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reclamation matters

Fall 2020

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The Reclamation Cost Estimator is an engineering-based program that uses your project and site parameters to estimate the equipment, labor, supply, and administrative costs associated with mine site reclamation.

Designed to quickly estimate the costs of a multitude of common reclamation tasks including water treatment, demolition, disposal, earthwork, reseeding, adit and mine closure, and long-term monitoring, the Reclamation Cost Estimator provides the tools, the methods and the costs associated with each activity common during and after mine closure.

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- Adits
- Shafts
- Drill Holes
- Leach Pads
- Ponds & Impoundments
- Pumping

DEMOLITION

- Buildings
- Foundations
- Pavement
- Culverts & Pipes
- Fencing

EARTHWORK

- Excavate/Stockpile
- Excavate/Load/Haul/Dump
- Load/Haul/Dump
- Slope Reduction
- Road Rehabilitation
- Spreading & Contouring
- Fine Grading

SITE-WORK

- Fence Installation
- Soil Stabilization
- Armoring
- Scarifying

DISPOSAL

- Vehicles
- Machinery
- Solid & Liquid Waste

MONITORING

- Well Construction
- Sample Collection & Analysis

PLANTING & SEEDING

- Seed
- Live Plant
- Soil Amendment

Greetings from the Northwest

BY DUSTIN WASLEY, P.E., PRESIDENT OF ASRS

I think it is safe to say that we have had an interesting 2020, one none of us will forget.

Founded in 1973, our society has evolved and changed over the years from our first inception as an advisory council in West Virginia, to now the American Society of Reclamation Sciences (ASRS), which extends internationally.

My first involvement with ASRS (then ASMR) was attending the 2013 Annual Meeting in Laramie, WY. I was immediately drawn to the welcoming nature of the society and the high technical content of the presentations. I was hooked! Since then, I have been actively involved with the society, including hosting the annual meeting in Spokane, WA in 2016, serving on the national executive committee (NEC) and the strategic planning subcommittee, and now as president.

This is the first year we have not held our annual meeting since the 1984 inaugural meeting in Owensboro, WY. While this was disappointing to myself and many others, it was necessary given travel limitations and health concerns across the U.S. and world. I know that we were all looking forward to visiting Duluth in 2020, but the good news is that you will get your chance in 2022. The status of our 2021 annual meeting in Boise, ID is in discussion; our local planning committee has been meeting and we will keep you posted.

We are in the third year of implementing our strategic plan. The remaining focus areas are expanding and growing membership, implementing the branding campaign, revamping our technical divisions (TDs), assessing our journal name (JASMR), and investing in our early career professionals (ECPs) and students.

Membership has fluctuated over the years. Since 2013, membership has declined from roughly 400 to 250 in 2020. Some of the decrease is related to the lack of hosting the 2020 annual meeting, where people typically renew their membership and new attendees opt to join the society. To continue our viability and thrive as a society, we need to increase our membership, including more opportunities to "plug in", such as technical webinars, technical bulletin boards, and events that invest in our ECPs and students. We are planning to hold our first webinar this fall, so please watch for more information on these valuable opportunities for you, our members. If you have additional ideas, please reach out to me.

With our new name, we are implementing a new look and feel through a branding campaign. The branding campaign rollout will include a brand style guide that outlines logos, colours, icons, etc., to be used by the society to keep a fresh and consistent look and feel. We will also be updating our social media accounts and creating a new ASRS brochure to educate and recruit new members. There are more things related to branding that you will see in the coming months, including revamping our website.

We also have a new TD representative, Julie LaBar, that is leading the charge on revamping our technical divisions. The NEC feels that as we grow and change, our TDs also need to be assessed and updated to reflect the broader focus of our society. Since our inception, mining has been at the heart of our society and will remain an essential part into the future.

The NEC is discussing what to do with our journal name since we are no longer ASMR. Our journal is a vital and important part of our society. Since 2012, we have had two or three journal issues each year. Dick Barnhisel, the journal editor-in-chief, has worked tirelessly to make sure that this happens. Thank you, Dick! We will keep you posted on the journal.

Lastly, the future of our society is in the hands of our ECPs and students. We want to recruit more and invest in our ECPs and students. The NEC is working with our ECP representative, Hannah Patton, to come up with new and fresh ideas to help grow this important group of our society. We are considering ideas such as additional scholarships, additional stipends, splitting the ECPs and students into two groups, and more. If you have ideas, let us know – your opinion matters!

As we take on the remainder of 2020, take heart knowing we are pushing forward to strengthen our society and make an impact to the communities where we live, work and play. Thank you for electing me to serve you and this society, it is an honor! If you have any questions, thoughts, comments, concerns, or anything at all, please reach out at dwasley@geoengineers.com.

Be well!

Balance?

BY JEFF SKOUSEN, WEST VIRGINIA UNIVERSITY

At the time of this writing, the people of the world are experiencing a pandemic caused by the COVID-19 disease that began in November 2019. According to the Centers for Disease Control and Prevention (CDC), 4,542,579 total cases were recorded in the United States with 152,870 deaths as of August 1, 2020. Worldwide as of the same date, COVID-19 cases surpassed 17,859,763 with a reported 685,179 deaths. Our lives and the lives of our children are disrupted, many of us have been quarantined for lengthy periods during the past six months, many have lost jobs and financial security, and we have lost family and friends. Our normal routines have been completely disordered and little relief is expected for the rest of the year. We hope for a vaccine or a discovery that will bring a cure, but we all need to take action now. To curb the infection rates, we are distancing ourselves from others, wearing masks and other protective gear, and sheltering in place. Some are fortunate to be healthy and to work from home, while others are sick, unemployed, and barely getting by. These are unique, unusual times.

While working from home, most of us have realized the importance of staying focused with so many distractions around us. Like me, you may have been engaged in numerous Internet, Zoom or other forms of remote meetings where plans and ideas are shared and business is conducted. Many businesses have closed and workers are unemployed. Schools and universities are going to hybrid or online course instruction. We are fortunate to have so many ways of communicating with today's technologies, to have the capacity of working remotely and to perform normal tasks in an efficient and operational manner. Imagine if we didn't have these tools to continue to work and interact, or worse, what if we didn't have access to the necessities of life commonly associated with the aftermath of disasters like earthquakes and hurricanes. For example, what if communication lines were destroyed, food and water were unavailable, medical help and hospitals were inaccessible, and medical supplies were unobtainable. This pandemic is an opportunity to consider how we should be better prepared for troubles that are expected to occur in the future.

How do we maintain some type of normalcy or balance in our lives? In an article on "Life Balance," David Dickson says we have many different demands on our time that require our attention and action, especially during periods of stress. Sometimes we feel like we're trying to stay on a balance beam during a windstorm. So how do we keep balance with home life, work life, family life, health and other pursuits? David Bednar, a former university president and religious leader, said "You can't. Balance is a false notion because we can only do one thing at a time." He likened balancing the various aspects of our lives to an acrobat's spinning multiple plates on the ends of sticks. Each plate requires frequent and regular spinning or it will wobble and fall. It is impossible to maintain the spinning of 25 plates at the same time, but we can spin two or three. And as other plates become important, then we avert our attention to those plates as needed. Reducing the number of spinning plates is crucial to our personal well-being and satisfaction, and greatly aids in our capacity to focus and to be productive.

Continuing with this metaphor, you or I might have 50 plates that need to be spun, but we only can effectively deal with one, three, or six during a typical workday. To help keep the right plates spinning, we must continually remind ourselves, "What must be done now, today?" Priority is defined by the dictionary as "a condition regarded or treated as more important than another; having precedence over another; to come before something else." Therefore, we should prepare and do things in priority order. We can't forget all the others, but we must choose wisely to do "first things first."

Balance in life is never quite achievable. We can work at it and for a moment we may feel good at the place we have arrived. But our attempts at balance require constant reflection, determination, and course corrections.

Balance in life is never quite achievable. We can work at it and for a moment we may feel good at the place we have arrived. But our attempts at balance require constant reflection, determination, and course corrections.

Priorities will shift and the order of activities correspondingly must be modified. Time and energy expended in life's activities differ for college students, early career professionals, parents of small children, seasoned workers, families with teenagers and retirees.

Dickson concludes his article with, "Plates will come. Plates will go. Either way, you'll always have plenty to keep in the air. Achieving balance in our lives is a moving target and our priorities must change accordingly. With vigilance and setting of clear goals, you can best choose which plates to focus on. Just take a deep breath and keep on spinning."

So, what should we take away from Bednar's analogy—and from this global crisis? First, we think we control our lives, our environment, our health and everything around us. But when a global pandemic threatens our livelihood, our health, and our peace and security, it becomes apparent that we truly control very little! Because we cannot predict what will happen tomorrow, we should face today and focus on what we *can* do, rather than what we *can't* do. Second, when we acknowledge that balance is not truly attainable, we can find peace in accepting control over those few plates we can keep spinning, we can look for help from others to take over some of the other spinning plates, and we can be prepared to re-assemble the pieces of the broken plates we allowed to stop spinning.

*Thanks to David Dickson for his insight and James Thompson for helpful comments.

Meet an Early Career professional!

HANNAH PATTON – EARLY CAREER PROFESSIONAL NEC REPRESENTATIVE

Contact: hpatton@vt.edu

Hannah Patton was recently elected as the early career professional representative for the ASRS NEC board. Patton is a Ph.D. student in the Biological Systems Engineering (BSE) Department at Virginia Tech and is also working towards a simultaneous Master of Public Health degree. Patton has been a member of ASRS since 2016. She earned a bachelor's degree in environmental engineering from Saint Francis University. As an undergraduate, her research was focused on water quality and treatment in acid mine drainage impacted watersheds in Western Pennsylvania and Bolivia.

In 2019, Patton earned a master's degree in BSE from Virginia Tech. Her master's thesis was titled "Springing for Safe Water: Drinking Water Quality and Source Selection in Central Appalachian Communities." This research focused on households in the Central Appalachian coalfields who obtain their drinking water from roadside springs despite having access to point-of-use (POU) drinking water in their homes (Figure 1). She spent time working with community members to collect spring and tap water samples and compare household POU tap water quality to the quality of water obtained from roadside springs, allowing for households to make more informed decisions about their drinking water source.

Figure 1: Hannah Patton sampling a roadside spring for drinking water.

For her Ph.D. research, Patton is continuing to study private and public water systems in the Central Appalachian coalfields and has also spent time analyzing relationships between coal production, total maximum daily load (TMDL), and Safe Drinking Water Act (SDWA) data. In addition to graduate research, she is the president of the BSE Graduate Student Organization, the founder of the BSE Being Sporty Engineers Club, a graduate student member of the BSE Graduate Committee and the BSE Diversity Committee, and a member of the College of Engineering's Dean's Graduate Team.

In her free time, Patton enjoys trail running, mountain biking, backpacking, skiing, rock climbing, baking, crocheting and spending time with her rescue dog Olive. Patton is looking forward to representing the ASRS ECP community in the coming years and is eager to hear any questions, comments, concerns, and/or suggestions ASRS members may have.

CJ SPELLMAN – EARLY CAREER PROFESSIONAL

CJ Spellman has been a member of ASRS since 2016 and is currently a graduate student at the University of Rhode Island studying innovative iron-based water and wastewater treatment technologies.

Figure 2: CJ Spellman samples an acid mine drainage stream in Pennsylvania.

Spellman earned a bachelor's degree in environmental engineering from Saint Francis University where he was first exposed to legacy pollution issues and the importance of land and water reclamation by studying a variety of mine drainage topics such as open limestone channels and in-stream co-treatment with wastewater. For his master's thesis research, in collaboration with Saint Francis, Spellman studied the feasibility of co-treating mild (pH > 6.0) acid mine drainage with secondary municipal wastewater within an existing wastewater treatment plant located in Johnstown, PA. The wastewater plant in Johnstown is only a few miles from an urban mine drainage discharge, making it an ideal site for full-scale co-treatment (Figure 2). The research, which resulted in two peer-reviewed publications, showed generally positive results that implies co-treatment may be feasible at full scale and serve as a relatively low-cost alternative to active mine drainage abatement while also improving wastewater effluent quality. He hopes to present this work at a future society national meeting. His doctoral research will shift water reclamation topics where he intends to investigate new wastewater recycling (water reuse) treatment technologies, such as advanced oxidation, by conducting pilot-scale studies at various sites across southern New England.

