is crucial that selection of elements and methods be guided by specific restoration project objectives, additional factors such as the level of expertise and resources available must also be considered during monitoring plan development (25, 26). Consideration should be given to monitoring methods that can not only be implemented on a project-specific basis, but can also be learned through guidance documents and basic field training. This is a particularly important consideration if volunteers and/or citizens will be engaged in the monitoring work.

Monitoring Physical Elements. Numerous references document protocols for monitoring the physical elements associated with stream restoration projects, including stream flow, water temperature, climate conditions, and multiple in-stream habitat characteristics.

Flow is a major factor determining the habitat characteristics, water quality, and ecological assemblages in a stream or river. Continuous, automated monitoring of flow, as represented by a hydrograph, is complex and expensive, due to the nature of the equipment and expertise needed to conduct the monitoring work. The U.S. Geological Survey (USGS) is the national expert on stream flow monitoring, and has published numerous protocol documents on continuous flow monitoring, instantaneous flow measurements (Fig. 6), and the development of rating curves (a plot of water level [stage] vs. discharge). Several examples of these protocol documents include Wahl, et al. (27) and Turnipseed and Sauer (28). If continuous measurement of water flow and/or stage is an objective of pre- and post-restoration stream monitoring, this may best be accomplished in partnership with the USGS or a state agency with this type of monitoring expertise.

Water temperature is a critical factor influencing the biological activity and species composition in coldwater streams of the Driftless Area. Temperature also has an important influence on pH, density, specific conductance, the rate of chemical reactions, and solubility of constituents in water. Methods for continuous monitoring of stream temperature have been documented by the USGS (29), U.S. Forest Service (30) and the WDNR (31). Trout Unlimited has also published several protocol documents (32, 33) that are oriented toward volunteer engagement in continuous stream temperature monitoring (Fig. 7).

Fig. 7. Deploying a logger (right) for continuous measurement of water temperature at a stream restoration monitoring site.

Fig. 8. A weather station with instrumentation for continuous monitoring of air temperature, relative humidity, dew point (right), and rainfall.

Air temperature is the climate variable that best explains spatial and temporal variation in stream temperature (6). Because of the impact of air temperature on water temperature, it is important to monitor air temperature in the locale where stream temperature monitoring sites have been established. Hastings, et al. (33) provides protocols for continuous monitoring of air temperature, dew point, and relative humidity, as well as the collection of rainfall data (Fig. 8).

Stream geomorphology also plays a major role in determining the ecological condition of a coldwater resource, and can also have a significant influence on stream temperature. These geomorphic features include regional and local geology, water flow and velocity, stream channel shape, size, and slope, stream bank height, shape, and soil type, and stream bed substrate composition. As such, pre- and post-restoration assessment of key geomorphic (habitat) conditions is very helpful for understanding how a restoration project has improved the temperature regime and ecological health of a coldwater stream (Fig. 9). Furthermore, ongoing post-restoration habitat assessment at regular intervals can provide critical information on how a restoration project withstands high water (flood) events, and can also inform any needs for maintenance of the restoration reach (34). On a long-term basis, post-restoration habitat assessment at regular intervals can provide

Fig. 9. Evaluating geomorphic conditions at a stream restoration monitoring site.

information on how the restoration project withstands any climate-influenced impacts related to increasing temperature, precipitation, and runoff. Hastings, et al. (33) provides protocols for measuring four key geomorphic variables that have the greatest impact on stream temperature: stream width, water depth, water velocity, and canopy cover. Changes in these four variables from pre- to post-restoration may best explain any temperature improvement observed as a result of the restoration project. Other geomorphic (habitat) variables can also be measured as resources allow. These variables include: stream channel bankfull width and depth, stream bank height, depth, slope, and soil type, and stream bed substrate composition. Procedures for evaluating habitat characteristics in four key stream zones (stream bed, water column, stream banks, and flood plain) and an extensive glossary of terms related to habitat characteristics are provided by Simonson, et al. (35). The Minnesota Pollution Control Agency (MPCA) has also documented protocols for assessing physical habitat in wadeable streams (36, 37).

Monitoring Water Quality Elements. A common goal for watershed restoration projects is to improve water quality by reducing the delivery of sediment, nutrients, pathogens, and other pollutants to a stream. Confirming whether stream turbidity or another pollutant parameter is reduced as a result of the project is an intensive undertaking depending on the parameter targeted. This is in part because the factors that drive water quality parameters often operate at a scale that is larger than the project site. A typical restoration project is limited in length, compared to an extensive length of upstream channel above the project site. Various upstream conditions will likely hinder the ability of a monitoring program to detect a difference in stream sediment or temperature above and below a particular project site as a result of the restoration project. However, a strategic watershed-scale monitoring approach is recommended to validate water quality improvements where projects are implemented at a large scale or numerous projects connect over time (20).

Although the benefits of a restoration project for improving water quality can be difficult to quantify, characterization of post-restoration water quality conditions can be helpful for identifying any ongoing impacts on the stream. Monitoring the water quality of local spring sources and stream baseflow and runoff conditions within the restoration reach can provide valuable information on levels of nutrients available for stream eutrophication, sediment levels degrading fish and invertebrate habitat, and pathogen levels that may be impacting public use (Fig. 10). Water chemistry information can also be used to evaluate groundwater age and source, as well as watershed land use impacts that need broader attention.

Fig. 10. Collecting a water sample (top) and measuring water clarity (bottom) at a stream restoration monitoring site.

Numerous local, state, and federal agencies are monitoring water quality throughout the Driftless Area, so many protocol documents are available, depending on project objectives. Several examples of these protocol documents include MPCA (38) and MPCA (39).

Monitoring Biological Elements. Habitat use or population estimate monitoring requires more complex protocols. Such activities fall under the category of validation monitoring and include the response of aquatic and/or semi-aquatic biota (such as macrophytes, macroinvertebrates, fish, amphibians, etc.) populations as a result of changes in stream morphology and complexity (40, 41). These methods generally require species identification (taxonomic) skills as well as monitoring program design expertise. They are also likely to require special agency permits for collecting and/or handling these organisms.

Hunt (42) has emphasized the critical need to document quantitative changes in trout populations and their environment as a result of stream restoration. WDNR protocols for surveying trout populations can be found in WDNR (43, 44) and Lyons, et al. (45). Minnesota Department of Natural Resources (MDNR) protocols for surveying trout populations can be found in MDNR (46), while protocols used by the Minnesota Pollution Control Agency can be found in MPCA (47).

Macroinvertebrates serve as an important food source for trout (48, 49), and effective fisheries management must account for fish-invertebrate linkages and macroinvertebrate linkages with resources and habitats. Macroinvertebrates also serve as valuable indicators of stream degradation or improvement (50). Depending on project objectives and the metrics to be used to compare the pre- and post-restoration macroinvertebrate communities (51), many protocol documents are available for monitoring macroinvertebrates. Hilsenhoff (52, 53) and Plafkin, et al. (54) describe the single-habitat kick-sampling method (Fig. 11), which can be used to calculate multiple metrics and a Hilsenhoff Biotic Index (HBI) value. MPCA (55) describes a multi-habitat sampling method which can be used to calculate multiple metrics and a Macroinvertebrate Index of Biotic Integrity (MIBI) for coldwater streams. Garry (56) describes a simplified multi-habitat sampling method which can be used to determine the variety of macroinvertebrates present in a stream.

Macrophytes are often an important component of stream ecosystems, providing habitat for macroinvertebrates and fish and physical substrate for periphyton. Furthermore, macrophytes can provide water quality benefits by reducing the downstream transport of fine sediments and intercepting and assimilating nutrients. Since macrophytes are differentially responsive to environmental conditions, they can be used to monitor responses of stream ecosystems to anthropogenic impacts (57). Depending on project objectives and the metrics to be used to compare the pre- and post-restoration macrophyte communities, a number of protocol documents are available for monitoring macrophytes, including those provided by Scott, et al. (58) and Bowden, et al. (57). A simplified, semi-quantitative method can also be employed to visually estimate the percent coverage of macrophytes within a stream channel transect or quadrat, to the nearest 5% (Fig. 12). The establishment of stream channel transects is described by Hastings, et al. (33).

Monitoring Riparian Area Elements. The riparian areas created by stream restoration projects provide multiple benefits, including flood control and storage, water quality improvement via sediment and nutrient processing, groundwater recharge, carbon sequestration, and critical habitat for mammals, birds, reptiles, amphibians, and pollinators. Improved riparian area management can also provide stream resilience to climate change (via shading and groundwater infiltration, for instance). Depending on project objectives, many opportunities exist for monitoring the benefits created by riparian area restoration. Hastings (59) provides guidance on incorporating nongame wildlife habitat into stream restoration projects (see Hastings and Hay, this volume). This guidance includes recommended pre- and post-restoration monitoring protocols that can be used to determine if the nongame habitat features accomplish their intended purpose of improving the diversity and relative abundances of targeted nongame species. Additional protocols for monitoring a wide variety of riparian area elements can be found in MPCA (36) and MDNR (46).

Fig. 11. Using a kick-sampling protocol to collect a macroinvertebrate sample at a stream restoration monitoring site.

Monitoring Scale. Although the focus of stream restoration monitoring is typically on a site or reach, remote sensing options such as Geographic Information Systems with aerial photography such as National Agriculture Imagery Program (NAIP) imagery (60), Light Detection and Ranging (LiDAR) data, and infrared imagery can be applied to effectiveness monitoring. Information collected from such a broad scale can be used to help interpret the variability of data collected at a finer scale (61). For further information on specific methods, refer to Roni (26) and Dauwalter, et al. (62).

Monitoring Toolbox. Consideration should be given to establishing a toolbox of standardized stream restoration monitoring protocols that span a range from simple to complex, yet relevant physical, water quality, and biological metrics. A toolbox approach may be important, as expertise and cost will help define who uses these monitoring metrics.

Fig. 12. Estimating the presence of macrophytes at a stream restoration monitoring site.

