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.

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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).

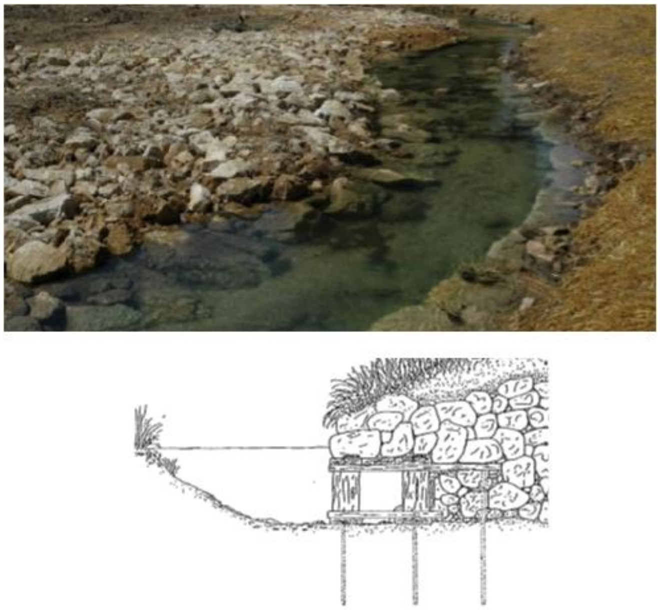

Fig. 5. Typical installation of trout habitat LUNKER structures in a Driftless Area stream.

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.

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.

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).

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.

Fig. 10. Collecting a water sample (top) and measuring water clarity (bottom) 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.

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).

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

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).

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

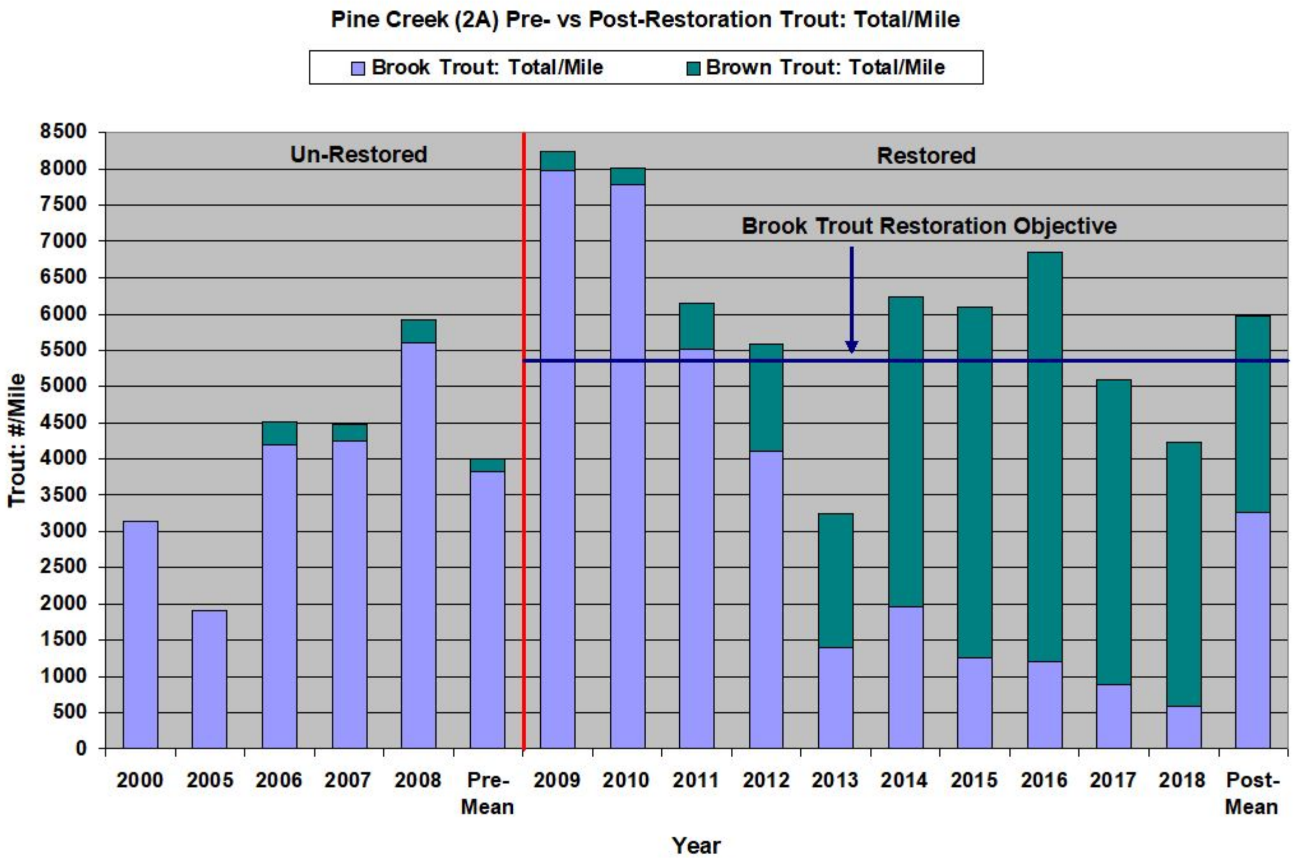

Fig. 13. Pre- and post-restoration abundance of Brook Trout and Brown Trout in Pine Creek.

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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