2020 ASRS Professional Award Winners

Editor's note: Award winners were selected and would have been presented with their awards at the ASRS National Meeting in Duluth, Minnesota this past June. But since the meeting was canceled, the awards will be given at the next meeting in Boise, Idaho in June 2021.

This award is the highest honor the society has and recognizes those in research, teaching, outreach, and administration. The award is given to a person who has distinguished themselves in the field of disturbed ecosystem reclamation at the local, regional, national and international levels.

Dr. Christopher Barton – William T. Plass Award

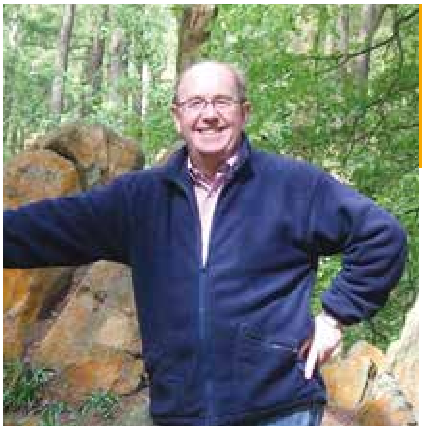
Dr. Chris Barton has led an incredibly productive career in research, practicing and teaching of mine land reforestation, both regionally in the eastern United States and internationally in Australia. Contributions to the field of mine land reforestation is highlighted by over 20 years of research and teaching at the University of Kentucky.

Dr. Barton earned his B.S. at Centre College at Danville, KY, and his M.S. and Ph.D. at the University of Kentucky at Lexington. While at the University of Kentucky, Dr. Barton has advised 27 graduate students and five post-doctoral scholars, as well as mentoring many undergraduates and other faculty members. He always takes the time to share his knowledge and experience with others.

He serves as an associate editor of two international journals and recently co-authored multiple chapters in two books. He was also one of the researchers who established the five steps of the Forestry Reclamation Approach that has gone on to become a best management practice for reforestation on disturbed mine sites.

As the founder and president of Green Forests Work, a non-profit organization dedicated to the reforestation of legacy mine lands, he has directed over 17,000 volunteers to plant over 2.8 million trees on nearly 4,500 acres on legacy mine sites in the Appalachia region of the U.S. Dr. Barton is one of the founding members and longtime co-chair of the Appalachia Region Reforestation Initiative (ARRI) Science Team and has had tremendous influence on the Forest Reclamation Approach. He has also collaborated his knowledge and practical experience in FRA and experimental mine reforestation with multiple mines in eastern Australia during a six-month sabbatical leave in 2012. This has led to recent (2020) award-winning mine reclamation programs in Hunter Valley and the Bowen Basins regions of eastern Australia. His list of honors and awards is long and includes the ASMR Richard I. and Lela M. Barnhisel Reclamation Researcher of the Year award in 2015.

Congratulation Dr. Barton on this well-deserved honor. He was nominated by Kenton Sena.



The Richard I. and Lela M. Barnhisel Reclamation Researcher of the Year Award recognizes substantial contributions to the advancement of reclamation science and technology through scientific research.

Dr. Neil Humphries – Richard I. & Lela M. Barnhisel Reclamation Researcher of the Year Award

Dr. Neil Humphries has shown outstanding leadership in reclamation research while focusing on soil ecology, as well as reclamation ecosystems in the mining industries throughout the United Kingdom.

Dr. Humphries' education started a long career (42 years) in research and development which can be summarized as management, restoration and re-creation of soil-based ecosystems and biodiversity after drastic disturbances. Dr. Humphries received his B.S. from the University of Exeter, his B.A. from Cambridge University and his Ph.D. from the University of Liverpool.

Activities by his companies always have maintained high standards to ensure that the research on soils and agricultural use of disturbed sites be carried out in a meaningful manner. Dr. Humphries and his associates always maintained a desire to make sure the findings were reported so others could benefit from their experiences. Dr. Humphries first published articles in the Proceedings of ASSMR in 1994 and has since published 18 articles in other ASMR proceedings and seven articles in JASMR.

Dr. Humphries has sought cutting-edge technology and practices to find practical and meaningful advancements in reclamation of disturbed ecosystems. His outstanding research has led to a large array of honors and awards, including the ASMR William T. Plass award in 2013.

Congratulations Dr. Humphries on another outstanding honor for your dedication to reclamation research. He was nominated by Richard Barnhisel.

The Reclamationist of the Year award recognizes individuals demonstrating outstanding accomplishments in the practical application or evaluation of reclamation technology. It also rewards individuals responsible for implementing innovative practices or designs for new reclamation strategies.

William Zeaman – Reclamationist of the Year Award

Bill Zeaman received his B.S. and M.S. degrees from the University of Southern Illinois Carbondale in Forestry. He also received a B.A. in sociology from Southern Illinois University and has earned multiple credits in many diverse courses that have continued throughout his career.

He is an environmental supervisor with the Missouri Department of Natural Resources, Land Reclamation Program in Jefferson City, MO. Zeaman has been a significant asset during his 24 years of service with the department and has offered oversite and guidance to more than 250 mine operators for successful reclamation standards in Missouri.

Zeaman has implemented multiple different technological advancements that streamline and simplify regulatory oversite inspections and communications. This allows for better compliance and for quicker remediation to any potential issues within the regulated community. He was a critical resource in the development and implementation of the department's online environmental portal. There was also a new online permitting system developed under his guidance, which allows regulated entities to easily manage their mining permits online.

As a mentor, Zeaman has ensured that his staff's professionalism and quality of work has resulted in improved reclamation that protects the environment and can be enjoyed by the landowners. Along with his busy schedule at work, he is involved in his local community and is often sought to share his knowledge and experience.

Congratulations Bill on this outstanding achievement! He was nominated by Mariah O'Brien.

Bill Locke – Pioneer in Reclamation Award

This award is presented to an individual that has had significant impact and influence in the field of environmental science and reclamation relating to disturbed ecosystems over their entire career.

Bill Locke has led a career in land reclamation that has left a memorable impression with all those who have been touched by his passion for ecosystem restoration.

He received a B.S. degree from Norwich University and is a registered professional engineer in the State of Wyoming. Locke's career in reclamation as the program manager with the Wyoming Abandoned Mine Lands Program has exemplified his drive and passion to return these disturbed sites back to usable and enjoyable parcels. During Locke's 18 years, the Wyoming AML Division has supported mine land reclamation research, when allowed by funding, within the Abandoned Coal Mine Reclamation Research Project at the University of Wyoming. Many reclamation projects using geomorphic surface designs were implemented during his tenure. His work in the area of geomorphic mine reclamation in the Gas Hill's Region of Central Wyoming has initiated and supported interest in a variety of mine land research projects related to ecosystem diversity. Recently this research was published in the Journal of Environmental Management and highlighted with the Special Award in Reclamation by ASMR in 2014.

While at the Wyoming AML program, Locke guided reclamation at over 18,000 acres of disturbed mine lands and oversaw the elimination of more than 460,000 feet of dangerous abandoned mine highwalls. More than 1,800 underground mine portals, shafts and subsidence features were also closed during his oversight. Under Locke's direction, a field mapping program using a GIS platform set the standard for databases for the Abandoned Mine Lands Inventory System nationwide. Many of reclamation projects during his oversite resulted in national honors and awards from the Office of Surface Mining.

Congratulations to Bill for receiving this award. He was nominated by Doug Beahm.

Dr. Wu Xiao "Jeremy" – Early Career Award

This award is intended to recognize an early career member of ASRS that is involved in reclamation research, teaching, and/or on-the-ground reclamation practices within academics, regulatory oversite or in an industry position. The nominee must have been employed in their field for a minimum of three years, but not more than 10 years.

Dr. Wu Xiao has completed all his education through the China University of Mining and Technology in Beijing, while receiving a Bachelor of Engineering, Master of Engineering, and Ph.D. The Ph.D. was a joint program with Southern Illinois University in Carbondale, IL.

He is now a senior research fellow and doctoral supervisor in the Department of Land Management at the School of Public Affairs at Zhejiang University. Based on his letters of recommendations, he was strongly recommended for teaching and research based on his work ethics and performance at SIU, Carbondale. His research performance has been exceptional, with over 26 journal articles, multiple proceeding papers, and book chapters.

He has been honored with a vast range of research and talent awards throughout various programs in China. His latest achievement was in 2018 when he was honored Outstanding Young Scientific and Technological Talents through the Ministry of Natural Resources in China. He is also the scientific editor of the *International Journal of Coal Science and Technology.*

Dr. Wu Xiao's future looks bright and promising. Congratulations and keep up the good work! He was nominated by Brenda Schladweiler.

BioMost Inc. –
Distinction in Reclamation Award

This award recognizes a specific project in which a company has demonstrated excellence in reclamation design, implementation and overall success resulting in the conservation of natural resources and the ecosystem.

The Tar Creek Superfund Site in Northeast Oklahoma has provided multiple challenges to the restoration of a severely disturbed ecosystem. Shortly after listing, the impacts to surface waters were deemed to be “irreversible manmade damages” and were considered untreatable. The Southeast Commerce passive water treatment system that was designed and constructed by BioMost Inc., has proven this statement false. The resulting water treatment quality has led to ecological recovery and significantly increased fish species diversity and abundance.

BioMost Inc. designed and provided pioneering innovations in the water treatment process that addressed several site-specific issues that were complicated challenges, with the resulting outcomes being demonstrably positive. BioMost Inc. met these challenges and exceeded expectations showing a true reflection of the practical side of “excellence in reclamation.”

Congratulations to BioMost Inc. on this outstanding accomplishment. Nominated by Robert Nairn.

2020 ASRS Memorial Scholarship Award Winners

ASRS Memorial Scholarship: Bachelor of Science
KRISTEN SOUCHECK

Kristen Soucheck has long held an interest in nature and conservation, which led her to pursue a degree in environmental engineering at the University of Oklahoma. She became interested in soil and groundwater remediation while completing an internship with Geosyntec Consultants. Through undergraduate research with the Center for Restoration of Ecosystems and Watersheds, she has further explored this interest by studying the connectivity of mine pool waters. Upon graduation, she plans to complete a master's degree in environmental engineering at the University of Oklahoma and eventually work in remediation consulting.

ASRS Memorial Scholarship: Master of Science
DAYTON M. DORMAN

M'Kenzie (Dayton) Dorman received her M.S. in environmental engineering at the University of Oklahoma in December 2019. She is currently a doctoral student and a graduate research assistant under Dr. Robert Nairn, and a research member of the Center for Restoration of Ecosystems and Watersheds (CREW). Her master's research focused on reviewing the effectiveness of novel float-mix aerators to increase dissolved oxygen, degas carbon dioxide, and promote iron oxidation and retention in passive treatment oxidation ponds. Dorman hopes to earn her professional engineering license and enter academia following graduation to further promote diversity in STEM.

ASRS Memorial Scholarship: Doctoral Student (Tie)
MICHELLE VALKANAS

Michelle Valkanas received her B.S. in biology at Duquesne University in Pittsburgh, PA. She then worked for RJ Lee Group (Monroeville, PA) for two years as an analytical chemistry technician before returning to Duquesne University to earn her Ph.D. in biological sciences. She is currently a Ph.D. candidate in Dr. Nancy Trun's lab and is studying bioremediation of abandoned coal mine drainage. Valkanas looks at how microbial communities impact passive remediation systems built to treat abandoned coal mine drainage. Her work has led to several publications and has been presented 31 times, including at the last three annual ASRS Meetings. Additionally, she serves as an associate editor of the JASMR and the chair of the Ecology Technical Division. Valkanas is a Duquesne University Bayer graduate fellow and a National Center for Science Education graduate fellow. She has received two research grants from the Geological Society of America, including the Honorary Gould Research Grant, and from the Scientific Research Society, Sigma Xi. Upon completion of her dissertation, she plans to obtain a post-doc position in engineering so that she can continue to study passive system design and efficiency before ultimately working for an environmental consulting firm.