Role of Volunteer Monitoring and Citizen Science. While agencies, colleges/universities, and consultants may very capably implement more complex monitoring protocols, their resources are often limited. As such, volunteers and non-governmental organizations (NGOs) can play a key role to support stream restoration monitoring. State and local volunteer monitoring and citizen science programs are good examples of the application of simplified monitoring protocols that allow consistent comparisons of ecologically-relevant metrics. A rich history of volunteer monitoring exists in Wisconsin, including Water Action Volunteers (WAV) and the Citizen-Based Monitoring Partnership Program (CBMPP). The Minnesota Pollution Control Agency's (MPCA) Citizen Stream-Monitoring Program (CSMP) began in 1998, with the goal of giving individuals across Minnesota an opportunity for involvement in a simple, yet meaningful stream monitoring program. Volunteer water monitoring has been a component of the Iowa Department of Natural Resources (IDNR) since 1998, via IOWATER. In 2017, however, IDNR launched a new, locally-led volunteer water monitoring program to help Iowans better understand their local water quality.

Furthermore, nonprofit organizations often have significant capacity to garner enthusiasm and support for volunteer monitoring at the local, state, regional, and national levels. For example, Trout Unlimited has prepared a national protocol manual for stream temperature monitoring (32) and a regional TUDARE protocol manual for stream restoration monitoring (33). With guidance and standardized protocols available, local Trout Unlimited chapters are becoming increasingly involved with stream restoration monitoring.

Additional Considerations

Project Location Documentation and Photographic Monitoring. All qualitative and quantitative monitoring should occur in conjunction with proper documentation of project location, as outlined in Gerstein, et al. (63) and Collins (23). Also, photopoint monitoring (64) is recommended at all stream restoration sites, regardless of the monitoring type employed. Pictures are particularly valuable when sharing project results with funders and the public. It is important to locate photo points so that they allow for repeated unobstructed photos once vegetation becomes well established. Detailed notes on the precise location and direction of photo points are also critical (20).

Monitoring Timeframe and Documenting Trajectory. Baseline data should be collected shortly before the project begins and immediately following its completion. Implementation monitoring should occur as soon as possible within the first year after project implementation. Ideally, the duration of effectiveness monitoring should depend upon the expected amount of time required to reasonably ascertain whether project objectives have been met. In other words, the monitoring timeframe should reflect the time necessary for identified attributes to change as a result of the restoration project (65).

Depending upon the element, monitoring project sites for ten years or more may be desirable (65). However, this is generally longer than funding for most projects will allow (8). Many restoration funding contracts last three to five years, with monitoring conducted during that time period. Site conditions three to five years post implementation may be reasonable indicators of whether the restoration project is likely to have the desired effects, even if the duration of monitoring is insufficient to ascertain a direct response and thorough achievement of project objectives. Ideally, subsequent visits at a minimum of three- to five-year intervals are recommended to document ongoing changes in site response and trends in trajectory (8).

Because of their potential to influence monitoring survey results, environmental stresses, project maintenance, and seasonal factors should also be considered when planning the timing of effectiveness monitoring. Structural integrity is a concern for any type of stream restoration project (60, 63). Ideally, stream bank structures and riparian vegetation should be assessed after high flow events to determine the project's ability to maintain its integrity following extreme physical conditions.

Monitoring should not be confused with maintenance. Ideally, a visual evaluation of the project site should be conducted annually by the contractor, project manager, or landowner to assess maintenance needs (20).

Control and Reference Sites. A *control site* is a stream reach in the vicinity of a project site that is similar to the project site with regard to disturbance and impact, but it has not been restored. A *reference site* is an unimpacted (or least-disturbed) site that serves as an example of ideal restored conditions. When chosen carefully, control and reference sites can provide a useful context for interpreting project success and how soon the trajectory of each attribute will reach the "predisturbance condition" (20).

Control sites serve to illustrate changes occurring naturally as a result of climatic and site conditions, versus those occurring as a result of the restoration project. A control site is generally an unrestored stream reach with similar conditions and scale as the project site prior to treatment. An alternative form of a control site, useful for documenting the effect of specific restoration techniques, is a site with similar conditions that was treated with a different restoration method. This type of control site allows for the evaluation of restoration technique effectiveness (20).

Monitoring appropriate control sites in conjunction with restored sites provides useful information that can document whether changes in site conditions are a result of the restoration project or a natural occurrence. Parties that have the necessary resources to locate and monitor control sites may find that they are valuable in ascertaining trends and isolating long-term project benefits from natural environmental variation. However, control sites that are directly comparable to restoration sites are often difficult to locate and access. For these reasons and the increased time commitment required, it is usually unrealistic to expect most parties involved in project monitoring to monitor control sites in conjunction with each restoration site (20). Long-term monitoring sites (sentinel sites) established by the agencies can sometimes serve as control sites where appropriate (66).

Reference sites illustrate ecological features of a pre-disturbance state and have been useful for both planning restoration projects and establishing quantifiable project objectives. Water resource managers are generally aware of the most disturbed streams in a region, but the range of attainable stream conditions is less apparent. Relatively undisturbed reference sites can provide examples of the attainable community structure, dominant and intolerant species, species richness, habitat conditions, and the spatial variations of those variables. The ranges of these variables at relatively undisturbed sites represent the attainable ecological conditions and uses of disturbed streams and watersheds if they were to be restored(67). Harrelson et al. (68) note that reference sites can be elusive and difficult to find. In many cases, watershed scale impacts such as stream channelization or aggradation and current land use practices have precluded the ability of any stream reach to represent reference conditions for all attributes. In regions with very few or no undisturbed watersheds and streams, the term 'least-disturbed' has been used to describe reference sites that are used for comparison of physicochemical and biological information, such as in the wadeable streams assessment conducted by WDNR in the Driftless Area (69). Hughes, et al. (67) suggest a three-phase process for selecting regional references sites that can be used to assess stream potential. The necessary number and location of reference sites will vary with the size and variability of the region and the requirements and resources of the water resource managers.

Monitoring for Climate Change

As previously noted (Introduction), stream restoration has been identified as an adaptive management strategy that can help lessen any impacts of climate change on coldwater streams, including warming and flooding related to changes in precipitation patterns (6). One of the necessary components of an adaptation strategy is measuring the results of the chosen management activity. Since most adaptation strategies will be implemented on a decadal-scale time frame, it is imperative that measurement and monitoring programs are implemented as soon as possible. Throughout the Driftless Area, several key monitoring objectives should be considered, to document climate change impacts on coldwater streams and evaluate the ability of stream restoration projects to provide resiliency to climate change:

1. Provide long-term data to document climate change impacts on Driftless Area coldwater streams, including those related to water temperature, flow, and stream channel geometry (70). This could be accomplished by establishing long-term "sentinel" monitoring sites on coldwater streams throughout the Driftless Area. A sentinel site could include a weather station (air temperature, relative humidity, dew point, precipitation), as well as water temperature and flow monitoring. An example of the value of long-term stream temperature data for evaluating climate-related changes is provided by Johnson (71), who notes that temperatures in the Kinnickinnic River in western Wisconsin have increased by 1.8-2.7°F (1.0-1.5°C) during the past 19-23 years.

2. Conduct pre- and post-monitoring of select streams targeted for restoration projects, to determine if these projects are providing short-term and long-term benefits for climate change resiliency.

Case Studies of Stream Restoration Monitoring

Historically, the most common approach for evaluating stream restoration projects regionally is to conduct detailed investigations at a few representative restoration projects. These are simple case studies that may evaluate one or two projects in detail by monitoring before and after restoration. The goal is to simply answer questions about the effectiveness of an individual project at a reach scale (9). Most of the published evaluations of restoration projects fall into this category of simple case studies.

At state and local levels, several case studies provide examples of evaluating stream response to restoration. These studies include pre- and post-restoration monitoring of physical, chemical, and biological attributes, to determine whether project objectives were achieved. The case studies below serve as functional and successful examples for stream restoration practitioners who wish to incorporate a monitoring component in a restoration project.

State of Washington. The Washington State Recreation and Conservation Office (72) provides an excellent summary of the monitoring work conducted in Washington State, to assess the response of stream habitat and localized salmon populations to restoration projects.

Pacific salmon are a cornerstone of culture and economy in the Pacific Northwest (73). In the twentieth century and early in the twenty-first century, salmon populations declined to the point where Endangered Species Act (ESA) protection was enacted in the mid-1990s. As part of the recovery plans, stream habitat restoration was recommended and has been applied prolifically throughout the region, at a cost of nearly half a billion dollars since 1999 in Washington State alone.

In 2004, Washington State established a project-scale effectiveness monitoring program to assess the response of stream habitat and localized salmon populations to the restoration efforts. The goals of the Project Effectiveness Monitoring Program were to address several management questions:

1. Are restoration treatments having the intended effects in terms of improvements in localized habitats and use by salmon?

2. Are some treatment types more effective than others at achieving specific results?

3. Can project monitoring results be used to improve the design of future projects?

The Project Effectiveness Monitoring Program monitors a subset of the restoration projects funded, in eight discrete categories of commonly implemented project types. Within each category, monitoring indicators have been established, including a success criterion for each indicator. The same protocol and data analysis procedures are used to evaluate projects within a given monitoring category. Using the same procedures allows the performance of each indicator to be compared across projects in each category. The objective of the Project Effectiveness Monitoring Program is to evaluate the success of projects at the category level, thus providing feedback on how the projects in a monitoring category are affecting the desired physical and biological conditions impacting salmonid populations. Collaboration with other monitoring programs and coordination with project sponsors and local monitoring entities (lead entities and regional staff) are also supported as a part of this project. Interpretation and presentation of monitoring results is an integral part of the Project Effectiveness Monitoring Program.

