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FROM THE EDITOR'S DESK

Greetings…I hope you have enjoyed the summer as much as I have. Given that I'm now retired, I now have a wealth of "free time" on my hands, although I'm still doing some teaching and writing. I took time to drive out to Rocky Mountain National Park this summer. Niagara Falls was magnificent as usual especially viewed from the Canadian side and I did see many fine-looking wetlands along the highways in South Dakota. While in the Rockies I participated in a wetland field trip led by Dr. David Cooper (an internationally recognized fen expert), saw many wildflowers (see *Notes from the Field*), and "hiked" up a steep seepage fen. Also saw plenty of elk and moose in the Park. On the trip back east, I stopped in Kansas to see the status of a Tom Biebighauser-designed wetland that we created in early May as part of an EPA-sponsored workshop for state agencies and tribes. The site was on the floodplain of Little Cedar Creek and part of Cedar Niles Park (a future Johnson County Park). The soil was clayey (probably Wabash series – a silty clay) as it felt much like modelling clay when we planted several species. I'm happy to report that a few species have done extremely well especially soft-stemmed bulrush (*Schoenoplectus tabernaemontani*) and boneset (*Eupatorium perfoliatum*). It will be interesting to see how the vegetation changes over time.

Ralph Tiner
WSP Editor

This issue of WSP contains the Society's response to a blue ribbon panel's request for advice on how to improve funding for wildlife conservation in the U.S., a state-of-the-science report on "fracking" with a focus on wetlands (of course), articles on Michigan's floristic quality assessment and on the plight of Mesopotamian marshes, a student profile, summaries of six student projects funded by SWS, and another of Doug Wilcox's cartoons. I've also included some photos from the Rocky Mountain wetland field trip in *Notes from the Field*.

While I continue to receive manuscripts for future issues, I'm still encouraging SWS members and other wetland specialists to submit articles on projects or topics of interest. WSP is a means of spreading the word on your good work as well as providing an opportunity for creative natural history writing. And for students, please consider highlighting your research through a student profile. If you have any questions, please feel free to contact me at: rtiner@eco.umass.edu.

Meanwhile…happy swamping! ■

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Cover photo:
Riparian wet meadow along East Inlet, a tributary of Colorado's Grand Lake
Photo by Ralph Tiner

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PRESIDENT'S MESSAGE

It's that time of year when students and teachers go back to school and some parents breathe a sigh of relief. The students have new school supplies, new teachers and classmates and their enthusiasm is high. Or perhaps you've just finished up an active summer field season in the wetlands and you just can't wait to start working up that data. Any way around it, this time of year is like a new beginning for many of us. And SWS is no different, we have something new making its debut this fall. We are excited to roll out our *SWS Webinar Series*. Take a look at what we've been working on since June and find out how you can get involved.

Kimberli Ponzio, PWS
SWS President

Communication & Education. The brand new ***SWS Webinar Series*** will start this fall (Sept 15th, 1:00pm ET) with Dr. Ariana Sutton-Grier talking about "Innovative Policy Opportunities for Wetland Conservation." These webinars are just another way we are working to increase the value of your membership and enhance our ability to communicate science effectively.

A new Wetland Promotions subcommittee has been formed and is charged specifically with establishing ways to promote wetlands and SWS. One of their first efforts will be to conduct an SWS-wide photo contest in fall 2015 with the goal of collecting your best international wetland images for use in a wetland calendar and on our website. So get your cameras ready!

We have added a Wetland News section to the website so that you can keep up-to-date on wetland issues. Did you notice our alerts about the World Wetland Network Report or the panel review of the Nicaragua Canal Impact Assessment? Go take a look! Please contact our newest SWS staff member, Alli Schultz aschultz@sws.org, if you have any wetland news items that you are interested in sharing.

Partnerships. At the invitation of the Ramsar Secretary-General, Professor Nick Davidson has been officially nominated to represent SWS on the Ramsar Scientific and Technical Review Panel (STRP) for the 2016-2018 triennium. SWS plans to renew its commitment with an SWS-Ramsar memorandum of cooperation this fall.