ASRS Memorial Scholarship: Doctoral Student (Tie)
MICHAEL FINN CURRAN

Michael Curran grew up in Manasquan, NJ, the heart of the Jersey Shore where he was exposed to ecosystems ranging from rivers, oceans, forests and farmlands. He attended the University of Delaware and earned B.S. degrees in biological science, geography, and foreign languages and literature (concentration: Ancient Greek/Roman studies). During that time, Curran worked as a technician on an NSF grant to study how native versus alien plants impacted food webs in suburban ecosystems. Later, he was lucky enough to be offered to go on an eight-week study abroad to Costa Rica with the professor who ran the Tropical Forest Restoration Ecology and Conservation Biology study. Upon graduating from Delaware, Curran spent some time traveling along the east coast and Appalachian Mountains before returning to New Jersey to work in a plant nursery. He realized that restoration ecology was a passion of his and found an offer for a graduate research assistantship at the University of Wyoming to study land reclamation and ecosystem restoration on oil and gas well pads in the western U.S. Prior to receiving his M.S. in rangeland ecology and watershed management in 2014, he was offered a Ph.D. position to expand his research. In May 2020, he'll graduate from the University of Wyoming with a Ph.D. in Ecology. Curran plans to stay closely involved with reclamation throughout his career, but has not closed the door on any potential avenues. Currently, he is applying for jobs in consulting and for post-doctoral research positions. He is grateful for the network he has been able to meet through ASRS and regardless of where he winds up geographically, he plans to stay active within the society.

THE BEGINNING OF *reclamation matters*

BY JEFF SKOUSEN,
EDITOR OF *RECLAMATION MATTERS*

When I first arrived at West Virginia University as a new professor and reclamation specialist in 1985, I met Ben Greene, president of the West Virginia Surface Mining and Reclamation Association. The association published a magazine called *Green Lands*, which served as a glossy publication to show how areas mined for coal were reclaimed and became "green lands." Since I was the new reclamation specialist in the state, Ben asked that I provide an article in their magazine each quarter, which meant I needed to come up with an interesting reclamation article four times a year!

Dan Miller, the editor of the magazine, gave me free reign on the articles and topics I contributed, and they varied from acid mine drainage to revegetation, from mining/reclamation regulations to reforestation, and from water treatment to wildlife habitat (Figures 1 to 3).

From 1986 to 2002 (when the magazine ended), I published 55 articles in *Green Lands*. These articles allowed me to address current and critical needs in the mining and reclamation industry. I learned more from writing these articles than those who may have read them, and I gleaned much information from a wide range of wonderful co-authors. It was a sad day for me when *Green Lands* ceased publication. I wondered how I could continue this type of

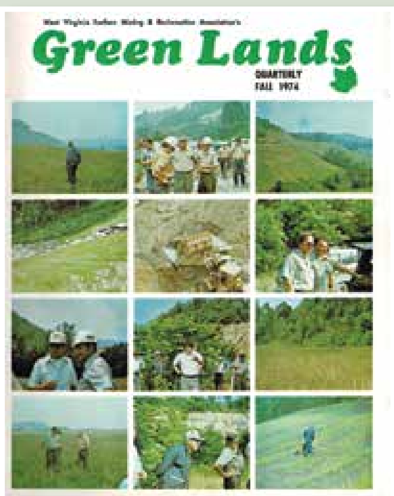


Figure 1: One of the early editions of Green Lands *in fall 1974. Dr. Richard M. Smith (WVU) and William T. Plass (USFS and ASMR) are in the lower middle photo. This issue highlighted the annual Interagency Evaluation Tour that reviewed mining and reclamation practices in West Virginia. This tour engaged the industry and regulators and was held each year from 1965 to 1986.*

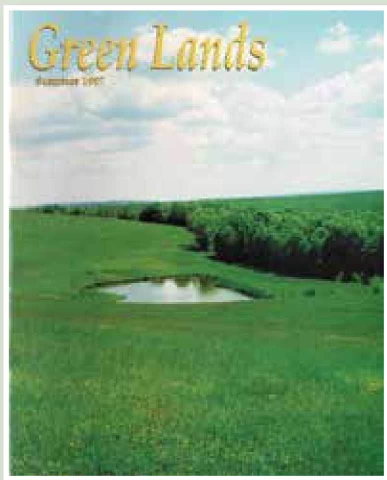


Figure 3: The cover of the summer 1997 issue featured a reclaimed pasture at a northern West Virginia mine site. A variety of post-mining land uses were described and Skousen's contributed article was on Remining: Benefits and Costs.

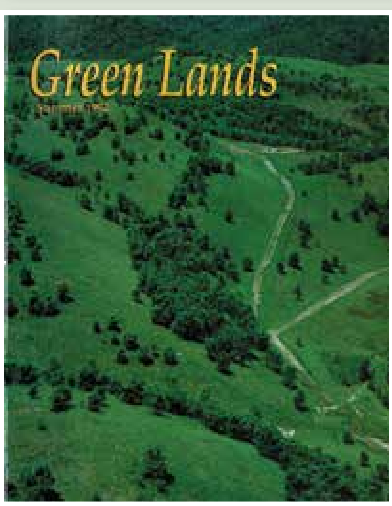


Figure 2: The cover of the summer 1992 issue of Green Lands *showed reclamation at a mountaintop mining site in southern West Virginia. This issue highlighted a tour of the Hobet Mining operation by junior high students and civic organizations. They saw "Big John", the largest dragline in West Virginia. Skousen's article on alkaline addition to prevent acid mine drainage was included.*

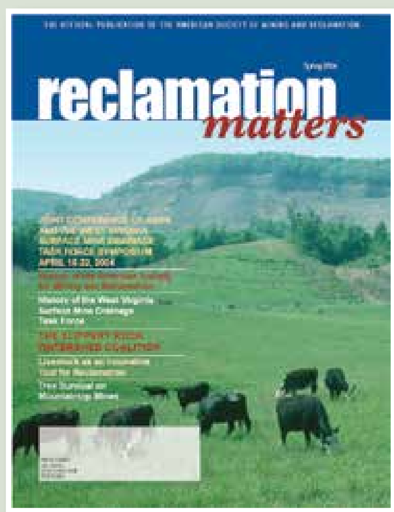


Figure 4: This is the cover of the first edition of Reclamation Matters *in spring 2004. It served as the program booklet for the 2004 National ASMR Meeting in Morgantown, WV.*

extension outreach by bringing mining and reclamation research and issues to scientists, regulators and the industry. An opportunity shortly became available.

In 2002, I agreed to host the American Society of Mining and Reclamation's (ASMR) annual meeting in Morgantown, WV. I had hosted the annual meeting before in 1990 in Charleston, WV, so I was familiar with running large meetings. I have also organized the annual West Virginia Mine Drainage Task Force Symposium which is held each spring in Morgantown with an attendance of around 300 people for the past 31 years (since 1989!).

The 2004 ASMR meeting in Morgantown would combine ASMR and the WV Task Force meetings into one. Organizing and executing a four-day conference with a potential attendance of 600 people required much preparation and planning. I established a committee and we began negotiating for a venue, selecting field trips, planning social events and garnering donations. We planned four concurrent sessions with about 120 presentations, developed several pre-meeting workshops and field trips during and after the conference, and ordered all the meal functions including breaks, lunches, dinners and a special recognition banquet. An exhibit hall would allow 50 exhibitors to show their products and services. On top of that, we solicited papers and abstracts that would be printed in a proceedings which required me to arrange for reviewing, editing and publishing.

I was particularly worried about publishing a professional-quality program with exhibitor advertisements, pertinent articles, and a meeting agenda with descriptions and happenings of the conference that would be given to attendees.

I served as ASMR's president in 2003 and the national executive committee listened to a pitch from David Langstaff from Lester Publications, a communication company that specialized in publishing magazines. They proposed publishing a magazine for ASMR, with ASMR being responsible for providing the content, including articles, society news, meeting information and updates. The company would sell advertising for the magazine and the income from sales would pay for production and mailing expenses. The magazine would be printed and mailed without any cost to ASMR!

Figure 5: The spring 2011 edition had reclamation articles from Wisconsin and Pennsylvania, and included the program for the 28th National Meeting in Bismarck, North Dakota.

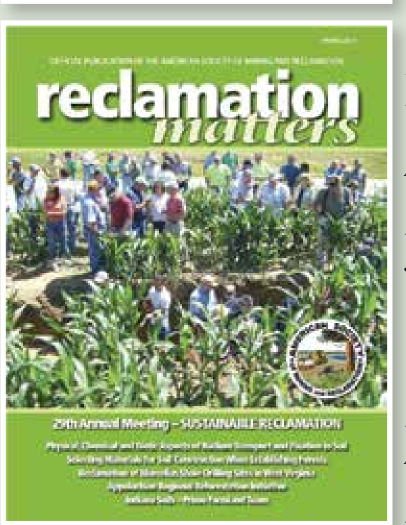


Figure 6: The spring 2012 edition included articles on prime farmland, reforestation, Marcellus Shale gas-fracking reclamation, and radioactivity in soils. It also included the 29th National Meeting program that was held in Tupelo, Mississippi.

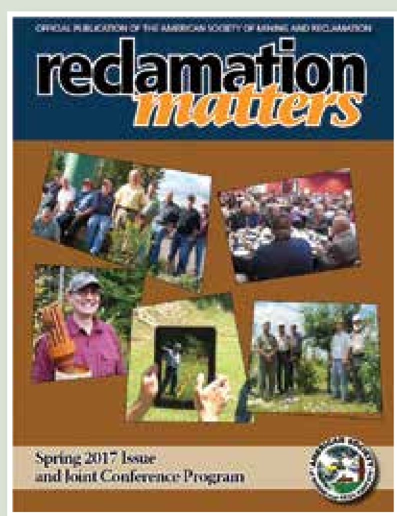


Figure 7: The spring 2017 issue of Reclamation Matters *contained articles on three organizations that joined together for their annual conferences in Morgantown, WV: ASMR, WV Mine Drainage Task Force, and the Appalachian Regional Reforestation Initiative. Included in the magazine was the meeting information, the program of presentations, descriptions of social events, announcement of award winners, a listing of exhibitors, and articles on the development of each organization.*

Figure 8: The 32nd edition of Reclamation Matters *in spring 2020 provided articles on the history of iron mining in Minnesota, the reclamation of areas where peat is mined, and oak growth on reclaimed lands. It also served as the program for the 37th National Meeting in Duluth, Minnesota. This conference was canceled due to the global pandemic of COVID-19. The meeting in Duluth was postponed and will be held in 2022.*

Eureka! Here was my opportunity! I quickly envisioned a way to get the program published for our annual meeting and for future annual meetings. Plus, this also afforded me an opportunity to write and solicit extension-type articles that would reach a broad audience in the mining and reclamation industry much like *Green Lands* did from 1970 to 2002.

We signed a contract with Lester Publications in 2003 and I agreed to serve as editor for the first several editions of the magazine. I assumed someone else would take the editorship as the need for programs for future annual meetings would be required. David Langstaff, my initial contact, created DEL Communications Inc. in 2009, and I have worked with Lyndon McLean at DEL on the magazine layout and content for the past 10 years.

The magazine is now in its 16th year and this is the 33rd edition of the magazine. ASMR recently changed its name to the American Society of Reclamation Sciences (ASRS), and all editions of the magazine can be found on the ASRS website (www.asrs.us/).