The program is intended to provide feedback on the response of stream ecosystems and salmonids to restoration actions, in order to improve restoration and ensure that the most effective restoration actions are being implemented to cause the desired improvements in stream habitat and fish response. Analysis, interpretation, and communication of the results from monitoring are, therefore, a cornerstone of the program. Use of monitoring data to improve project designs and planning is an ongoing effort that continues to develop as more effective communication strategies are identified between communities of scientists, project designers, and project sponsors. Based on the monitoring work conducted, restoration outcomes can be summarized for four restoration categories, including:

1. Instream Habitat: Instream Habitat projects have been successful in improving all habitat indicators monitored, which includes pool habitat and large woody debris abundance. However, Instream Habitat projects have been less successful in affecting salmonid use, with no significant changes in juvenile Chinook Salmon *O. tshawytscha*, juvenile Coho Salmon *O. kisutch*, juvenile *O. mykiss*, or Bull Trout *Salvelinus confluentus* densities following implementation.

2. Riparian Planting: Riparian Planting projects were successful at ensuring planting survival, improving woody cover, and improving riparian communities by increasing the proportion of reaches with canopy, understory, and ground cover. These results show that Riparian Planting projects are successful in improving the quality and quantity of riparian vegetation along streams. Planting projects did not, however, improve streambank erosion or stream shading. Improving both bank erosion and shading depends on having mature vegetation that can provide deep roots to secure stream banks and be tall enough to provide shade; therefore, waiting for projects to become more mature may help yield more significant results.

3. Livestock Exclusion: Livestock Exclusion projects were successful at reducing stream bank erosion, and appear to also be on track to improve stream shading. Shade-providing plants are increasing as projects keep livestock out of streams. Livestock Exclusion projects have not successfully helped to increase the area where canopy, understory, and groundcover vegetation are present, but it may take more time for vegetation to recover to contribute to the canopy layer.

4. Floodplain Enhancement: Floodplain Enhancement projects have successfully improved connectivity of streams to their floodplains, as measured by an increase in floodprone width after restoration. Salmonid use of restored areas shows some signs of improvement as well, with significant increases in densities of juvenile Chinook and Coho Salmon. Chinook Salmon show a strong response, while the Coho Salmon response is mixed. However, several other habitat metrics have not significantly changed after restoration. Pool habitat and riparian condition have not shown any signs of improvement after restoration, and densities of juvenile *O. mykiss* have not increased.

State of Wisconsin. The Wisconsin Department of Natural Resources has a rich history of conducting state-wide, long-term monitoring to evaluate the benefits of stream restoration projects for trout. Published evaluations of techniques in Wisconsin to enhance living conditions for trout in streams are many (3, 4, 74–79). In addition to these published reports, an unknown number of unpublished evaluations exist in the files of WDNR fish managers as part of their station records for waters under their management jurisdiction (3).

In combination, Hunt (3) and Avery (4) evaluated 103 state-wide habitat restoration projects completed on 82 trout streams in 36 Wisconsin counties during the 1953-2000 period. These evaluations were conducted by WDNR fishery management and research biologists and University of Wisconsin-Milwaukee staff.

The success of each project was judged on the basis of the percent change within a restoration reach for four categories of trout:

1. total number of trout
2. number of trout ≥6-inches (legal size)
3. number of trout ≥10-inches (quality size)
4. total biomass, with all categories standardized on a "per mile" basis

Two levels of success were determined: Level 1= post-restoration increases in the population variable of 25% or more; and Level 2= post-restoration increases in the population variable of 50% or more. The habitat restoration techniques employed were grouped into 6-9 categories based on the predominant techniques, which included:

1. Bank covers and current deflectors
2. Bank cover logs and deflectors (high gradient)
3. Beaver dam removal
4. Channel excavation with whole log covers and boulders
5. Streambank de-brushing
6. Streambank de-brushing and half-logs with or without brush bundles
7. Sediment trap and/or gravel spawning riffle
8. Riprap

9. Other combinations

The beaver dam removal category, in restoration reaches supporting allopatric Brook Trout populations, achieved the highest success rates. In sympatric trout populations, the "Wisconsin-style" bank cover and current deflector category achieved the best success rates. The channel excavation with whole log cover and boulders category achieved good results regardless of the trout species present. The bank cover logs and current deflectors category achieved excellent success in high gradient (1-3%) streams. For projects involving allopatric populations of wild Brook Trout or wild Brown Trout, success rates were similar, but in sympatric situations Brown Trout responded much more positively than did Brook Trout to habitat restoration. The composite analyses conducted by Hunt and Avery provide near-identical (Levels 1 and 2) success rates for 244 trout population variables, with composite Level 1 and Level 2 success rates of 59% and 49%, respectively.

Results of the combined analyses provide fisheries managers with habitat restoration choices segregated by regions in the state. Wisconsin's Driftless Area encompasses portions of the west-central (WC) and south-central (SC) regions of the state. In the WC region, bank covers and current deflectors (Category 1) achieved the highest Level 1 and Level 2 success rates. Although this type of habitat improvement is the most expensive, it provides trout population benefits for at least 30 years. In the SC region, bank cover logs and deflectors (high gradient) (Category 2) achieved the highest success rates. Streambank de-brushing and half-logs with or without brush bundles (Category 6) and riprap (Category 8) achieved good success rates in the WC and SC regions, respectively. The "other combinations" category (Category 9) of habitat restoration was highly successful in the SC region. Avery notes that this may be due to the fact that the "bank cover/current deflector" habitat restoration technique was almost always included in the "other combinations" category.

Finally, the growing interest in the impact of human activities on non-game species and endangered plants and animals makes it imperative for the WDNR to evaluate the impacts of habitat restoration on other vertebrates, invertebrates, and plants within the aquatic community and riparian corridor (see Hastings and Hay, this volume). Such multidisciplinary studies are beyond the expertise of fisheries managers and will necessitate both physical and monetary cooperation and involvement from many other disciplines within and outside the WDNR. With increasing budget constraints, this recommendation is meant to encourage better long-term planning and to ensure that future studies have an experimental design that will quantitatively answer as many questions as possible.

Pine Creek, Wisconsin (Driftless Area). In 2007-2011, the Wisconsin Department of Natural Resources (WDNR) and the Kiap-TU-Wish Chapter of Trout Unlimited (Kiap-TU-Wish) conducted an extensive stream restoration project at Pine Creek, a native Brook Trout stream in the Driftless Area of Wisconsin (80). Primary project objectives were as follows: 1) Improve stream temperature regime and armor for climate change; 2) Reduce stream bank erosion to 10% of pre-existing conditions; 3) Increase coarse stream bottom substrate by 50%; 4) Increase numbers of Brook Trout by 40-50%; 5) Increase numbers of Brook Trout 10-inches and larger (quality size) by 50-100%; and 6) Increase aquatic macrophyte growth by 25%.

The Pine Creek Restoration Project restored 2.11 stream miles at a cost of $270,000. In 2009, the project was recognized by the National Fish Habitat Action Plan as one of 10 national "Waters to Watch".

The restoration work at Pine Creek was accomplished using techniques developed by WDNR fisheries managers across the Driftless Area (81, 82). Steep eroding banks were sloped back (typically at a 3:1 slope) to open the stream channel to the flood plain, thereby dissipating flood energy. As a result, stream bank erosion and sedimentation are greatly diminished, water can infiltrate in the riparian area, and water pollutants can be removed and processed. Where suitable, "LUNKER" structures were added to provide trout cover from predators and refuge during floodwaters (5). These structures were covered with rock and soil and then reseeded to stabilize the stream banks. Boulder clusters and root wads were installed to enhance midstream cover. In addition, plunge pools were excavated to create deep water and over-wintering habitat. The installation of bank cover narrows the stream, which results in bottom scouring that exposes gravel substrate favorable for aquatic insects and successful trout reproduction. Bank stabilization results in a decrease in suspended sediment during runoff events, thus improving water quality in the stream. An improvement in the temperature regime of the stream may also occur, due to a narrower, deeper channel, increased current velocity, and bank shading.

Key elements of a monitoring program to evaluate project success included physical and biological attributes measured pre- and post-restoration. Physical attributes included stream temperature and habitat (stream width, water depth, water velocity, canopy cover, stream bank height and cover, and stream bed substrate). Biological attributes included macrophytes, macroinvertebrates, and trout. WDNR staff conducted trout surveys, while Kiap-TU-Wish volunteers conducted all other aspects of monitoring.

Within the Pine Creek stream channel, the restoration project produced some notable improvements, including a 40% reduction in channel width, a 75% increase in water depth, a 62% increase in the presence of coarse stream bed substrate, a 42% reduction in embeddedness, and a 133% increase in macrophyte presence. Based on these data, Project Objectives 3 and 6 were readily met. The 40% reduction in stream channel width and the 75% increase in water depth may have been important factors contributing to the improved stream temperature regime in the lower restoration reach (Objective 1), where stream temperature susceptibility to air temperature was reduced (83).

Conversely, improvements in flow velocity and canopy cover, two additional key factors controlling summer stream temperatures (84), were not achieved by the project work. The slight reduction in flow velocity (-16%) was likely influenced by the increased presence of macrophytes (133%) in the post-restoration project reach. These macrophytes consisted primarily of watercress *Nasturtium officinale* and several varieties of aquatic grasses. The slight reduction in canopy cover (-20%) was not unexpected, as brushing of the stream banks occurred prior to the restoration work, largely to remove undesirable boxelder *Acer negundo* trees. With more time, improvements in canopy cover can be expected, especially those related to streamside shading provided by post-restoration riparian vegetation.