SWS is also working to forge a partnership with the Association of State Wetland Managers through a memorandum of cooperation. SWS and ASWM share the common goal of encouraging sound science in wetland research, management, restoration, policy, and conservation; meeting this goal requires enhanced collaboration between our organizations.

SWS leaders have been participating in the conferences of our sister-organizations (ESA, SER, etc.) and representing SWS to educate other professionals about wetlands and encourage interest in SWS as an organization.

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SWS Responds to Blue Ribbon Panel Request for Information on Funding U.S. Wildlife Conservation

Kimberli J. Ponzio, M.S., PWS, Society of Wetland Scientists, President
Andy Nyman, Ph.D., SWS, Past-Chair of Wildlife Section

Earlier this summer, the Society received a request from a Blue Ribbon Panel on Sustaining America's Diverse Fish and Wildlife Resources (<http://fishwildlife.org/?section=blueribbonpanel>; <http://www.fishwildlife.org/files/TheBlueRibbonPanelonSustainingWildlife_BROCHURE.pdf>) for information on how to equitably and sustainably finance fish and wildlife conservation to help prevent more species from becoming endangered. The Panel reached out to influential organizations for ideas on how to sustainably fund conservation work that will benefit the full array of fish and wildlife. SWS sent the following response which was presented to the Panel in a summary report in Washington D.C. on July 23rd:

"The Society of Wetland Scientists is a non-profit, international organization of over 3,000 individuals who engage in research, science-based management, conservation, protection, restoration, and promotion of sustainability of wetlands around the world. Our membership includes employees of national, state, and local governments, academic institutions, NGO's, and private consultants who are keenly interested in the actions and policies that affect wetlands and the variety of wildlife that make these diverse habitats their home. In 2008, we formed a Wildlife Section of the SWS that focuses on the relationships between wetland habitat dynamics and wildlife population dynamics. It is from this perspective that we offer these suggestions on how best to secure dedicated and sustained funding to support fish and wildlife conservation.

The Wildlife Section of the SWS recognizes that wetlands are often the focus of habitat that is acquired for wildlife management and that more funding is desirable to acquire and manage wetland wildlife habitat on public and private lands. We agree with efforts to increase funding from non-hunters via excise taxes on outdoor recreational equipment. While recognizing such efforts have been largely unsuccessful since the 1970s (see Loomis and Mangun 1987), our sense is that many non-hunters would support such taxes. However, this support has not been reflected by the policies and legislation offered by elected officials. We believe it is necessary for users of outdoor recreation equipment (recreational vehicles, bird seed/ feeders, photographic equipment, binoculars, nature books, etc.) to mount a grass-roots campaign to rival the one by hunters in the 1930s that led to the creation of the existing duck stamp and excise taxes on firearms and ammunition. In addition, dedicated sales tax revenue, like the 1/8 of 1 cent in Missouri and Arkansas, has been effective in funding non-game habitat conservation in those states. Approaches like this allow citizens to share in the conservation of important wetland habitat and the species that use them.

Below we offer additional, creative ideas that may prove to be successful if implemented strategically. Some ideas are specific while others are broadly applicable.

Develop state license plates supporting species or habitats (e.g. "Helping Sea Turtles Survive" license plates in Florida where 100% of the $23 over the base cost of the tag goes to two turtle conservation programs; Indian River Lagoon license tags in Florida where 100% of the $15 / tag funds lagoon restoration and education projects).

Institute low-cost permits to run ecotourism businesses on public lands (e.g. airboat excursions at public boat ramps).

Implement "Adopt-A-Manatee" (Florida), "Adopt-a-Park"(Minnesota), "Adopt-A-Trail"(Ohio) type programs for imperiled species and habitats (including wetlands) that are promoted at schools, libraries, rotary clubs, zoological parks, wildlife refuges, etc. This could be for solicitation of in-kind services, as well as, funding for research and protection of fragile ecosystems and species.

Utilize crowd source funding – a 21st century model deserves 21st century technology. This requires that adept users of FaceBook, Twitter, and other social media outlets are tasked with getting the word out and selling the program. Hire professional videographers, photographers, writers and speakers to make it work.

Sell "Sustaining America's Diverse Fish and Wildlife" merchandise (hats, t-shirts, backpacks, etc.) to market and brand the efforts of the group.