I am proud of this magazine. I'm happy with the wonderful articles that have been provided over the years by excellent colleagues, the programs that have been printed in the spring editions, and the announcements of award winners in the fall editions. I congratulate DEL Communications for the professional way in which the magazine is produced. I have been honored to work with their talented and creative editors and production crew.

Reclamation Matters is a wonderful outlet for mining and reclamation information, and I hope you have enjoyed reading it as much as I have enjoyed helping to produce it.

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Establishing small trees and shrubs on mined lands using the Forestry Reclamation approach

BY J. SKOUSEN, A. MONTELEONE, M. TYREE, R. SWAB, J. GRONINGER, M. ADAMS, D. BUCKLEY, P. WOOD, R. WILLIAMS, S. EGGERUD, P. ANGEL, AND C. ZIPPER

Figure 1. Understory plants in an Appalachian forest.

Under federal law, coal operators are required to restore the land to a condition capable of supporting the uses which it supported prior to any mining, or to higher or better uses (Surface Mining Control and Reclamation Act of 1977). Reforestation of mined lands aims to produce a sustainable forest similar to the forest that existed prior to disturbance (Zipper et al. 2011). The Appalachian Regional Reforestation Initiative (ARRI) encourages restoration of high-quality forests on reclaimed coal mines in the eastern USA (Angel et al. 2005, FR Advisory #1).

The Forestry Reclamation Approach (FRA) is a five-step process of known practices to successfully establish native forest trees on mined sites, which enables their survival, rapid growth, and development (Burger et al. 2005, FR Advisory #2).

The five steps are:

1. Create a suitable rooting medium for good tree growth that is no less than four-feet deep and comprised of topsoil, weathered sandstone and/or the best materials.
2. Loosely grade the topsoil or topsoil substitute established in Step 1 to create a non-compacted growth medium.
3. Use ground covers that are compatible with growing trees.
4. Plant early succession trees for wildlife and soil stability, and commercially valuable trees.
5. Use proper tree planting techniques.

Step 4 of the FRA encourages the planting of native early succession trees to provide food and cover for wildlife and to diversify plant communities, along with planting commercially valuable native crop trees. Davis et al. (2012, FR Advisory #9) note that more than 100 tree and shrub species grow in Appalachian forests (Figure 1) and they recommend planting small trees and shrubs in mined land reforestation projects in addition to crop trees. Among the early succession native tree and shrub species suitable for planting are eastern redbud, gray and flowering dogwood, American hazelnut, green hawthorn, common persimmon and elderberry.

Early succession trees and shrubs, as well as commercially valuable crop trees, which can be early, mid, or late succession species, provide many benefits to a forest ecosystem. When the first three steps of the FRA have been followed during reclamation, additional plant species from surrounding forests invade and colonize the site. However, many foresters acknowledge that planting a diversity of woody species at the start of forest re-establishment will enable more-rapid development of the functional and structural diversity of the ecosystem (Aerts and Honnay 2011; Cardinale et al. 2001). Also, the establishment of early succession woody species that produce fruits and seeds at a young age will attract birds and other wildlife that may bring seeds of plants from the adjacent forest, aiding those species' establishment in the reforested area. The intent of FRA reclamation is to develop a forest plant community that resembles the native forest, and thus to accelerate restoration of the land-use capability and ecosystem services that native forests provide (MacDonald et al. 2015; Zipper et al. 2011). A diverse plant community composed of both early and late succession species enhances the wildlife habitat potential, recreational, aesthetic and productive value of the reclaimed land (Burger 2011).

Reclamation planners have often focused on planting commercially valuable trees. Traditionally, these include oaks, maples, tulip-poplar and pines. Less emphasis has been on early succession and understory species. Few reforestation contractors plant multiple species of small trees and shrubs on reclaimed mines.

Since understory tree and shrub species are planted in fewer numbers than crop trees, less is known about their survival and growth. Nurseries may not stock a wide variety of native small trees and shrubs for reforestation plantings, hence, some of these beneficial species may not be available in sufficient numbers for large plantings. Thus, this advisory provides information about small tree and shrub species and gives guidance for selection of early succession woody species to be planted along with commercially valuable crop trees as recommended in Step 4 of the FRA. This information will help planners select suitable candidates for planting and help nurseries know which species to provide for reforestation contractors.

FR Advisory #9 (Davis et al. 2012) includes a list of trees and shrubs which are useful for reforestation.

The small trees and shrubs from that advisory are listed in Table 1. While almost all native woody plants provide wildlife benefits (for example, those that produce nuts such as the oaks and hickories), small trees and shrubs are particularly important for other food types and cover. Species such as dogwoods and eastern redbud grow rapidly and provide bird nesting sites, as well as fruits and seeds for food. Less frequent species like hazelnut, witch hazel and persimmon provide important structural diversity and unique fruits for food. Reclaimed forests are often plagued by invasive species such as autumn olive, multiflora rose, or Japanese barberry, aggressive competitors that are detrimental to native plant diversity and that can reduce food availability for wildlife (Wood et al. 2013, FR Advisory #13; Adams et al. 2019, FR Advisory #16). Rapid establishment of canopy cover by woody plants, such as that from early succession small trees and shrubs, can help deter invasions by invasive plants (Zipper et al. 2019, FR Advisory #17).

How well do small trees and shrubs survive?

To answer this question, we evaluated seven reforestation plantings on mined lands that included small trees and shrubs. Summaries of site conditions and survival results are below.

1. In a study in central Appalachia, Monteleone et al. (2018) reported survival and growth of 20 small tree and shrub species at four sites with a wide range of soil and site conditions in southern West Virginia. Slopes varied from rolling to steep and average soil pH ranged from 4.5 on one site to 7.5 on another. All four sites had been reclaimed using standard (non-FRA) techniques with topsoil and moderate compaction tracking, and herbaceous seeding with non-tree-compatible species (ground cover competition varied between 20 to 100 percent at the time of transplanting). The woody species were planted after herbaceous vegetation had been established.

Seven years after planting, survival of small tree and shrub species averaged 40 percent across the four sites, and five species out of the 20 had ≥50 percent survival (Table 2). The five were black cherry, Washington hawthorn, black chokeberry, hazelnut, and nannyberry (Figure 2).

Survival rates for 11 other species ranged from 37 to 47 percent (Table 2). Four species in this study had poor survival (≤30 percent) including elderberry, pawpaw, flowering dogwood and blueberry. All of these species all produced food and habitat benefits for wildlife.

2. In another set of studies, Tyree et al. (2017, 2018) examined 30 native tree and shrub species that were planted at the Flight 93 National Monument in central Pennsylvania (northern Appalachia) from 2012 to 2017. Of the 30 species, 10 were considered understory species. The Flight 93 Memorial site is located on a legacy mine site which had been revegetated with aggressive herbaceous plants during the 1980s. Soil materials were a mix of brown and gray sandstone/shale; soil pH ranged from 5.0 to 6.0. The area supported a moderate stand of herbaceous cover with a few volunteer trees scattered across the site. Mine soils were treated with deep tillage prior to planting (Burger et al. 2013, FR Advisory 11), and trees and shrubs were planted in the trenches created by soil ripping. Trees were measured five to seven years after planting.

Sumac and hawthorn had high survival rates, and both experienced natural regeneration at this site (Table 2). Because of regeneration, actual survival of planted seedlings for these species could not be determined and survival is shown as 100 percent. Black chokeberry had a 70 percent survival rate and dogwood had 60 percent. Ninebark, mountain ash, crabapple, and hazelnut showed 20 to 40 percent survival, while survival for elderberry was less than five percent. Based on the results of this study, five of the 10 species had greater than 40 percent survival (black chokeberry, ninebark, sumac, hawthorn and dogwood).

3. At the Catenary Mine, an active mine reclamation site in southern West Virginia, nine tree species were planted and two were small understory trees (Wilson-Kokes et al.

Eastern redbud.

Green hawthorn.

Black chokeberry.

2013). This site was flat to gently rolling and had four feet of non-compacted brown sandstone. Soil pH was 7.5 at the time of planting and decreased to 6.7 after eight years, while vegetative cover ranged from 40 to 70 percent. Eastern redbud and flowering dogwood had between 43 and 46 percent survival, respectively, eight years after planting (Table 2).

4. At a legacy mine site in Dickenson County, Virginia, four species survived poorly after four growing seasons (Evans et al. 2013). Eastern redbud survived at 37 percent, flowering dogwood and red mulberry showed 17 percent survival, and crabapple survived at a much lower rate of three percent.
5. At a site in Wise County, Virginia, three species were grown in alkaline siltstone with moderate grading and a tree-compatible groundcover (Fields-Johnson et al. 2012). After seven growing seasons, red mulberry and eastern redbud showed 86 percent and 67 percent survival, respectively (Table 2). Gray dogwood survived at 50 percent.
6. At an active mine reclamation site in southern WV, three understory species (eastern redbud, gray dogwood and green hawthorn) all exhibited ≥80 percent survival after one growing season (Kropchak et al. 2013).
7. At a southwestern Virginia mine site reclaimed with both weathered sandstone and unweathered siltstone after nine years (Zipper et al. 2012), dogwood species survival was 86 percent after nine years (Table 2). The nitrogen-fixing shrub bristly locust was also planted; it grew and reproduced prolifically across all site areas, but this shade-intolerant species remained present primarily in areas that had not yet achieved canopy closure, which were mostly those reclaimed using unweathered siltstone.
8. At a reclaimed mine site in southeastern Ohio, a pre-SMCRA forested area (planted 50 years ago) was recently cleared of understory invasive exotic plants (autumn olive, multiflora rose, or barberry) and planted with five native understory species. After one growing season, survival of all planted species exceeded 89 percent. Persimmon, eastern redbud, black haw, and gray dogwood had a 95 percent survival rate (unpublished data). Arrowwood survival was slightly lower at 90 percent. Pre-SMCRA forests may benefit from understory plantings and, due to soil preparation and control of competing vegetation, may have higher survival rates of trees than post-SMCRA sites.

Establishing understory woody species

The Forestry Reclamation Approach Advisories provide guidance on site preparation, mine soil selection and quality, compatible ground covers for reforestation plantings, woody species selection and planting guidelines on mined lands. Some important points are summarized below and these recommendations should be followed for planting of understory shrubs and trees.

1. SELECT AND PLACE SUITABLE SOIL MATERIAL

The Forestry Reclamation Approach specifies selecting the best available soil material. Forest Reclamation Advisory #8 (Skousen et al. 2011) explains that native soils are generally more favorable for tree and shrub growth than mine spoil materials. Plus, the native soils often contain seeds and other propagules of native plants that can establish to create a diverse plant community. Natural soils can be used alone if quantities are sufficient, or they can be mixed with mine spoils. When native soils are not sufficient or suitable, weathered brown mine spoils are preferred over unweathered gray spoils (Wilson-Kokes et al. 2013).

Soil assessment and testing should be done to help determine soil quality, soil amendments, and tree species selection (Burger et al. 2013, FR Advisory #11). Soil properties important to consider are color, pH, conductivity and compaction. Planners should extract a soil sample to a depth of six inches for every three acres of planting area and send samples for soil analysis

Gray dogwood.

Hazelnut.

Highbush cranberry.

to a reputable soil testing laboratory (Skousen et al. 2011, FR Advisory #8). Use the recommendations for lime and fertilizer application, loosening the soils by ripping (Sweigard et al. 2007, FR Advisory #4), and removing competing vegetation (Burger et al. 2013, FR Advisory #11).

2. DEVELOP A PLANTING PLAN AND SELECT APPROPRIATE WOODY SPECIES

A mixture of small trees and shrubs should be planted based on the guidelines of Davis et al. (2012, FR Advisory #9) and Rathfon et al. (2015, FR Advisory #13) and the information presented in this advisory. Trees should be planted at eight-by-eight-foot spacing using a mixture of compatible woody species suited for site types. The understory trees could be planted between the eight-by-eight-foot spacing of crop trees. Trees and shrubs should be matched to their appropriate moisture/site type.