A reduction in stream bank erosion is a primary objective

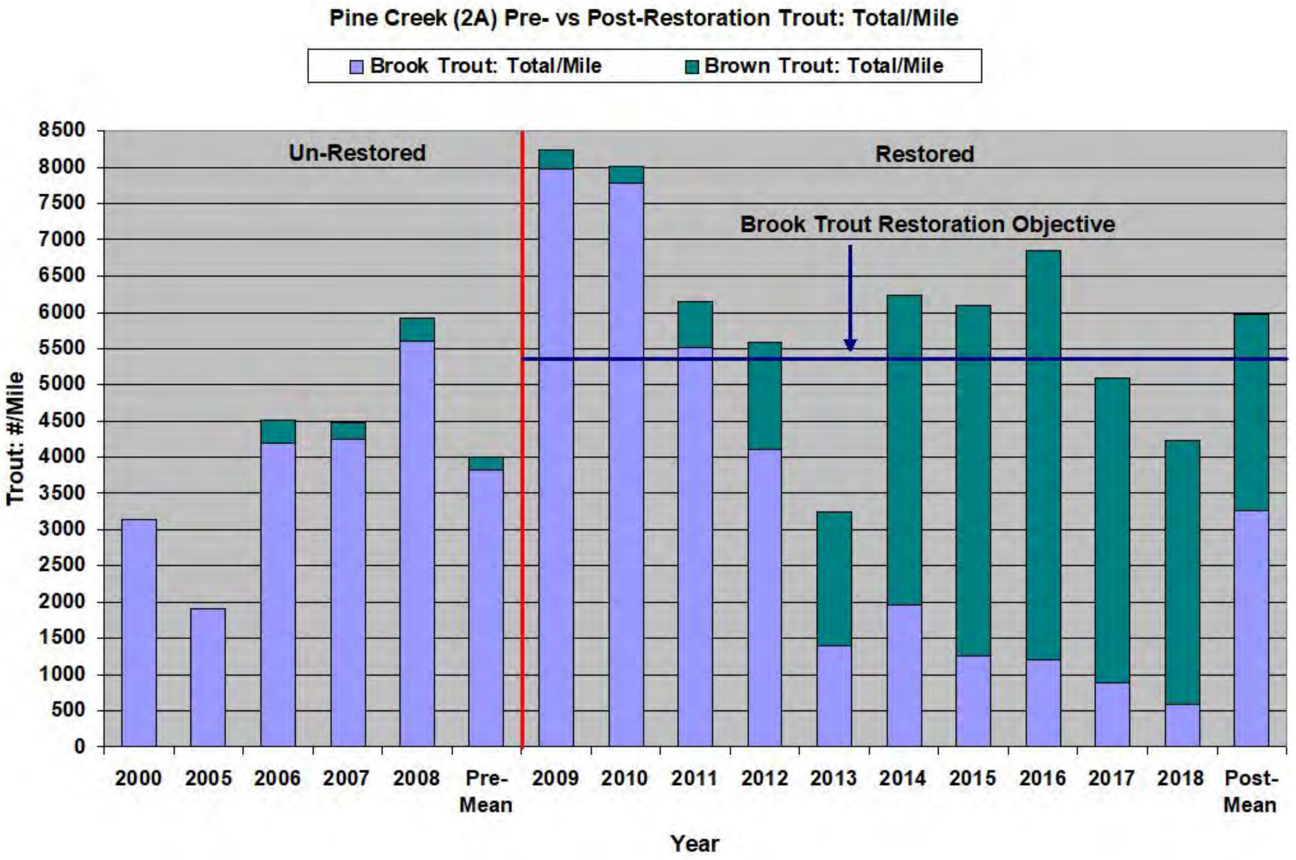

Fig. 13. Pre- and post-restoration abundance of Brook Trout and Brown Trout in Pine Creek.

of all WDNR trout stream restoration projects, and is noted as Project Objective 2 for the Pine Creek Restoration Project. Pre- and post-restoration stream bank erosion potential was not directly measured as a part of the project monitoring program, making it difficult to determine whether this objective was met. However, substantial reductions in bank height (62%) and bank depth (61%) were achieved, and stream banks were stabilized with rock and re-vegetated. As a result of project re-vegetation, a 27% increase in stream bank vegetative cover was evident post-restoration. All of these restoration benefits resulted in a considerable reduction in stream bank erosion potential within the Pine Creek restoration reach.

A post-restoration reduction in macroinvertebrate diversity was evident in Pine Creek, including a 32% reduction in total taxa, a 22% reduction in EPT taxa, and a 36% reduction in Chironomidae taxa. Chironomidae taxa represented the predominant share of total taxa, comprising 44% of the pre-restoration taxa and 41% of the post-restoration taxa. EPT taxa accounted for relatively small proportions of the pre- and post-restoration macroinvertebrate taxa, at 9% and 7%, respectively. Pre- and post-restoration HBI values were nearly identical and representative of very good water quality (possible slight organic pollution) (52).

The greatest unintended consequence of the Pine Creek Restoration Project was a significant post-restoration increase in Brown Trout abundance and decrease in Brook Trout abundance (Fig. 13). Within ten years post-restoration, numbers of Brook Trout per mile decreased by 85% (3,800 to 575), while numbers of Brown Trout per mile increased by nearly 2,000% (175 to 3,650). Project objective 4 targeted a 40-50% increase in Brook Trout numbers. Further, the abundance of 10-inch plus Brook Trout per mile in Pine Creek has decreased by 100% (30 to 0), compared to mean pre-restoration abundance. Project objective 5 targeted a 50-100% increase in 10-inch plus Brook Trout numbers. A continuation of this trend may lead to the loss of the Brook Trout fishery. With Brook Trout being the only native trout species in the Driftless Area, this project highlights the need for appropriate restoration techniques that can protect and enhance Brook Trout in streams that are subject to Brown Trout co-habitation. Hunt (3) notes that in streams with allopatric populations of wild Brook Trout, habitat restoration is typically successful at enhancing these populations. However, in sympatric situations, Brown Trout responded much more positively than did Brook Trout to habitat restoration. The dramatic post-restoration change in trout dynamics in Pine Creek suggests that trout stream restoration in the Driftless Area should not be a "one size fits all" exercise. An exceptionally cold temperature regime in Pine Creek did not provide a competitive advantage for Brook Trout, and Brown Trout removal was unsuccessful, even when abundance was low. Resource managers hoping to protect and enhance native Brook Trout streams, especially those vulnerable to Brown Trout co-habitation, should consider an adaptive management approach that creates habitat favorable for Brook Trout. This consideration will become even more critical as climate change imposes stream temperature regimes that are more suitable for Brown Trout, at the expense of Brook Trout.

Conclusions

Documenting changes in site conditions before and after restoration project implementation is critical to determining whether a project has achieved its objectives. Planning a monitoring program in conjunction with a restoration project facilitates the development of realistic, measurable project goals and objectives and the use of suitable protocols to assess project outcomes. In addition to documenting intended beneficial effects, consistent and systematic monitoring may also highlight inadvertent effects of restoration on target ecosystems. The information obtained through monitoring provides critical feedback to project participants and grantors. Furthermore, qualitative and quantitative monitoring outcomes can help restoration professionals decipher the reasons behind project successes and failures and apply those lessons to their practice (i.e., adaptive management). When project outcomes and the resulting lessons are presented and shared, they help increase the overall knowledge of stream ecosystems and shape the growing science of stream and watershed restoration. Even "unsuccessful" projects that fail to meet their stated objectives can contribute valuable information to this process. As stated by Palmer, et al. (85): "Assessment is a critical component of all restoration projects, but achieving stated goals is not a prerequisite to a valuable project. Indeed, well documented projects that fall short of initial objectives may contribute more to the future health of our waterways than projects that fulfill predictions." To make this possible, it is highly desirable and beneficial to communicate project outcomes and monitoring results beyond project partners, to restoration practitioners, permitting agencies, scientists, landowners, and other stakeholders (20).

Recommendations

Based on the current literature review, some stream restoration monitoring is being conducted in the Driftless Area, largely by state and federal agencies, and as a part of the Trout Unlimited Driftless Area Restoration Effort (TUDARE). The National Fish Habitat Action Plan (NFHAP) provides significant federal funding for aquatic habitat improvement and encourages monitoring to document restoration success. Although stream monitoring is being conducted by a broad variety of federal, state, and local governmental agencies, this monitoring is largely focused on assessing compliance with physical, chemical, and biological water quality standards (such as temperature, dissolved oxygen, pH, turbidity/TSS, bacteria, nutrients, biological indices, etc.). In contrast, little geomorphic and/or biological monitoring is being conducted in conjunction with local stream restoration projects. As a general rule, stream restoration monitoring efforts can be better targeted and coordinated, with an assurance that sound, scientifically-derived metrics are being applied to clearly link stream restoration to physical, chemical, and biological improvements. The timing is excellent for the development of standardized and scientifically-grounded monitoring protocols for evaluation of stream restoration success. Several questions should be considered with regard to stream restoration monitoring in the Driftless Area:

- Where and what types of stream restoration monitoring are occurring throughout the Driftless Area?
- Are there stream restoration monitoring gaps that need to be filled?
- Should a stream restoration monitoring database be established and/or should information on monitoring be included in a stream restoration project database?
- What are the lessons learned from the monitoring work that has been conducted, and how can these lessons be applied to improve stream restoration outcomes?
- Should a Driftless Area stream restoration monitoring committee or working group be established to enhance and/or guide the application of stream restoration monitoring?

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History of Restoration: Destruction, Renewal, and Hope for the Future of Driftless Area Trout Streams

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1. There has been an enormous amount of change in the Driftless Area landscape since Europeans settled the area. By the 1930's some 12 to 15 feet of sediment had eroded off the hillsides onto the valley floors from early farming practices.
2. To their credit, farmers realized early on that soil erosion was the limiting factor to economic stability in the region and implemented a variety of conservation practices (e.g., contour farming, grassed waterways).
3. Conservation practices reduced erosion and benefited stream flows and temperatures, and stream habitat restoration programs improved trout habitat over time.
4. The native Brook Trout *Salvelinus fontinalis* suffered early on, and were replaced by stocked Brown Trout *Salmo trutta*, but today both species can be found in streams in the Driftless Area.
5. Today, the Driftless Area is a destination fishery with a substantial economic impact on the regional economy.