Start a "Give the Gift of Nature" campaign (similar to WWF) to give a birthday or anniversary gift of conservation to the person who already has everything. Also, start a program of "In Memoriam Gifts" to donate to a fish and wildlife trust.

Develop techniques that focus on getting the young, digital generation outdoors so that they develop an investment in the environment and nature, even if it is tangential to the ultimate purpose; something such as geocaching, laser tag, etc.

Install outdoor movie screens in state/national parks that bring in guests during the night hours when visitation numbers are low and feature nature films (i.e. For kids - *Hoot* based on novel by Carl Hiaasen where kids save burrowing owl habitat from being developed in Florida, *Furry Vengeance* about animals sabotaging a new housing development that threatens to destroy wilderness areas in Oregon; For adults – *Dances with Wolves*, *Gorillas in the Mist*, *Fly Away Home*, etc.)

Finally, the most important aspect of any campaign, such as this, is to focus on education. It is critical to educate the public about the value of conserving fish and wildlife resources (not only for the species in those habitats, but also for themselves). Outreach should be in a variety of mediums to appeal to all generations effectively. Efforts for fundraising should be specific so that an individual feels like they can make a difference (no matter how small). Research shows that if a problem seems too big, people will see their contribution as insignificant and donate less or not at all (Vedantam 2014). So instead of an appeal for people to "donate to save fish and wildlife resources in America", it should take a more targeted approach such as "donate to build nest cavities for red-cockaded woodpeckers in Florida that don't have enough live pine trees to nest in."

The SWS appreciates the opportunity to offer suggestions on building a sustainable base of funding for fish and wildlife conservation in the nation. Although we expect that several of these ideas will be similar to other contributors, we are happy to support the effort that ultimately supports our mission to promote understanding, conservation, protection, restoration, science-based management, and sustainability of wetlands and the fish and wildlife that call these ecosystems their home. ■

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Annual Conferences. Thanks to all the hard work of the Local Planning Committee, SWS staff, and contributions of enumerable SWS volunteers, the meeting in Providence was a huge success! With scientific programming of the highest caliber (209 symposia, 188 contributed sessions, 85 posters, 5 field trips, and 4 free workshops) we attracted 675 attendees and put on a profitable meeting.

We hope that you are gearing up to participate in the 2016 Annual Meeting in Corpus Christi, Texas. Bring the family and come early to enjoy the Memorial Day weekend. And in response to members' suggestions concerning meeting format, we are offering an exciting three-day scientific program!

Governance. The Strategic Plan Committee worked diligently to update the SWS strategic plan and the plan was approved by the SWS board of directors at the meeting in Providence. You can view the new 2015-2020 plan on the SWS website at: http://sws.org/category/governance.html. Stay tuned for changes to the Standing Rules that will enable us to align our mission with that expressed in the new strategic plan.

Wetland Issues. SWS provided input to the Blue Ribbon Panel on Sustaining America's Diverse Fish and Wildlife Resources on how to equitably and sustainably finance fish and wildlife conservation that will benefit a full array of fish and wildlife. Our response was presented in a summary report in Washington D.C. on July 23 and can be found in this issue of *WSP*.

As you can tell, it's been a busy few months. But just like the students starting a new school year, I enthusiastically await what the future holds. I leave you with this quote from Rachel Carson: "Those who dwell, as scientists or laymen, among the beauties and mysteries of the earth are never alone or weary of life." ■

ADDITIONAL RESOURCES

Subscribe to Wetland Breaking News

The Association of State Wetland Managers produces a monthly newsletter that summarizes current events on wetlands – *Wetland Breaking News*. This is largely a collection of news clips addressing wetland issues. Access the latest issue at: http://aswm.org/news/wetland-breaking-news/892-current-issue#national. Past issues can also be accessed there. Sign up to be put on the mailing list. ■

Video Available to Aid in Using Wetlands Mapper

The U.S. Fish and Wildlife Service has produced a video tutorial to help people use the National Wetlands Inventory's "Wetlands Mapper." To access, go to: https://www.youtube.com/watch?feature=player_detailpage&v=CB398gj3O04. ■