3. USE GOOD PLANTING STOCK AND PROPER PLANTING PROCEDURES

Bare-root seedlings are the typical planting material on almost all surface mine reforestation projects, and proper planting procedures are described in FR Advisory #8 (Davis et al. 2010). For special plantings and where no bare-root seedlings are available for certain species, container seedlings (seedlings grown in pots) may be used. As noted in Zipper et al. (2018, FR Advisory #15), container seedlings are more costly than bare-root seedlings and they require more effort and time to plant because a bigger planting hole is needed. However, when planted correctly and protected, survival is generally higher and growth is more rapid for container seedlings. Herbaceous vegetation should also be established on non-vegetated soils and Burger et al. (2009, FR Advisory #6) describe compatible herbaceous vegetation that should be seeded in reforestation projects.

4. PROTECT AND MAINTAIN THE PLANTINGS

Re-establishing trees as bare-root seedlings on areas with pre-existing vegetation requires the competing vegetation be controlled or minimized (Burger et al. 2013, FR Advisory #11). Tree seedling survival and growth will improve as competition from other plants is reduced. Browsing and girdling of tree seedlings by wildlife can destroy tree and shrub plantings, so control measures such as tree tubes or wire cages can be used to protect seedlings until they are old enough to withstand browsing or grow out of the reach of browsers.

Conclusions

Based on the results of studies on understory tree and shrub survival and growth, a variety of small tree and shrub species can be planted along with crop trees during reforestation (Table 2). Many of these species showed >40 percent survival after five or more years of planting. Small tree and shrub species should be chosen for reforestation plantings based on their tolerance of site conditions, including geographic location, slope and soil type, pH, compaction, and herbaceous competition. Ripping tends to ease initial planting and increase subsequent survival. The understory woody species should make up between 20 to 30 percent of the planted species. These species should be distributed over the planting area and should be planted in locations where they will have the best chance for survival. As mentioned, understory woody species are important as wildlife food and cover, and contribute to ecosystem development and multiple uses of the forest.

Table 2 lists the survival of small tree and shrub species that have been tested in reforestation studies. Some performed well while others did not. If a species performed poorly in the studies highlighted here, this result alone should not preclude it from being tried and tested on other sites. Many of the species listed in Table 1 (Davis et al. 2012) have not been tested in field studies and are not included in Table 2 where no data were available. The untested species may still be considered for reforestation plantings if bare-root seedlings or containerized plants are available.

Table 1. Small trees and shrubs found in Appalachian forest communities (from Davis et al. 2012) and that can be planted in reforestation projects in Appalachia. Plants are listed in alphabetical order by Latin name. Plant species mentioned in this advisory are also added to the list. Crop trees and conifers have been removed.

Species	*Latin Name*	*Growth Rate*	*Site Type*	*pH Range**	*Wildlife Value*
allegheny serviceberry	*Amelanchier laevis*	moderate	moist	low-high	soft mast
false indigo bush	*Amorpha fruticosa*	slow	moist	low-high	browse
eastern redbud	*Cercis canadensis*	slow	moist	medium-high	browse
silky dogwood	*Cornus amomum*	moderate	moist	medium	cover
flowering dogwood	*Cornus florida*	moderate	moist	low-high	browse
gray dogwood	*Cornus racemosa*	moderate	all	low-medium	browse
American hazlenut	*Corylus americana*	moderate	moist	medium	hard mast
green hawthorn	*Crataegus viridis*	moderate	all	low-high	browse
common persimmon	*Diospyros virginiana*	slow	all	low-high	soft mast
American witchhazel	*Hamamelis virginiana*	slow	moist	low-medium	soft mast
sweet crab apple	*Malus coronaria*	slow	moist	medium	soft mast
red mulberry	*Morus rubra*	moderate	moist	medium	soft mast
American plum	*Prunus americana*	moderate	moist	medium	soft mast
bristly locust	*Robinia hispida*	rapid	dry	low-high	browse
black elderberry	*Sambucus nigra*	rapid	moist	low-high	soft mast
sassafras	*Sassafras albidum*	moderate	moist	low-high	browse
highbush blueberry	*Vaccinium corymbosum*	moderate	wet	low-high	soft mast
southern arrowwood	*Viburnum dentatum*	slow	all	low-medium	soft mast
blackhaw	*Viburnum prunifolium*	slow	all	low-high	soft mast
Kentucky coffeetree	*Gymnocladus dioicus*	slow	Moist	medium-high	cover
Added Species					
black chokeberry	*Aronia melanocarpa*	slow	moist	medium-high	soft mast
pawpaw	*Asimina triloba*	moderate	moist	medium	soft mast
ninebark	*Physocarpus opulifolius*	slow	dry	medium	soft mast
choke cherry	*Prunus virginiana*	rapid	all	medium-high	soft mast
staghorn sumac	*Rhus typhina*	rapid	all	medium-high	soft mast
mountain ash	*Sorbus americana*	slow	all	medium-high	soft mast
nannyberry	*Viburnum lentago*	moderate	moist	medium	soft mast
highbush cranberry	*Viburnum opulus*	moderate	moist	medium	soft mast

**pH range key: low pH <5; medium pH 5-7; high pH >7.*

As forests age and timber trees overtop smaller species, the amount of small-sized trees and shrubs will decline in the maturing forest interior. Where planting conditions allow, consider planting more small trees in areas likely to become permanent forest edges, such as along infrequently-used roads, parking areas, drainages, and along boundaries with open land so that natural reproduction and wildlife habitat enhancement provided by these small trees and shrubs will continue after most of the forest understory becomes too shaded to sustain optimal growth of these species. At these locations, the lasting presence of small trees will noticeably improve the appearance of the reclaimed area from a distance as their flowers, fruits and bright fall colors provide visual diversity and a vivid contrast at the forest edge where more visitors are likely to see them.

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Table 2. Survival results of small trees and shrubs based on field studies in Appalachia. The list of species is divided into good (>40 percent), moderate (30 to 40 percent), and poor (<30 percent) survival. Superscripts next to percentage survival refer to the reference studies listed in the footnote for each species. All studies were located in central Appalachia, except for Tyree et al. (2018), which was in northern Appalachia.

Species	*Latin Name*	*% Survival*
Good Survival		
serviceberry	*Amelanchier laevis*	44[1]
black chokeberry	*Aronia melanocarpa*	56[1], 75[2]
eastern redbud	*Cercis canadensis*	45[1], 42[3], 37[4] 67[5], 81[6]
gray and flowering dogwood	*Cornus spp.*	44[1], 60[2], 46[3], 16[4], 49[5], 80[6], 86[7]
hazelnut	*Corylus americana*	50[1], 30[2]
green hawthorn	*Crataegus viridis*	54[1], 100[2], 85[6]
crabapple	*Malus coronaria*	40[1], 37[2], 3[4]
apple	*Malus pumila*	41[1]
red mulberry	*Morus rubra*	41[1], 17[4], 86[5]
American plum	*Prunus americana*	44[1]
choke cherry	*Prunus virginiana*	44[1]
ninebark	*Physocarpus opulifolius*	40[2]
bristly locust	*Robinia hispida*	100[7]
sumac	*Rhus typhina*	100[2]
cranberry	*Viburnum trilobum*	47[1]
nannyberry	*Viburnum lentago*	52[1]
Moderate Survival		
persimmon	*Diospyros virginiana*	37[1]
pear	*Pyrus communis L.*	371
blueberry	*Vaccinium corymbosum*	30[1]
mountain ash	*Sorbus spp.*	252
Poor Survival		
black elderberry	*Sambucus nigra*	271, 22
pawpaw	*Asimina triloba*	91

1 Monteleone et al. 2018
2 Tyree et al. 2018
3 Wilson-Kokes et al. 2013
4 Evans et al. 2013
5 Fields-Johnson et al. 2012
6 Kropchak et al. 2013
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All Forest Reclamation Advisories are available on the Appalachian Regional Reforestation Initiative's web page (www.arri.osmre.gov). In addition, a compilation of Advisories 1-12 can be found in The Forestry Reclamation Approach: Guide to successful reforestation of mined lands, published by the USDA Forest Service, Northern Research Station, available from https://www.nrs.fs.fed.us/pubs/54344.

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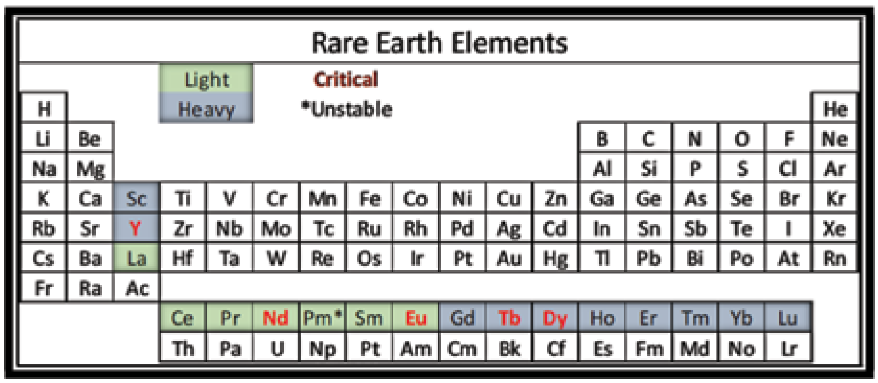
Recovery of rare earth elements from coal mine drainage

BY PAUL ZIEMKIEWICZ AND JEFF SKOUSEN, WEST VIRGINIA UNIVERSITY

Rare earth elements (REEs) are critical in today's technology-driven world. These elements are used in electronics such as smart phones, magnets, computers, televisions and most notably in national defense technologies. The REEs are located at the bottom of the periodic table (Figure 1) and include 17 different elements (Table 1). The elements listed as REEs are not really "rare," but they rarely occur in concentrations that make them economically attractive to mine and process.

Figure 1. The rare earth elements typically include the 15 lanthanides, plus Yttrium and Scandium. They are further classified as light, heavy and critical (See Tables 1 and 2). Promethium does not occur naturally.*



These elements occur in a wide variety of geologic formations but are rarely found in concentrations to facilitate extraction and refinement. Where they are found in significant concentrations, the ore body is often contaminated with radioactive thorium and uranium, which causes problems with handling and disposal of ores and processing wastes. As such, the U.S. currently imports 90 percent of its REEs from China. With increasing demand for REEs for technology and defense uses, U.S. mining companies have invested time and capital to discover and secure REE resources outside of China. Unfortunately, many of these companies entered bankruptcy or lost interest due to unpredictability in demand and shifting prices.

TABLE 1. List of 17 rare earth elements (REE) with their atomic number and symbol. Table from Thermofisher.com.

*Promethium is unstable and does not occur naturally.

**Scandium and Yttrium are classified as rare earths, although not lanthanides.

Atomic #	Element	Symbol
21	Scandium**	Sc
39	Yttrium	Y
57	Lanthanum	La
58	Cerium	Ce
59	Praseodymium	Pr
60	Neodymium	Nd
61	Promethium*	Pm
62	Samarium	Sm
63	Europium	Eu
64	Gadolinium	Gd
65	Terbium	Tb
66	Dysprosium	Dy
67	Holmium	Ho
68	Erbium	Er
69	Thulium	Tm
70	Ytterbium	Yb
71	Lutetium	Lu

Only two REE mines started production outside of China in response to this demand. The Mount Weld deposit in Australia began production in 2013. The ore from Mount Weld is processed in Malaysia, whose operating permit has come under scrutiny because of unsafe practices for disposing of radioactive waste, and hence their production of REEs has ceased. The second mining operation, Mountain Pass located in the U.S., has experienced instability in reaching full-scale production due to lower REE prices and uneven distribution of light versus heavy REEs in the ore body.