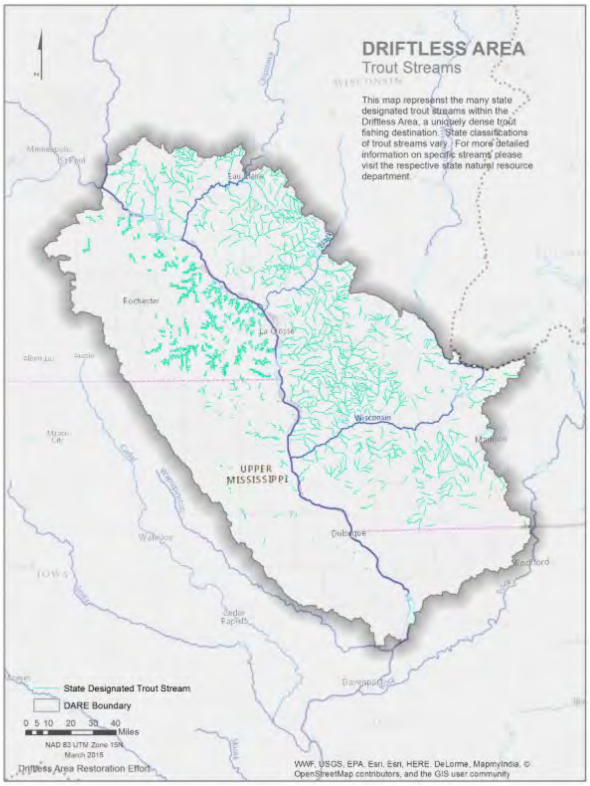
Fisheries Management | Habitat Management | Restoration | Recovery | Trout | History

The Driftless Area of Southwest Wisconsin, Southeast Minnesota, Northeast Iowa, and Northwest Illinois is a unique landform of the United States (Fig. 1). There is no evidence that the last glaciation altered the area unlike most of North America (Splinter, page 5). This lack of glacial drift gave the Driftless Area its name. Unfortunately, there has been an enormous amount of change in the landscape since Europeans settled the area.

The 1800's

Although there had been travellers through the Driftless Area since the late 1500's, it wasn't until the 1820's that the major migration of mostly northern Europeans occurred. They found a landscape that looks significantly different than it does now. Most of the land on either side of the Mississippi River was tall grass prairie or oak savannah. The predominant landforms are coulees, from the french verb "couler" which means, "to flow". Limestone and sandstone bluffs that tower some 400 feet above the valley floor characterize it. The first settlers found a plethora of narrow, deep, crystal clear, spring fed streams that were full of Brook Trout *Salvelinus fontinalis*. Records of 18 to 20 inch fish were not uncommon.

Logging was the first industry with dozens of sawmill sites using the abundant water resources to float millions of board feet of logs from the great forests to the north. Agriculture did not become a major industry until the 1850's with advent of the moldboard plow that was able to cut through the thick sod layers of the prairies. The first crop was wheat as this was the grain early farmers were most familiar with. Wheat was "king" until the 1880's when dairy became the main industry and remains the main industry today (1).



This map represent the many state designated trout streams within the Driftless Area, a uniquely dense trout fishing destination. State classifications of trout streams vary. For more detailed information on specific streams please visit the respective state natural resource department.

Fig. 1. The Driftless Area of southwestern Wisconsin, southeastern Minnesota, northeastern Iowa, and northwestern Illinois. Credit: Driftless Area Restoration Effort (DARE).

Statement of Interest

Coon Valley in the Driftless Area was the first large-scale demonstration project by the Soil Conservation Service (now known as the Natural Resource Conservation Service) in the 1930's due to soil erosion from agricultural practices. Today, the Driftless Area contains a vibrant stream restoration community and destination trout fishery.

This chapter was reviewed by J. Hastings.

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Fig. 2. Sediments from historical erosion deposited on top of pre-settlement floodplain with dark organic soils (line mid-photo).

Fig. 3. Grass waterway in field adjacent to Driftless Area stream.

Unfortunately the "up and down" farming practices that worked well in northern Europe where precipitation may only be 10 inches per year were unsuited to a climate with 32 inches of annual precipitation (1). In addition, the "loess" soils of the region have a consistency of melted ice cream when they are saturated. Hillside dairy grazing quickly denuded the vegetation and the animals' hooves compacted the soil preventing percolation of rainwater and snowmelt. Aldo Leopold later referred to this phenomenon as "water off a tin roof". Soon "rills" began to form. These became head cuts, then gullies, then small canyons. Flash flooding which was rare before European settlement became common by the early 1900's as millions of tons of sediment started their downslope movement. By the 1930's some 12 to 15 feet of sediment had eroded off the hillsides onto all of the valley floors on both sides of the Mississippi River. Accretion rates were 2 to 3 inches each year (Fig. 2). The Kickapoo watershed in southwest Wisconsin alone had 36,000 acre-feet of sediment that had eroded into the valley. If this soil were placed on a NFL playing field the result would be a "dirt monument" reaching 12.4 miles into the sky. As sediment inundated the valleys roads, bridges and fences had to be rebuilt as the earlier ones were buried by tons of soil (1).

Trout, Sediment, and Instream Habitat

Not surprisingly, the Brook Trout fishery also suffered. Lower stream sections became deeply entrenched and middle and upper reaches lost their defined channel and became braided. Instream habitat was lost. Spring flow and base flow were reduced as surface water runoff exceeded groundwater recharge. As streams became wide, shallow and unstable, water temperatures rose and the Brook Trout fishery was replaced by species more associated with warmer water (2).

To their credit, these farmers realized early that the massive amount of soil erosion occurring was the limiting factor to economic stability in the Driftless Area. They petitioned the federal government for help. This resulted in the nation's first watershed project just outside of Coon Valley, Wisconsin. At an experimental farm, the Soil Erosion Service was formed. This later became the Soil Conservation Service and is now the Natural Resource Conservation Service. At this site farming practices that are now standard in the Driftless Area (contour strips, terraces, grass waterways, etc.) were developed and perfected (Fig. 3).

By this time Brown Trout *Salmo trutta* were stocked in area streams, as they are more tolerant of the warmer, more turbid stream conditions (2). Postwar rod and gun clubs initiated some habitat restoration efforts in the 1950's to provide overhead cover for the put-and-take fishery (3). By the 1970's, some stream conditions were improving as better farming practices allowed more groundwater infiltration to occur (4). Although some carryover of stocked Brown Trout occurred, little or no natural reproduction could be found in most waters, as stream temperatures remained high.

Instream habitat structures were short lived as little attention was given to reconnecting the stream to its floodplain, allowing the still frequent flash floods to erode around the single wing deflectors commonly used leaving them high and dry. In the early 1980's Wisconsin Department of Natural Resources made a major change in instream habitat efforts in the Driftless Area by developing a different overhead structure (LUNKERS) and by sloping the stream banks to reconnect the stream to it's floodplain (Fig. 4)(5, 6). As a result, floods no longer caused the amount of damage that was common with earlier efforts.

The 1985 Farm Bill proved to be a watershed event (pun intended) resulting in more groundwater percolation. The Conservation Reserve Program (CRP) paid farmers to idle and plant perennial vegetation on thousands of acres. Cross Compliance required producers receiving any agricultural subsidies to have and follow a conservation tillage plan on their farms. By the late 1980's, base flow and spring flow increased as more perennial vegetation improved groundwater infiltration resulting in colder stream temperatures (7). Fisheries surveys in many streams found more carryover of Brown Trout and for the first time natural reproduction as stream conditions improved (8).

Local efforts by fisheries personnel to improve trout survival resulted in an experimental stocking program of "feral" Brown Trout and Brook Trout. Adults from naturally reproducing, non-stocked streams were stripped of eggs and milt and the subsequent young were raised in a partially covered raceway with automatic feeders to keep human contact to a minimum.

Fig. 4. Recently restored Driftless Area stream with stream buffer, sloped banks, and armored streabank toe.

Fig. 5. Angler fishing a restored Driftless Area stream.

To compare survival of the feral fish against the hatchery strains, matched cohorts were stocked in several streams. A year later the feral trout had out survived the domestic strain fish by a factor of 6:1. A statewide wild trout program was initiated in 1995.

A Destination Fishery

By this time the number of non-local anglers (driving more than 50 miles) increased significantly as word of the ever-improving fishery in Driftless Area spread. Entrepreneurs catered to more urban anglers by providing lodging and more upscale dining experiences. By 2008, a Trout Unlimited economic study found that trout fishing in the entire Driftless Area was a $1.1 billion USD industry and growing (9).

Unfortunately, some of the same issues that plagued the streams in the 1930's still exist. When commodity prices reached record levels several years ago much of the long idled or conservation tillage acreage was plowed up and planted into row crops (10). "Up and down" farming increased along with greater amounts of soil erosion. Large concentrated animal feeding operations (CAFO) in excess of 1,000 animal units increased groundwater issues as more liquid manure is spread on shallow soils over karst limestone. Feedlots adjacent to trout streams allowed large amounts of manure and sediments to enter the water, especially during high flow periods (11).

All of these issues could be addressed by converting more acreage into managed grazing systems (12). Producers using this technology reduce sediment and nutrient runoff as well as reduced amounts of herbicide and pesticide issues by replacing row crops with perennial grasses and forbs. Land is divided into "paddocks" restricting cattle access to a small area for a short time with adequate rest periods to allow vegetation to recover. Research has shown that producers using managed grazing systems can show a profit of $524 USD per cow versus a profit of just $132 USD per cow using a conventional confinement system.

Today the Driftless Area rivals angling opportunities that are found in the western and some northeastern U.S. streams. Waters that were non-trout in 1980 had naturally reproducing, self-sustaining populations of both Brook Trout and Brown Trout by 2010 (Fig. 5). Just in the four counties of the La Crosse Area in Southwest Wisconsin, more than 400 miles of newly classified trout water was added to the "Trout Book" bringing the total to more than 1,000 miles. Numbers in excess of 3,000 trout per mile are not uncommon in streams where only 200 fish per mile could be found just two decades before (6). A 2017 follow up study of Trout Unlimited's 2008 economic impact found that trout fishing had added another 500 million dollars bringing the total to $1.6 billion USD (13). This amount is expected to increase as more local communities realize the positive economic impact of healthy watersheds.

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Standards of Practice in Stream and River Restoration

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1. Stream restoration in the United States is big business, with annual expenditures in the billions of dollars and increasing every year.
2. Stream restoration, broadly defined, before 1980 typically involved basic reconnaissance and little or no engineering design or related standards of practice.
3. Perhaps the most important reasons for standards of practice is to help develop criteria for measuring project success. Failure to establish clear goals and objectives for projects makes establishing design criteria difficult or perfunctory.
4. Because of the variability of natural systems (e.g., streams), some have argued that standards for unique restoration projects are implausible or inappropriate, but the restoration engineering community has expressed a need for performance-based design criteria and guidelines to develop such criteria.
5. Standards of practices for the restoration in the Driftless Area are proposed in this paper.