There continues to be a strong need to find domestic, predictable supplies of these critical elements, regardless of their pricing. Many industrial processes rely on REEs for their products, including catalysts, metallurgy, petroleum refining, catalytic converters, ceramics, phosphors and electronics. The availability of heavy REEs are of particular concern because identifying geologic sources of these elements in the U.S. have been unsuccessful. Of the 15,000 tons of REEs used by the U.S. every year, approximately 800 tons (five percent) are required for the defense industry. To develop secure, predictable, domestic supplies, the U.S. Department of Energy's National Energy Technology Laboratory (USDOE NETL) initiated a national competition in 2015 to develop economical and environmentally safe methods for extracting REEs from domestic material sources.

The presence of REEs in coal was known as early as 1964. In 2014, the USDOE analyzed the economic feasibility of recovering REEs from coal, coal refuse and coal fly ash as material sources. In 2015, with a small startup grant from USDOE, researchers at West Virginia University sampled AMD precipitates from nine sites and found significant concentrations of REEs in these precipitates formed during acid mine drainage (AMD) treatment (Ziemkiewicz et al., 2016).

A detailed study of REE occurrence in the northern and central Appalachian Coal Basin was developed by Dr. Paul Ziemkiewicz, director of West Virginia University's Water Research Institute (WRI). He and his team at WVU collected AMD from both surface and underground mines and collected precipitates formed during AMD treatment with alkaline chemicals at these sites (Figure 2). The aqueous samples were acidified in two percent nitric acid and analyzed using ICP-MS by certified laboratories. The precipitate samples were digested using sodium peroxide and re-dissolved in hydrochloric acid and analyzed by ICP-MS.

Ziemkiewicz and his team found an average total REE concentration of 258 ug/L (or ppb) with a range of 8 to 1,139 ug/L in aqueous samples of AMD (Table 2). The REE concentration from AMD precipitates averaged 517 mg/kg (or ppm) with a range of 29 to 1,286 mg/kg, a concentration factor of more than 2,000 over aqueous AMD samples (Table 2). The AMD precipitates contain almost 10 times more REE concentrations than U.S. coal (66 mg/kg) (Vass et al., 2016). Another important finding was that REE concentrations were much higher in aqueous AMD samples with a solution pH of 5.0 or less (Figure 3).

Table 2 shows the concentrations of individual REEs in samples of untreated AMD and samples of AMD precipitates formed during AMD treatment. Elements highlighted in green are "light," those highlighted in blue are "heavy," and those with red lettering are termed "critical" elements. *Note: mg/kg (ppm) is 1,000 times greater than the unit ug/L (ppb). Therefore, the concentration of REEs in precipitates is more than 1,000 times greater than in raw, untreated AMD.

Given the high REE concentrations extracted from AMD precipitates, estimates of REE production from AMD treatment plants could produce from 800 to 2,200 metric tons (Mg) of REEs per year (Ziemkiewicz et al., 2016). The high concentrations of REEs in AMD sludge and their processing

Figure 2. Typical AMD treatment pond where precipitates are captured and allowed to settle from treated AMD.

TABLE 2. REE concentrations.

Element	Untreated AMD (ug/L)*	Precipitates (mg/kg)*
Sc	13	16
Y	70	125
La	11	62
Ce	42	108
Pr	7	15
Nd	39	74
Sm	14	21
Eu	4	5
Gd	19	28
Tb	3	5
Dy	17	26
Ho	3	5
Er	8	13
Tm	1	2
Yb	6	10
Lu	1	2
Total REEs	**258**	**517**

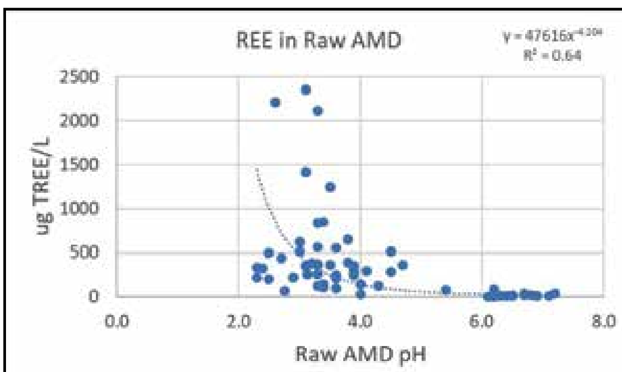


Figure 3. The relationship between the pH of raw AMD and the concentration of Total REEs (TREE) in the aqueous phase. Clearly, higher concentrations of TREEs occur in AMD at less than 5.0 pH.

and sale on the market provide an opportunity to recover some of the costs of treating AMD. This financial recovery would encourage companies to maintain AMD treatment which would improve the quality of streams and rivers in the region. AMD treatment is an environmental and costly obligation for mining companies; therefore, collecting and processing the REEs from these AMD treatment precipitates could create a revenue stream and provide a financial return from a costly treatment and disposal process. This process would promote a new industry for economic development and generate a secure domestic supply of REEs.

To evaluate the monetary value of REEs in AMD, the average prices of REEs were compiled for the lanthanide series plus Yttrium from 2008 to 2015. Using a detailed pricing structure and analysis (see Vass et. al., 2016), a value of $89 per kg of total REEs was identified. (More information on the assumptions used for pricing is available from the authors and in the two cited papers). Using this value, a minimum estimate of the value of REEs in AMD precipitates is $3 million per year.

Now that REEs were identified and quantified in AMD precipitates and a monetary value placed on the precipitates if all the REEs could be extracted, additional work was needed to separate REEs from the other elements in AMD treatment precipitates (Fe, Al, Mn, Ca, Mg). Therefore, a procedure for economically recovering REEs from AMD precipitates was needed to realize this estimate of tonnage and monetary potential, and whether the process of recovery was economically viable at a production scale.

Figure 4. West Virginia University's REE Extraction Facility produces highly concentrated rate earth products from AMD precipitates. This sample is 87 percent rare earth oxide.

Separation technologies such as ion exchange, solvent extraction, or selective precipitation can be used to recover REEs in an oxide form. Once separated, the REE oxides could be packaged and sold to refiners with advanced capabilities to turn the oxides into metals (Figure 4). These processes utilize smelting or electrolysis to isolate REE metals that can then be sold on the open market.

In 2018 with NETL funding, a bench scale pilot plant was opened through a joint venture among WVU, Rockwell Automation and Shonk Investments LLC on West Virginia University's campus to test the technical and economic feasibility of scaling-up their extraction and refining technology with plans to rapidly commercialize the process.

In 2019, this project was successful in identifying economically attractive recovery of REEs from AMD such that USDOE Secretary Rick Perry announced the award of $5 million to the WVU team to expand their process to a full-scale field facility to be built into a new AMD treatment plant near Mt. Storm in northern WV. Figure 5 shows a conventional AMD treatment plant operated by the West Virginia Department of Environmental Protection where AMD precipitates will be generated and collected.

This phase of the project will be achieved by collaborating with the West Virginia Department of Environmental Protection's Office of Special Reclamation to design and build the treatment plant, Rockwell Automation to provide the sensor and control technology and TenCate Corporation to engineer materials to further concentrate REE-extracted materials. The on-site processing plant will reduce costs of operation significantly and pave the way for a new industry in Appalachia.

These collaborations are vital to the success and implementation of this pilot facility. Support of West Virginia's congressional leaders has been key. Senator Joe Manchin said, "These projects allow continued use of our domestic resources in an environmentally friendly way and will help reduce our vulnerability to foreign sources of rare earth elements."

Senator Shelley Moore Capito added, "REEs are essential to modern advanced manufacturing, and WVU's technology will help provide a domestic source of this material while cleaning up legacy mine waste. This is a win-win-win for our economy, our national security, and the environment."

Representative David McKinley stated, "WVU's work to develop a domestic REE source is critical and this funding will help to build an American supply chain and ensure that we are not dependent on other nations for our supply."

With this new funding, the WVU team will scale up and demonstrate how AMD treatment and watershed restoration can operate hand-in-hand with REE recovery. Success will generate a revenue stream that will offset stream restoration costs and point the way toward a new way of thinking about environmental cleanup – one that engages market forces while fulfilling a critical national need.

Figure 5. The West Virginia Department of Environmental Protection's Muddy Creek AMD treatment plant near Albright, WV, showing the lime silo and system control building in the lower left, two clarifiers and Geotubes across the creek for collection and dewatering of AMD precipitates.

In conclusion, this is a great opportunity to demonstrate the economics and environmental benefits of combining AMD treatment, watershed restoration and critical mineral recovery. The team at WVU has worked together for the past several years and are poised to move rapidly toward commercial development.

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ASSISTING NATIVITY VERSES NOVELTY: Tree migration in the age of the Anthropocene

BY MARGARET D. CRITCHLOW AND JENISE M. BAUMAN, WESTERN WASHINGTON UNIVERSITY

Forest restoration has become a global focus during the 21st century with the United Nations setting ambitious targets calling for the reforestation of millions of hectares of land (Löf et al. 2019). This is prompted by the fact that forests provide numerous ecosystem services, including carbon sequestration, land stability, soil erosion control, water quality protection, temperature buffering, timber and non-timber provisions, and outdoor recreation. As the human population continues to grow, the need for these ecosystem services will continue to increase, likely faster than forests will be able to naturally regenerate (Spathelf et al. 2018). In addition, climate change further complicates historical forest function, affecting forest productivity and longevity, resilience to insect and disease outbreaks, and the maintenance of soil and water relations within the region. These changes are often rapid and intense, outpacing natural adaptation of forest communities, which present a challenge to restoration professionals and land managers. In response, recent initiatives reconsider central goals and techniques of restoration. Namely, innovative methods to restore forests to function and build resiliency are beginning to move into the forefront, rather than historical composition in the period of rapid climate change (Corlett 2016).

Is Climate Change Rare?

When measured within the timescale of planet Earth, climate change is quite common. Changes in solar irradiance can cause dramatic shifts in climate, which can be due to variation in the Earth's orbital patterns including the degree of ellipticity of the Earth's orbit around the sun, the angle, and the wobbling of the Earth's axis. Together, these variations in the orbital patterns produce Milankovitch cycles of solar input that correlate with the glacial and interglacial cycles over the last 800,000 years (Chapin et al. 2012). In fact, in the last 650,000 years there have been seven cycles of glacial advance and retreats; last seen in North America with the Wisconsin glaciation (~12,000 years ago). More recent climate change events are associated with a new epoch called the Anthropocene – a chronological term marking the beginning of the industrial revolution in the mid 1700's, where anthropogenic activities have had a significant global impact on the Earth's surface. Although some warming reflects an increase in solar input, recent warming between 1750 to 2020 are directly linked to human activities that caused an increase of concentrations of radiatively active gases in the atmosphere; the largest being atmospheric CO_2 primarily from the burning of fossil fuels.

Tree Migration in the Time of Rapid Climate Change

Trees will respond to this rapid change in one of three ways: they may go extinct, they may evolve adaptations to the new climate regimes, or they may migrate over long distances. With regard to the latter, trees have evolved sophisticated methods for migration. This migration can be a very slow process by short steps across the landscape or very rapid when mediated by long-distance dispersal jumps (Ohlemüller et al. 2012). Prehistoric records show that migration patterns of vegetation and ecological disturbances change in response to climate. For example, pollen records of spruce *(Picea spp.)* and oak *(Quercus spp.)* species in North America have shown movement of these species that originally were widespread throughout the U.S. Midwest northward into northeastern Canada over the past 18,000 years. In the southwestern United States, the once dominant pinyon pine *(Pinus remota)* was replaced by the Colorado Pinyon *(Pinus edulis)* illustrating the subtle changes among species that will retain functional vegetational groups during climate change (Lanner and Van Devender 1998).

Wind updrafts have been linked to trans-continental movement in many plant species, but humans have most certainly been tree's most consistent long-distance dispersal mechanism. Whether this entails delicious (and quite addictive) food resources, aesthetically pleasing flowers and foliage, shade production of canopies, or the utilitarian value of timber and non-timber forest products – this co-evolution between humans and trees have increased the already rapid motion of tree migration through time and space. However, this is problematic when it results in range shifts that are not mindful of the integrity of natural functional groups within ecosystems (i.e., invasion of a non-native species, the conversion of large-scale forests to monocrop grass plants, introduction of novel pests and diseases, etc.).

Species are responding to climate change pressures by moving poleward faster than prehistoric times, which may result in the transformation of tundra to boreal forests, boreal to temperate forests, and grassland encroachment in temperate forests (Thuiller et al. 2008). For many tree species, Forest Inventory Analyses have indicated higher regeneration success at the northern edge of their ranges and seedling densities nearly 10-times higher in northern latitudes than in southern latitudes (Woodall et al. 2009). Using ecosystem-based, climate-envelope models, Hamann and Wang (2006) predict that shifting climates may facilitate tree migrations in the northern hemisphere that will result in spatial redistribution and range expansion of the Interior Douglas fir *(Pseudotsuga menziesii ssp. glauca)* and Ponderosa Pine *(Pinus ponderosa)*. These types of species shifts are expected to move northward and upward in elevation, which may problematically reduce the range of threatened species such as whitebark pine *(Pinus albicaulis)* and other vulnerable mountain plant species (McLane and Aitken 2012).

Other noted examples of migration include invasions of species from the south displacing northern species in northeastern forests, the significant expansion of black spruce *(Picea mariana)* in northern Quebec, and significant improvements in seedling recruitment and growth of the white spruce *(Picea glauca)* within the coastal tundra (Iverson and McKenzie 2013). Collectively, these data suggest that the process of northward tree migration in North American forests are approaching rates of 100 kilometers/century in response to climate change (Hamann and Wang 2006).

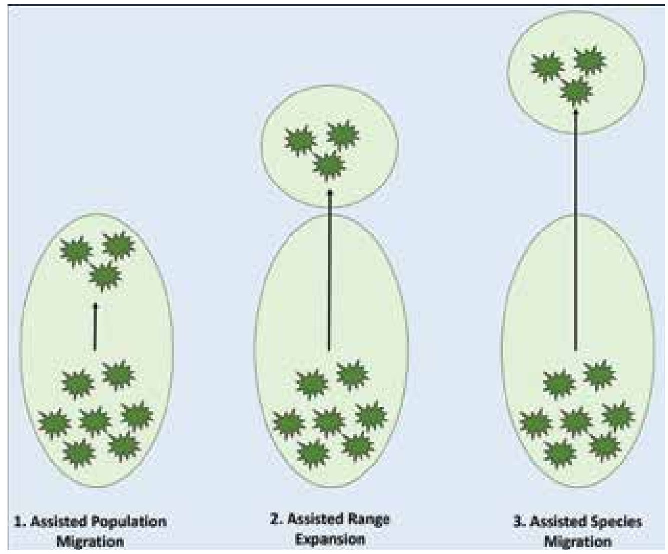
Using Assisted Tree Migration as a Novel Strategy within the Anthropocene

How can a tree species migrate at a pace of 100 kilometers/decade through a fragmented landscape where urbanization, suburban sprawl, natural resource extraction, and agricultural production have severed the historic forested corridors? Short-distance migrations may not be enough for adaptation given the extreme climate shifts, and long-distance dispersals may be altered by impervious surfaces (such as a seed landing in a parking lot versus landing in a freshly disturbed forest soil). Therefore, it is feared that the inability for dispersal in a fragmented landscape will constrain the rate of migration resulting in the extinction of many tree species and the reduction of forest function and adaptability in the age of rapid climate change (Neilson et al. 2005). Further, forests cultivate a tight link between solar energy and the hydrologic cycle, which when severed, leads to warmer and drier soils that are often difficult to restore with native forest trees (Chapin et al. 2012).

Climate change is influencing the re-distribution and population structures of forest pests and pathogens, while also affecting the way forest systems resist and tolerate interactions with insects and microorganisms. Therefore, restoring these forests with adaptive and resilient tree communities may require alternate methods in lieu of replanting historic genotypes or allowing successional trajectories to accomplish natural recovery. Climate change adaptation strategies may need to consider transformational restoration concepts that utilize novel ecosystems, plan for novelty in active restoration, and move species beyond their native ranges (Hobbs et al. 2011).

Assisted migration is the intentional movement of threatened species based on projected climate conditions, with the intent to build ecosystem resilience, minimize ecosystem loss, sustain ecosystem function and conserve threatened native species (Williams and Dumroese 2013). This is an example of transformative restoration that will facilitate tree migration while increasing landscape connectivity (Ciccarese et al. 2012).

Figure 1. Various degrees of assisted migration: 1) assisted population migration moves trees within the current range, 2) assisted range expansion moves species outside of range, and 3) assisted species migration moves tree species far outside of range to prevent extinction (adapted from Williams and Dumroese 2013).



While this idea is not without controversy, it represents an important shift in a restoration framework away from strict replication of historical reference sites to restoration goals that prioritizes resilient forest ecosystem function. Assisted migration is a more interventionist approach than traditional restoration, which challenges land managers to plan for the future, rather than bringing a landscape back to a past framework (Corlett 2016). Candidates for assisted migration include economically important timber species, species with small, endangered populations and low fecundity, and species suffering declines due to insects or diseases.

Assisted migration can be done in varying degrees: 1) assisted population migration moves trees within their current range, 2) assisted range expansion moves species outside of their range, and 3) assisted species migration moves tree species far outside of their range to prevent extinction (Figure 1; Williams and Dumroese 2013). Tree movements can also be classified as geographic along elevation gradients, climate based on the number of frost-free days, and/or temporal where the current climate of the migrated population corresponds to the future climate of the target site (Dumroese et al. 2015). This differs from deliberately introducing species because assisted migration utilizes ecological and climate-envelope models that predict the direction of migration and optimal distance for seed transfer based on adaptations to temperature and precipitation variables (Spathelf et al. 2018). Species can be chosen for specific traits or services, and in this way, a resilient, adaptable ecosystem can be constructed that can withstand a variety of conditions; i.e., drought, prolonged heat and freezes, competitive interactions, and other extreme weather events predicted for the future climate (Bräuning et al. 2017).

Figure 2. Lodgepole Pine (Pinus contorta var. latifolia) *infested by Mountain Pine Beetle in British Columbia, Canada. Land managers are considering using assisted migration to replace this decimated species with Douglas-fir* (Pseudotsuga menziesii) *and Ponderosa Pine* (Pinus ponderosa)*, which are modeled for northern migration. Photo credit: Gunter Marx.*

Before officially termed "assisted migration," foresters in Europe have applied this technique for centuries. In more recent decades, this artificial extension of range distribution has been applied by foresters by the intentional transfer of non-native trees into matching European climates (Spathelf et al. 2018). Practices such as "active adaptation" couple silvicultural tools with alternative species to develop a resilient stand structure in forests threatened by climate change impacts (Mason and Bathgate 2012). Current research is assessing the physiological and evolutionary adaptability of tree species from the Caspian forests of Iran to determine novel conifers for future European afforestation projects. In many European countries, few native forest stands remain and forestry production is achieved by using non-native conifers in highly degraded landscapes that are no longer hospitable to native trees (Stanturf et al. 2018). However, this replacement, thought profitable, does not mean that it doesn't cause other problems. The experience with the introduction of U.S. Pacific Northwest native Douglas fir into Europe has been both positive and negative with reliable establishment in some regions and concerns regarding invasion potential in others (Wohlgemuth et al. 2019).

Successful testing and conducting of assisted migration in North America are site-specific with different target applications for industry, restoration and conservation. In Canada, policy changes allowed for the assisted migration of the western larch *(Larix occidentalis)* and are considering whitebark pine *(Abies albicaulis)* to be moved into climates more conducive for growth. As an example of range expansion, Alberta is considering ponderosa pine and Douglas fir as a replacement for lodgepole pine, which are declining due to threats from both climate change and the mountain pine beetle (Figure 2; Pedlar et al. 2011). British Columbia Ministry of Forests, Natural Resource Operations, USDA Forest Service, and other governmental and private agencies are partnering on the Assisted Migration Adaptation Trial. This project is taking 15 tree species from 40 sites in British Columbia, Washington state, Oregon and Idaho and planting them at 48 test sites outside of the native range throughout western North America (Figure 3; Marris 2009). Species currently being evaluated include: sub-alpine fir *(Abies lasiocarpa)*, amabilis fir *(Abies amabilis)*, grand fir *(Abies grandis)*, western red cedar (Thuja plicata), yellow cedar *(Callitropsis nootkatensis)*, western hemlock *(Tsuga heterophylla)*, trembling aspen (Populus tremuloides), paper birch *(Betula papyrifera)*, Sitka spruce *(Picea sitchensis)*, interior spruce *(Picea glauca X P. engelmannii)*, western larch, Douglas fir, lodgepole pine, white pine *(Pinus monticola)* and ponderosa pine (O'Neill et al. 2013).

Another U.S. Forest Service initiative is the Adaptive Silviculture for Climate Change and includes assisted migration by assisted range expansion. Species including ponderosa pine, lodgepole

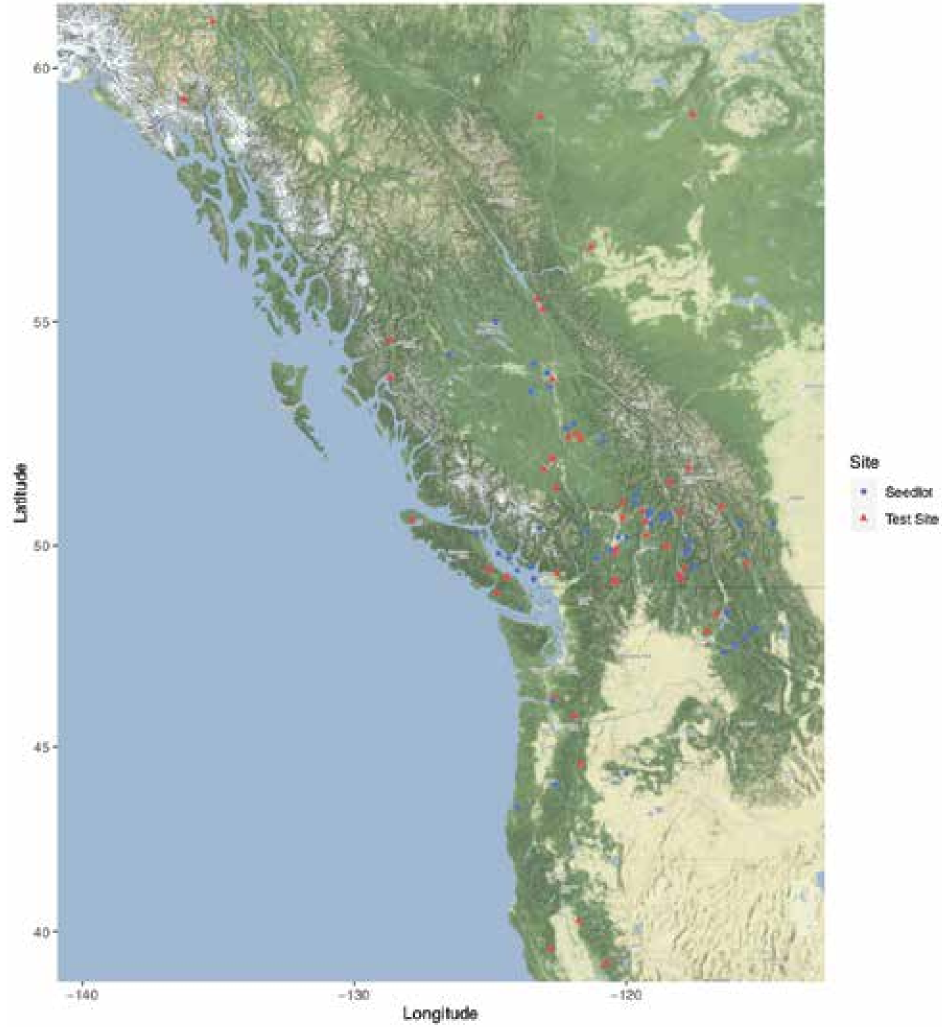


Figure 3. Map of seedlot and experimental planting locations in the Assisted Migration Adaptation Trial (adapted from O'Neil et al. 2013). This project is studying various tree species from 40 seedlots (blue circles) in British Columbia, Washington state, Oregon and Idaho and planting them in 48 test sites (red triangles), outside of the native range. Site coordinates and design adapted from B.C. Forestry, and terrain map from Stamen Maps using R Spatial Visualization with ggplot2 (Kahle and Wickham 2013).

pine, western larch, yellow cedar and Douglas fir are being introduced hundreds of miles outside of their native ranges to encourage a novel species composition designed for end-of-century climate change conditions (Handler et al. 2018). In U.S. Appalachian restoration projects, the loblolly pine *(Pinus taeda)* has been introduced northward due to its ability to grow in poorly drained soils impacted by hardpans in some coal mine reclamation sites (Hansen et al. 2015). A citizen-driven initiative has assisted the species migration of the threatened conifer, Florida Torreya *(Torreya taxifolia)* from its native range in Florida into North Carolina, Tennessee, Ohio, Michigan, Wisconsin, New Hampshire and Oregon (Figure 4; Torreya Guardians 2016). This organization has established specific criteria to ensure that species and sites are appropriately chosen and unintended consequences of introducing a novel species are minimized (Table 1).