Driftless Area | Goals | Objectives | Engineering | Design | Monitoring

Fig. 1. Restored Driftless Area stream with armoring of the bank toe. Credit: Dauwalter.

Historically, stream restoration projects in U.S. were designed and implemented by state or federal agencies, who completed assessment, design, and construction internally. The vast majority of trout stream habitat projects were small in size and were able to be done cheaply by government work crews. In the past 20 years, as funding has increased for stream restoration projects, average project size, complexity and cost have increased. In addition, our understanding of stream hydrologic and geomorphic processes has expanded greatly. Stream restoration is big business, with annual expenditures in the billions of dollars and increasing every year (1).

As Koonce (2) details, designing and implementing stream restoration techniques is a field of engineering and landscape architecture that has no generally agreed upon standards of practice. Many different approaches are used, some analytical and others experience based, which leads to confusion and disagreement among professionals and complicates adequate review of proposed and completed projects.

Restoration is defined as the action of returning something to its former condition. The Society for Ecological Restoration defines ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. However, it is noted that stream restoration commonly refers to a wide range of project types and activities, including bank stabilization, channel reconstruction and fish habitat installation (Table 1). In this section, historical and current views on stream restoration standards of practice are outlined, and recommendations are made for applying standards of practice to projects in the Driftless Area.

Industry Development of Practice Standards

Stream restoration project implementation before 1980 typically involved basic reconnaissance and little or no engineering design or related standards of practice. Urban stabilization projects utilized and are often still utilizing threshold channel design standards or standard riprap calculations for basic hard armoring, threshold channel design being focused on little to no channel boundary movement at or below design flows (3, 4). The Natural Resource Conservation Service (NRCS) has developed some standards for channel and wetland restoration, but these sometimes involve hard armoring streambanks to a specified water surface elevation (e.g., 25-year return interval flow)(Fig. 1). More recent guideline documents integrate geomorphology, bioengineering, and hydraulic engineering in channel and bank stabilization design (5–10). From the evolution of these documents, it is evident that in the last 30 years, stream restoration practitioners have been slowly developing a

Statement of Interest

In the last 30 years, stream restoration practitioners have been slowly developing a collective standard of practice without formally documenting or even being aware of the process. Perhaps the most important reason for developing standards of practice is to help develop criteria for measuring project success.

This chapter was reviewed by B. Nerbonne.

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Table 1. Restoration has been defined with a very specific definition, but it is also used as a term that encompasses a variety of other related terms and definitions. From Roni (18).

Term	Definition
Restoration	To return an aquatic system or habitat to its original, undisturbed state. It can be partitioned into passive (removal of human disturbance to allow recovery) or active (active manipulations to allow recovery). It is broadly used to include additional terms below.
Rehabilitation	To restore or improve some aspects of an ecosystem but not fully restore all components.
Enhancement or Improvement	To improve the quality of a habitat through direct manipulation (placement of structures, addition of nutrients).
Reclamation	To return an area to its previous habitat type but not necessarily fully restore all functions (e.g., removal of fill to expose historical floodplain).
Creation	Construction of new habitat or ecosystem where it did not previously exist (e.g., creation of off-channel pond).
Mitigation	Action taken to alleviate or compensate for potentially adverse effects on aquatic habitat that have been modified or lost through human activity (e.g., creation of new wetlands or replace those lost through land development).

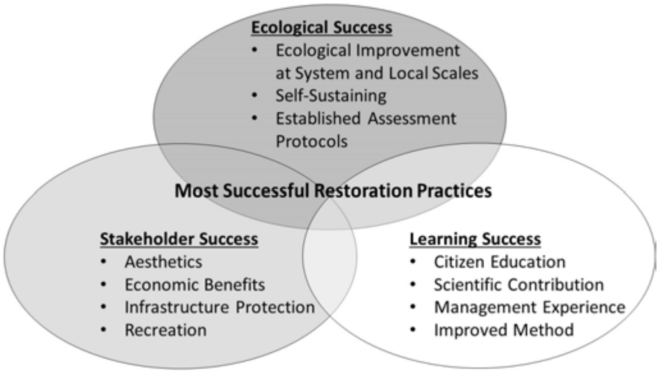

Fig. 2. The most effective river restoration projects lie at the intersection of the three primary axes of success. From Palmer, et al. (17).

collective standard of practice without formally documenting it or even being aware of the process.

Why Standards of Practice?. Perhaps the most important reason for developing standards of practice is to help develop criteria for measuring project success. Sustainable practices in the field of river restoration include the development of project design criteria, and a set of measurable goals for a project (11). Such criteria might specify the river flows under which a project will remain stable, or they might specify areas and volumes of restored habitat. These numeric criteria are measurable and can help determine if a project was successful or not.

Researchers have long stressed the relationship between goals and objectives and monitoring of project effectiveness (2, 5, 12–16). As Koonce (2) states, failure to establish clear goals and objectives also makes establishing design criteria difficult or perfunctory.

Prior to establishing numeric design criteria, it is recommended that project specific performance criteria be established. These answer the more general question, "what are we trying to achieve by doing this project?" and can be unspecific. In their review on the subject, Palmer, et al. (17) proposed five general criteria for measuring stream restoration project success from an ecological perspective:

- The design should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site.
- The river's ecological condition must be measurably improved.
- The river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed.
- During the construction phase, no lasting harm should be inflicted on the ecosystem.
- Both pre- and post-assessment must be completed and data made publicly available.

This list is a good starting point for developing performance criteria for Driftless Area projects. Other performance criteria may include such things as increased juvenile or adult cover, increased spawning habitat, improved habitat for turtles and other herptiles, increased bird habitat, or hydrologic improvements such as reduced peak flows and increased base flows. There is room in this process for the inclusion of other performance criterion that relate to recreation (angling) and agriculture, two obviously important regional considerations. Palmer, et al. (17) argues rightly that projects labelled restoration successes based on recreational or agricultural criteria should not be assumed to be ecological successes, and that projects initiated in whole or in part to restore a river or stream must also be judged on whether the restoration is an ecological success (Fig. 2).

Performance criteria and the subsequent numerical design criteria are established through consensus with the project funders, managers, and designers. The following list is an example of some of the potential numerical design criteria for an idealized channel meander restoration project:

- Design flows - The project shall be designed while considering baseflow (4.5 cubic feed per second [cfs]), bankfull (12.8 cfs), and flood flows (50 years for floodplain stability, 100-year return interval flow for bridge stability).
- Installed elements shall be designed to undergo minimal adjustment for the first eight years after establishment of vegetation. During this initial period, installed below bank project elements shall be stable up to but not in excess of the 10-year flood event, whereas floodplain

elements shall be stable up to but not in excess of the 25-flood event.

- The project will create 4.13 acres of new stream channel (sub-bankfull) including a 20% increase in pool habitat and spawning habitat over existing conditions, 14.5 acres of reconstructed floodplain, and 4.2 acres of off-channel vernal pool wetland habitat.

- Reconstructed road crossings shall be designed to pass flows up to the 50-year return interval flow. Crossings shall be designed to safely overtop without damage up to the 100-year return interval flow.

The above example list is a truncated set, but the criteria shown illustrate several important points. First, design criteria establish the project risk boundaries, inside which the designers must develop plans. The design flows are established, as are the areas and volumes of habitat to be created. The designer now has a set of recorded design targets from which to base the design.

Second, the above criteria include event-based performance, which is critical given the unpredictable nature of river flow. The above project could design all elements to withstand the 1,000-year flood event, but those solutions would likely be prohibitively expensive, involve structural armoring, and would not be conducive to improving trout populations, which is typically the main goal of Driftless Area projects. Project partners in this case have decided upon different flood flows for initial stability.

Third, the criteria include temporal limits on stability. This is a critical distinction in river restoration projects. Ideally, the least expensive and most ecologically sound projects would be those that establish a stream that is dynamically stable and self-maintaining in the future. Any stream restoration that involves hard armoring of any kind, particularly in alluvial systems, will eventually fail, because the natural tendency of rivers is to adjust both in cross-section and location within a valley, either slowly over a series of smaller events (e.g. sub bankfull) or dramatically during larger flood events. The above example establishes a period of non-deformability, which allows for stabilizing vegetation to establish. Beyond this initial period, the river is allowed to adjust. The alternative is to design a channel that is also non-deformable or static in the long term, which may be desirable if the goal is to protect infrastructure or cropland. The design life of a static project is then based on the longevity of the materials and the forces acting on those materials.

The standards of practice that assist in design criteria development then include, among others, adequate assessment of the geomorphology and ecology of the project area, prediction of the geomorphic response of the reach in question, accurate assessment of the hydrology of the region and the watershed, calculation of hydraulics of the reach, determination of the sediment transport affecting the project reach, and assessment of factors that will determine vegetation establishment (e.g. soils, climate)(Figs. 3, 4).

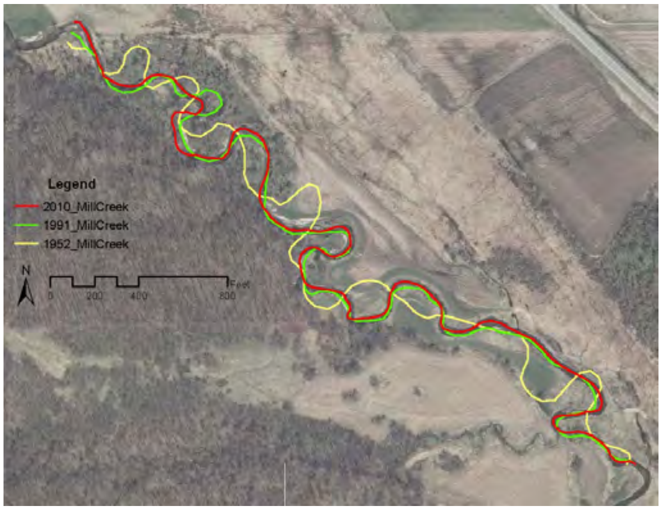

Fig. 3. Evaluation of the planform geometry of Mill Creek, Minnesota across three time periods. Credit: Inter-Fluve, Inc.

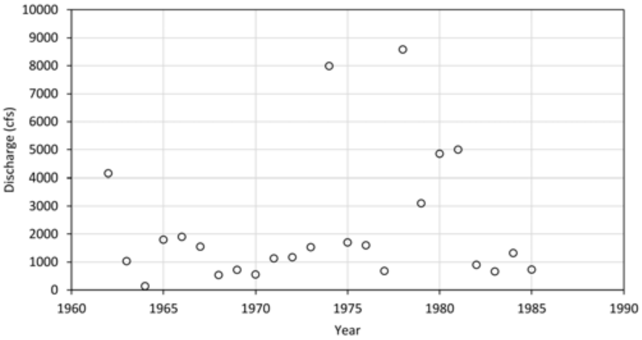

Fig. 4. Annual peak steamflow for Mill Creek, Minnesota from 1962 to 1985. Credit: Inter-Fluve, Inc.

The Role of Engineering

In the 20th century, engineering of waterways was concentrated on either retaining water or removing water from urban/agricultural areas, resulting in damming, channelization and armoring of millions of miles of urban systems. This approach did not typically include consideration of ecological consequences. Conversely, habitat improvement or stream restoration focused on fisheries in rural areas with limited engineering considerations. Modern practitioners of river restoration are recognizing that the synthesis of multiple disciplines is required for successful restoration (2).

As river restoration projects become larger and more complex, the risk associated with them increases. Projects involving channel relocation, floodplain grading, bank stabilization and road crossing modification or replacement can fail in a variety of ways. Failure of water projects can result in the loss of the taxpayer or private funding that paid for implementation, loss of future restoration funding, and damage to life and property. These risks and the definitions of engineering and landscape architecture in most states require that modern river restoration practice be subject to the rules governing those fields. The state of Wisconsin defines the practice of engineering as "any professional service requiring the application of engineering principles and data, in which the public welfare or the safeguarding of life, health or property is concerned and involved, such as consultation, investigation, evaluation, planning, design, or responsible supervision of construction, alteration, or operation, in connection with any public or private utilities, structures, projects, bridges, plants and buildings, machines, equipment, processes and works."

Landscape architecture is similarly defined by Wisconsin statutes as including, among other services, "the production of a graphic land area, grading, drainage, planting or land construction plan; and the planning of a road, bridge or other structure with respect to the aesthetic requirements of the area on which it will be constructed. . . "

Engineers and architects assume professional liability for the designs they produce. According to the American Society of Civil Engineers (ASCE), the purpose of licensure is to demonstrate competence in the field of engineering and to perform a design that safeguards the life, health, and welfare of the public and to comply with the principles of sustainable development (see ASCE Code of Ethics). As Slate, et al. (19) described, licensure and the affixing of an engineering seal to a design do not guarantee "success" of a project, but the seal indicates that the engineer has exercised his or her best professional judgment upholding the industry "standard of care" in the design process. Civil engineers and architects have many available design standards for myriad structures such as curbs, catch basins, stairs, doors, walls, bridges, streets, lighting, and so on. They design these structures based on industry standards and apply a factor of safety to ensure that the designs function as planned.

Engineering of Natural Systems

It is becoming more widely accepted that engineering and architectural professionals need to seal river restoration designs. Those that design river restoration projects without obtaining a professional seal need to be aware that they may be practicing engineering or landscape architecture without a license, which is illegal in every state in the United States. Simply practicing with an expired license can result in thousands of dollars of fines. Engineers and architects carry liability insurance that can, but not always, cover the work of the designer in the event of a failure under conditions not covered by the design criteria. For instance, if a fish passage culvert project is designed to be stable up to the 100-year event, and is washed away during a 50-year event, the design engineer may need to enlist his or her engineering liability insurance. This highlights the importance of developing solid design criteria to protect both the project owner and the designer. Design reports or technical memoranda should be developed for every project to clearly spell out the design criteria.

Because of the high level of risk involved, obtaining engineering liability insurance to cover river restoration may not be a simple process. Some pioneering firms have had to develop personalized insurance coverage specific to river restoration work, and premiums regularly exceed those for standard civil engineering (G. Koonce, pers. comm.). Engineering liability insurance for the design of recreational boating and kayak courses is so specialized and expensive that only a few firms in the country are able to practice.

River restoration using large wood (Fig. 5) introduces additional risk that is often poorly understood by novice or part-time practitioners and often requires significant engineering *due diligence*, that is, care that a reasonable person exercises to avoid harm to other persons or their property. Failure of large wood projects can occur due to inadequate assessment of buoyant and drag forces, trapping of debris, potential scour and erosion, torqueing, soil pumping and piping, and can lead to significant infrastructure failure due to downstream transport and racking on bridges, culverts and other infrastructure. Additional risks of large wood projects include occupational health and safety of installation contractors, attractive nuisance hazards, increased flooding, and the pinning and trapping of recreational boaters.

Fig. 5. Wood incorporated into a stream restoration project in southwestern Wisconsin. Credit: D. Dauwalter.

Every project requires a level of engineering due diligence to help minimize risk. The amount of engineering due diligence varies along a spectrum, with simple and inexpensive, low risk projects requiring less, and more complex larger projects requiring more. Skidmore, et al. (20) demonstrates this level of due diligence under the River Restoration Analysis Tool approach. The River RAT guidelines are an example of a system that directs practitioners to standards applicable for their required level of engineering due diligence.

River systems engineering differs somewhat from standard structural civil engineering in many ways, and these differences make it difficult to develop simple standards of practice:

1. Because of the many fields involved with river restoration, training and education in river restoration often must be gained from a variety of sources. Just the science of forensic fluvial geomorphology alone is complex, and accurate assessment requires many years of experience. Assessment of geomorphic stability and identification of potential problems is subjective and prone to error. Overestimation of bank erosion rates and channel adjustment are common and can lead to unnecessary or misapplied restoration projects. Civil engineers, even those with hydraulic engineering focus, are not necessarily trained in river restoration but are nevertheless designing and overseeing the construction of river restoration projects. Most civil engineers lack education and training in ecology, botany, and geomorphology. Conversely, many fisheries biologists and stream ecologists are practicing geomorphology and designing projects without geomorphology and engineering education, and only limited training related to those fields. It is thus critically important that people obtain cross-over education and training, and collaborate with other experts in the appropriate fields.

2. Natural materials vary in their shape, density, and longevity. Stone, soil, wood, and vegetation come in a variety of forms. Wood, for instance, can be green or dried, of variable diameter and length, have variable root and branch forms, and varying concentrations of resin, tannic acid, and lignin, all of which influence design life.

3. Multiple disciplines are needed to understand how project components fit together in a natural system. A project design typically needs to consider not only civil engineering and stormwater engineering, but also geology, geomorphology, hydrology, soils, hydraulics, sediment transport, botany, fisheries, stream ecology, horticulture, the social sciences, and occasionally environmental engineering when dealing with contaminated sediment.

4. River restoration projects have factors that revolve around streamflow, which is increasingly unpredictable. Baseflow for habitat varies during drought and wet years and with changes in landuse. Peak flows are highly variable and subject to changes in landuse, climate, and local weather patterns. Sediment movement is dependent on streamflow, and also on local perturbations such as riparian management, debris accumulations, local soil variability, and manmade structures.

5. Vegetation growth rates and the success of bioengineering solutions depends heavily on contractor warranties regarding watering, and also on streamflow and precipitation, which can very greatly.

6. Installed conditions can change greatly over time. Wetlands may convert to forested swamp, or a riparian grass community may convert to shrub scrub or forest over time, thus changing floodplain roughness and affecting both stream power and sediment movement. Conversely, forested riparian zones may be logged or converted to agricultural uses, and watersheds may experience increased impervious coverage with development. Geomorphic conditions such as channel base elevations, sediment movement, lateral channel migration, floodplain aggradation may increase or decrease during wet and dry periods.

7. Catastrophic or geomorphically significant floods may reset conditions on a watershed or reach basis and completely eliminate installed projects. The commonly understood equilibrium channel condition of streams can be wiped out, and channel locations can change dramatically during large floods (21, 22). Civil engineering projects are subject to extreme weather such as tornados, and earthquakes in tectonically active areas, but these impacts to civil projects are relatively rare. Extreme floods in the Driftless Area are becoming much more likely with increased global warming effects. Precipitation falling in 100-year storm events has increased by 37% in the Midwest, with as much as 50% of annual total precipitation falls during 10 days of the year in the western Great Lakes region. Accumulated precipitation during these 10 days has increased dramatically, with increases of 20-30% observed from 1971-2000 in many locations (23–25).

8. Although civil site areas, elevations, and soils can differ, standards can be developed more easily because building and structural components are typically the same. Buildings require customized foundations, but they are almost always concrete, the standards for which are established. In contrast, each subreach of a stream in the Driftless Area, or anywhere for that matter, is different from the next. Although some reference analog conditions may be similar to the project reach, there are almost always idiosyncrasies associated with a particular site. Floodplain morphology may differ, bank soils may differ, bedrock contacts are variable, floodplain encroachment and filling vary, roads and road crossings impact hydraulics during flooding, agricultural practices differ, watershed and valley morphology are unique, and riparian management varies (Fig. 6).

Fig. 6. Transition from open understory riparian vegetation to dense understory at Trout Run in southeast Minnesota. Credit: D. Dauwalter.

Standards of Practice for River Restoration

Because of the above variability, some have argued that standards for unique river restoration projects are implausible or inappropriate (11). The river restoration engineering community has expressed a need for performance-based design criteria and guidelines to develop such criteria (19). In many ways, standards have been developed over time and are continually being refined. Open channel design methods and channel design methodologies based on hydraulic and geotechnical principles have been around for decades and some are updated regularly (5, 6, 9, 26–28). New standards are being published based on increased levels of experience. For instance, the U.S. Bureau of Reclamation and Army Corps recently published the Large Wood Manual detailing practices used in the industry, and some states have published habitat restoration guidelines that guide the level of engineering for various projects (10, 12).