Table 1. Proposed criteria to assess species suitability for assisted migration (adapted from Torreya Guardians 2016).

Criteria	*Description*
Neediness	Species is highly vulnerable to extinction in its current habitat.
Irreversible problems in current range	Persistent and ongoing damage or changes in species' current environment, such as disease or climate change, render other population control efforts ineffective.
Suitability of target range	Science supports that the intended location offers suitable conditions for the species.
Low risk for recipient ecosystems	Evidence and understanding of species' life cycle, such as seed dispersal, indicates that there is minimal likelihood of the species becoming invasive or otherwise damaging to the target ecosystem.
Barriers to unassisted migration	Geographical or biological barriers exist that prevent the species from moving to this target range without human intervention. Time may also be a factor, even without physical barriers to migration.
Reconstructing past range	Evidence exists to support that this species once occupied the target range or is genetically or functionally similar to species that formerly occupied the target range.

Figure 4. A Florida Torreya (Torreya taxifolia) *specimen grown in the United States Botanical Garden in Washington, D.C. Due to its high vulnerability to extinction and limited range, the Florida Torreya has been considered as a candidate for assisted migration, and citizen volunteers have organized its transport and seeding in northern states. Image taken by Sarah Stierch, sourced from Wikimedia Commons for use under CC license 4.0.*

The Pros verses the Cons of Assisted Migration

The benefits of assisted migration may fill the lag time and overcome the inability of natural migration within significantly fragmented landscapes. When carefully planned, it is intended that the resulting novel forest system will maintain the original ecosystem function and services with a resilience better adapted to rapid environmental change. This is coupled by the prediction that this technique may pose fewer ecological risks and economic costs, and can address the problems of maintenance, productivity, and stand health over time (Williams and Dumroese 2013). Assisted migration is beginning to be utilized within climate change adaptation plans; however, there is no consensus from scientists and land practitioners due to lack of research, conservation challenges, existing policies and climate uncertainty (Hewitt et al. 2011). While assisted migration can benefit ecosystems by providing resilient species that also fill needed roles, it is also a relatively new concept and has multiple risks, which will require stricter guidelines and policies to cultivate a better understanding of outcomes.

Being a relatively new concept involving intentional movement of species, assisted migration is being met with valid ethical and ecological concerns. Primarily, the concern about the invasion potential of a newly-introduced species is an obvious and imperative consideration. Conversely, depending on tolerance, interactions with other species and dispersal, an introduced species could be maladapted to the novel ecosystem (Winder et al. 2011). Tree symbiont availability, such as mycorrhizal fungi, has played a role in plant migrations and will be required for the establishment of certain tree species. This has been demonstrated with the poor establishment of Douglas fir in soils lacking fungal symbionts (Pickles et al. 2015) and with the potential invasion of restoration Pinus species in Costa Rica when fungal inoculum has been applied (Bever 2003).

There are also concerns regarding the unintentional movement of plant pathogens and pests with the tree stock (Hoegh-Guldberg et al. 2008). Further, species movement and placement are dependent on the accuracy of the climate and species distribution models, which may vary with regard to the rate and trajectory of climate change at both the seed source and planting site. Developing a set of standards to determine if a species is a good candidate for assisted migration could help to address some of these concerns and provide some objective support for choosing to utilize assisted migration (Figure 5).

Should You Adopt Assisted Migration Plans in your Reclamation Efforts?

Although life on Earth has evolved under a constant state of change, the Anthropocene has brought a unique set of challenges for many species, making historical mechanisms of adaptation much less straightforward. With typical pathways of tree migration becoming less feasible due to challenges such as habitat fragmentation, restoration efforts may require novel interventions in order to conserve forest function. Assisted migration has been put forth as a possible solution; however, it is a relatively new concept requiring careful and ongoing evaluation from scientists and land managers. Like many interventionist, transformative restoration techniques, concerns have been raised over unintended consequences of moving species. Understanding species interactions, along with disturbance and equilibrium patterns in individual landscapes, will better inform assisted migration decisions and increase the likelihood that both species and ecosystem resilience to climate change will persist. Therefore, more research and post-planting monitoring is required for the selection of appropriate species, calculation of migration distances, and seed sources for suitable planting sites (Pedlar et al. 2011). For land practitioners considering this technique, Table 2 (adapted from Williams and Dumroese 2013) provides resources for land managers, such as methods to evaluate species vulnerability to climate change, matching seedlots with planting sites, seed zones used to select

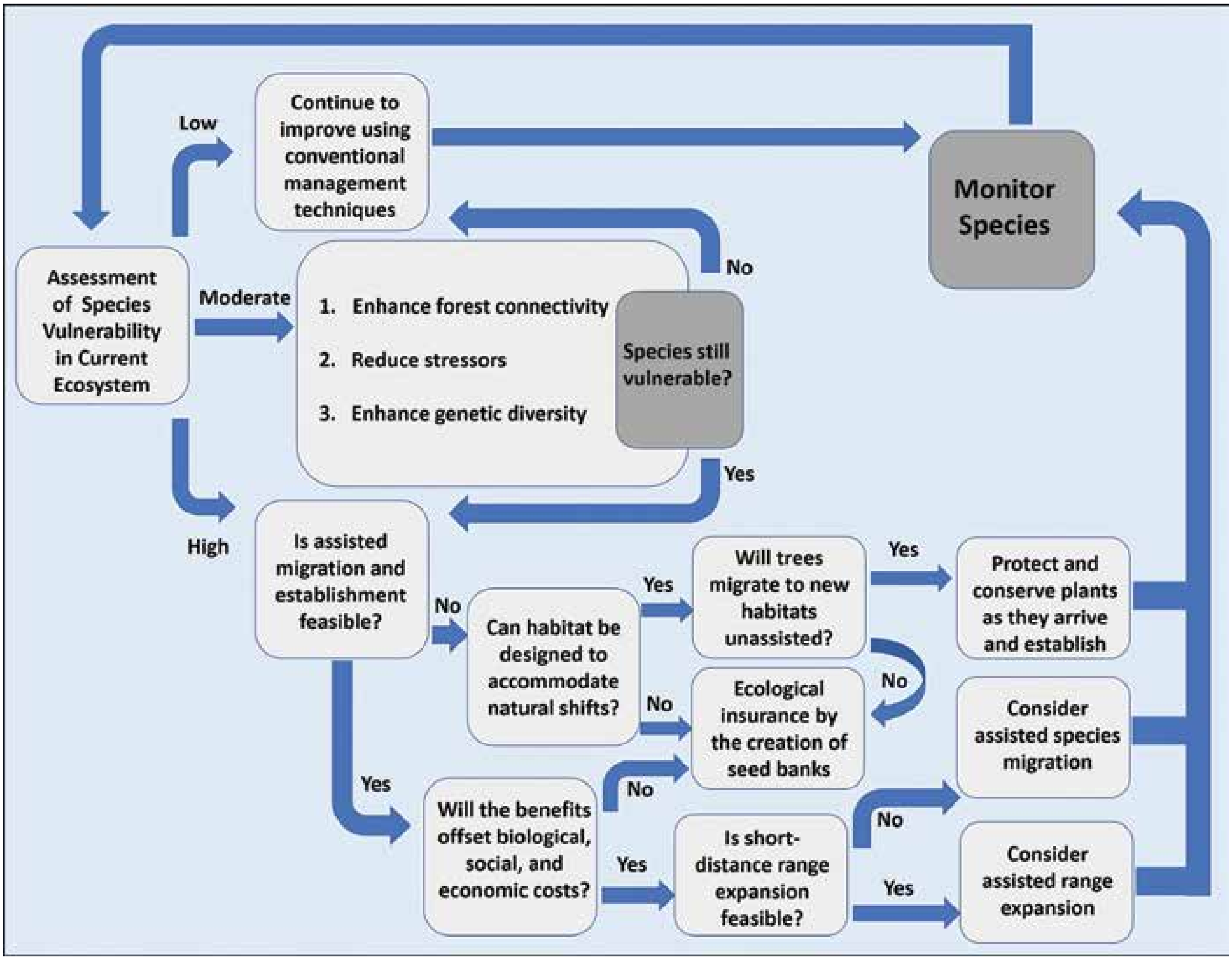


Figure 5. A decision-making framework for Canadian tree species migration adapted from Hoegh-Guldberg et al. (2008) and Winder et al. (2011). After assessing the tree species, actions are directed based on vulnerability and likely candidates for assisted population migration. Regardless of the management action, monitoring is emphasized following any assisted migration approach.

deployment areas and modeling tools for migration distances. As more research is done to develop increasingly precise models and clear criteria for assisted migration, it is hoped that this practice could be beneficial in conserving both plant genotypes and forest ecosystem function to sustain ecosystem services for centuries to come.

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Table 2. Available resources for decision-making in assisted migration for North America. Adapted from Williams and Dumroese (2013).	
Resource and Manager	*Description*
Center for Forest Provenance Data Oregon State University and US Forest Service	Public access database for researchers to share and access data from studies on forest tree species.
Centre for Forest Conservation Genetics University of British Columbia	Research on population level genetics of forests in temperate and boreal ecosystems, and their adaptations to climate.
Climate Change Resource Center US Forest Service	Educational resources for individuals looking to understand the effects of climate change on ecosystems, including forests.
Climate Change Tree Atlas US Forest Service	Mapping tool that shows individual species' current range and maps potential range under various models of climate change.
Forest Seedling Network Forest Seedling Network	Directory connecting seedling vendors with land managers in the western US, along with management resources and other educational materials.
Forest Tree Genetic Risk Assessment North Carolina State University and US Forest Service	Ongoing project developing a method to determine priority tree species for conservation based on risk of extinction.
MaxEnt (Maximum Entropy) Phillips et al. 2016	Open source software for modeling species' ecological niches and ranges.
Native Seed Network Institute for Applied Ecology	Resources for land managers to procure native seedlings and developing effective restoration plans.
Seed Zone Mapper US Forest Service	Interactive map illustrating seed zones, representing the area where a plant species would have the highest likelihood of successfully growing.
Seedlot Selection Tool Oregon State University and US Forest Service	Interactive map allowing users to input parameters such as seedling type, location, climate scenarios, and known transfer limits to identify suitable seedlots or target sites depending on the intended goal.
SeedWhere Natural Resources Canada and Canadian Forest Service	Similar approach to the Seedlot Selection Tool, where users can designate climate and site variables to determine suitable target regions for seedlings based on multiple models.
System for Assessing Species Vulnerability (SAVS) US Forest Service	Tool developed to determine a species' risk of extinction due to climate change, producing scores which can be compared to one another.

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