Some state agencies have placed special emphasis on the analog-empirical methodology offered by the Rosgen method, also called the reference reach method or natural channel design (29, 30). Some ecologists and fisheries biologists at state and federal agencies have invested heavily in this approach, which involves several weeks of short course training in data collection, analysis, and design. In general, the Rosgen approach emphasizes empirical relationships of valley and channel form and relates these to channel evolution through comparison of current and potential channel forms (31–34). The Rosgen approach is somewhat controversial, as described by Lave (35), and has been a source of debate among academics and practitioners for over twenty years (29, 34, 36–40).

The Rosgen approach is attractive to both engineers and non-engineers, and has been used successfully by many practitioners in the region. Short course training in geomorphology, ecology, and other disciplines is an excellent way for professionals to expand and progress toward a more complete understanding of the various disciplines. Reference reach or analog based design techniques can still be conducted without taking short courses or directly applying every aspect of the Rosgen methodology as published. Many practitioners educated and trained in fluvial geomorphology use analog and empirical data as part of a larger design process.

Hydraulic analysis is often part of the due diligence for stream restoration projects, and may be simple at-a-station calculations (e.g. Manning equation) or more complex computer models. Some situations require hydraulic modeling as part of due diligence. Projects in Federal Emergency Management Agency (FEMA) mapped areas must not cause a rise in the 100 year flood elevation compared to the modeled pre-project condition. Many design criteria detail stability requirements under various flows (such as the bridge safely overtopping during the 100-year return interval flow).

Standard practices for hydrologic and hydraulic modeling are changing rapidly as technology advances. As recently as 2000, geographic information systems (GIS) software were not advanced enough or readily available for application in the river restoration field, and hydraulic modeling software was expensive and time consuming. Advances in technology on many fronts have led to a synthesis of laser and GPS satellite-based surveying, powerful hydrologic models, computer aided drafting (CAD) software and both one- and two-dimensional hydraulic modeling (e.g. HEC-RAS). The programs used today make it much easier to assemble data and produce robust, predictive models incorporating hydrology, geomorphology, hydraulics, and sediment transport analysis where data allows.

The tools described above comprise a variety of standard practices. No single method or prescribed combination of methods can satisfy all of the engineering or architectural due diligence requirements, nor should they be expected to given the variability in river restoration as noted above. The amount of due diligence should not be dictated to the designer by a strict set of standards or a singular methodology. As Slate, et al. (19) asserts, "by gearing designs to satisfy specified, measurable criteria, engineers will be able to select the most appropriate design methods for a given project across a wide variety of boundary conditions and system processes." What is needed is a broader professional acceptance of multiple scientific design approaches for river restoration projects, a distinction between engineering and non-engineering practices, and quantifiable project goals to more easily evaluate success or failure.

Standards of Practice and Monitoring. Design criteria are documented in design reports, but are also reflected in specifications and plans. Many specifications have been standardized by state agencies, and thus are also a part of the industry practice standard. Design criteria, plans and specifications all form the basis for project success monitoring. Plans and as-built plans can be used to determine physical changes such as erosion, deposition, sediment movement, and changing channel dimensions, and ecological surveys can document changes in riparian vegetation, stream macroinvertebrate communities, and fish populations.

Setting realistic and achievable goals is an important part of design criteria development, and is supported by standards of practice. One of the first practice standards employed is the stakeholder meeting, the first of which is used to establish realistic project goals. Palmer, et al. (17) argue that rather than attempt to recreate unachievable or even unknown historical conditions, a more pragmatic approach is one in which the restoration goal should be to move the river towards the least degraded and most ecologically dynamic state possible, given the regional context (17, 41–43). For example, although a prairie dominated floodplain and riparian area may have been the historical condition for a particular reach, prairie restoration is extremely difficult to achieve and maintain, and may not be an achievable goal. Similarly, designing a project to increase Brook Trout *Salvelinus fontinalis* spawning may be desirable, but if piscivory by Brown Trout *Salmo trutta* is high, and the geology and geomorphology preclude meaningful installation and maintenance of Brook Trout spawning habitat, another performance criterion may be more appropriate.

As mentioned above, Palmer et al. imply that monitoring should be completed for every project. It is, however, unrealistic to expect every project to include the same level of monitoring. The degree of monitoring should be commensurate with the level of project risk, complexity, and cost. Simple projects may only need repeat photography or perhaps a site visit annually for the first few years post construction. Other projects may need a comprehensive monitoring plan based on assessment of design criteria. Some basic monitoring elements are listed below:

- **Stability** – Short term stability and long-term project change can be monitored by tracking physical changes both before and after construction, and for milestones proceeding ahead from Day 1 of post construction (site maturity). These have as their base, project surveys that include the following:
    - *Pre- and Post-Project Surveying* – Geomorphic or engineering-based surveys can be modified to include desired monitoring. For example, in addition to hydraulic or topographic sections shot for drafting purposes, permanent cross-sections or digital elevation models (DEMs) can be surveyed in greater detail and more permanently monumented for long term monitoring. GIS based surveying makes this process easier by reducing the need for multiple benchmarks.
    - *As Built Surveying* - Surveying of key structures or forms such as pools, riffle forms, bars, boulders and pocket water, large wood pieces, and other elements allows for monitoring of changes, and helps to document differences in project drawings versus what is actually constructed.
    - *Repeat Photography* - Photographs taken from established photo stations are an inexpensive way to monitor changes in vegetation communities and channel stability. Photogrammetry is now being

used whereby photographs from multiple perspectives are translated into actual topographic surface data. Drone photography allows for GIS located, low flying aerials to conduct repeat photography during both low and high-water events. Drone imagery can be extremely valuable in calibrating both pre- and post-construction flood modeling by accurately and safely documenting flood extents at known flow levels.

- **Fisheries** – Designing biological monitoring studies, including fisheries, is a complex science in and of itself (44, 45). Showing fisheries population changes that demonstrate changes related to large projects is difficult, and for small projects nearly impossible. Confounding variables such as attraction, production, climate, stream flow, temperature, turbidity, year class strength, angling and natural mortality must be quantified and controlled to the degree possible (46).

- **Macroinvertebrates** – Measuring the presence or absence of macroinvertebrates is relatively simple, but measuring population size changes related to restoration projects is challenging. Because of the inherent variability in macroinvertebrate populations, quantification of aquatic insect and macroinvertebrate populations typically requires a large number of samples and is cost prohibitive. A simpler approach is to employ studies that focus on the tolerance of species or families of invertebrates to water and habitat quality (indices of biotic integrity), or behavioral groups that reflect assemblages and can help monitor changes as a result of a project (e.g. functional feeding group assemblages). Qualitative studies such as biotic integrity comparisons, feeding group analysis, diversity indices and relative abundances require fewer samples and are less expensive. There are many references available to aid in macroinvertebrate monitoring (47–53).

- **Plants** – Plant success is critical to any river restoration project. Construction contractor warranties for plant health can be integrated into a long-term operations and management plan. Typically, contractors need to monitor and/or replace plants and seeding annually for 1-3 years, after which, project owners or partners need to take over monitoring of plant community success. Plans can include monitoring tree and shrub health, coverage of native species seeding or plug plantings, plant protection (cages, tree tubes etc.) maintenance and eventual removal, invasive species treatment, and plant watering. There are many Federal, state and local resources for native plant restoration and monitoring. State resources include local land and water conservation offices, University extension, and documents such as the Minnesota Board of Water and Soil Resources *Wetland Restoration Guide* that offer guidance related to plant management and monitoring (54).

Several authors have addressed the need for monitoring stream restoration projects, and have presented generalized outlines (14, 18, 45, 55–58). Guidelines for monitoring stream projects have been published by many state and federal agencies, and cover both physical and biological monitoring strategies (47, 59, 60).

Recommendations

In summary, standards of practice in river and stream restoration involve a variety of methods covering multiple disciplines (Fig. 7). The key to successful projects is to develop performance and design criteria that protect the project owner and designer from excessive liability, allow the engineer or designer to design a project that will meet multiple objectives while improving ecological health, and establish targets for monitoring success. The following recommendations are offered related to the application of design practice standards in the Driftless Area:

1. Channel design for stream restoration involves many sciences, and successful collaboration among people and fields of study is essential to project success.

2. Design standards of practice should be performance based, and centered around established performance criteria and published, project specific numerical design criteria.

3. Any development of a performance-based set of standards should consider multiple methods or design approaches involving multiple disciplines to achieve a common goal. No one methodology should be adopted as a standard of practice.

4. Engineers and landscape architects, if part of a design team, should work with other disciplines to ensure success.

5. Design goals should be clearly defined and based on general physical principles and channel processes, rather than solely referenced to an empirically defined equilibrium state. Urban and rural infrastructure influences, climate change impacts, changing landuse and potentially damaging flooding must be considered when determining the amount of engineering due diligence required.

6. Geomorphic assessment by qualified personnel should form the basis of any watershed or stream restoration program. Quantifying the geomorphic state of reaches, stages of channel evolution, channel stability, and future changes can help determine potential projects and both the spatial and temporal sequencing of those projects. Geomorphic based watershed assessments, combined with local management knowledge of angler and landowner goals, can better target available funding to have the most positive impact. Qualified personnel should have a combination of education, training, and demonstrated experience in evaluating stream geomorphology.

7. Stream restoration within a watershed should generally flow from headwaters to downstream to address hydrologic solutions for reducing peak flows and increasing base flows.

8. Stream restoration practitioners optimize the benefits of available design strategies, including analog, empirical and analytical approaches, and must ensure that the unique constraints and hydraulic characteristics of their project reach are quantified.

Fig. 7. Stream restoration project in southeast Minnesota.

9. Performance criteria and design criteria should consider both time and space considerations, short term, and long term deformability and successional changes.
10. Design criteria should form the basis of short and long term monitoring programs.

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