Past Issues of *Wetland Science & Practice* to Go Public

On Feb. 6, the SWS board of directors voted to allow free public distribution of past issues of *WSP*. This means that all issues published prior to the June 2014 issue will soon be available via the internet. More recent issues will also be phased in for distribution as they reach the one-year threshold. This means that the audience for *WSP* articles is virtually limitless. Such availability will hopefully stimulate more interest in contributing to the journal. We are working out the details for distribution and welcome this opportunity that will promote the good work done by our members. ■

STATE-OF-THE-SCIENCE REPORT

Hydraulic Fracturing: Potential Impacts to Wetlands

Lori A. Sutter[1], Nathaniel B. Weston, and Steven T. Goldsmith, Villanova University Department of Geography and the Environment

INTRODUCTION

Unconventional oil and gas extraction using hydraulic fracturing has disrupted traditional energy technologies. Shale formations are a vast global resource (US EIA 2011) facilitating a worldwide transition to gas-centric economies. While hydrocarbon reserves in shale formations exist globally (Figure 1), most of the production of gas from shale currently occurs in North America (Nicot and Scanlon 2012). With over 50,000 new unconventional oil and gas wells being drilled annually since 2000 in central North America alone (Allred et al. 2015), and a likely production growth of 60% in the U.S. (US EIA 2015), it is no surprise that unconventional gas drilling has received much attention in recent years. However, its potential impact on natural resources, particularly water quality and quantity, has also garnered much attention in the media and more recently in the scientific literature. Adding fuel to this controversy is a the recent draft EPA report press release with its headline: *Assessment shows hydraulic fracturing activities have not led to widespread, systemic impacts to drinking water resources and identifies important vulnerabilities to drinking water resources* (US EPA 2015a). Here, we summarize the unconventional oil and gas drilling process, discuss benefits, and describe the environmental concerns potentially affecting wetlands, including both those contained and overlooked in EPA's recent draft report.

Extracting Oil and Natural Gas from Shale. Recent advances in the hydraulic fracturing process combined with the advent of horizontal drilling technology has resulted in the rapid development of unconventional oil and natural gas deposits in the United States. Conventional oil and natural gas extraction involves drilling single, vertical wells into naturally occurring reservoirs of gas or oil, but hydrocarbons in shale deposits are distributed throughout sedimentary rock deposits and are unavailable using conventional drilling techniques. A single vertical well would access only a small amount of either oil or gas trapped in pore spaces of the relatively thin shale layer. To increase the efficiency of resource extraction in shale deposits, two advances in drilling technology have been paired: directional drilling and hydraulic fracturing (Figure 2). Directional drilling allows a well to be sunk to the depth of the shale deposit (often thousands of meters below the surface) and then turned to direct the well horizontally through the shale. The horizontal portion of the well that is in contact with the shale can also be thousands of meters long. This portion of the well is then hydraulically fractured. During hydraulic fracturing, a mixture of water and sand, along with a proprietary mixture of "fracking fluids," are pumped down the well at high pressures (10,000–20,000 psi; Jackson et al. 2014) to fracture the surrounding rock and release hydrocarbons held in micropores and/or adsorbed onto organic matter in shale deposits (Nicot and Scanlon 2012). This natural gas or oil can then travel through the fissures created in the shale to the well. The injected water also returns to the surface with the hydrocarbon resource (discussed in more detail in General Environmental Concerns). Individual wells may be fractured multiple times resulting in the return of both the hydrocarbon resource and wastewater. The paved pads supporting the necessary drilling infrastructure may host multiple wells.

The first large-scale foray in unconventional drilling using horizontal drilling and hydraulic fracturing occurred in the Barnett Shale in Texas (Jackson et al. 2014). There are now more than 15 active shale plays (oil and gas accumulations with similar physical characteristics) in the U.S. (Brantley et al. 2012) with the seven regions accounting for 95% of domestic oil production growth and all domestic natural gas production growth during 2011-13: Bakken, Eagle Ford, Haynesville, Marcellus, Niobrara, Permian, and Utica (Figure 3; US EIA 2015a). Daily natural gas production from these regions in July 2014 was estimated at 1,292 million m^3 (45,646 million ft^3) with Marcellus (36%), Eagle Ford (16%), and Haynesville (15%) as the three biggest producers (US EIA 2015a). The Marcellus region has the highest production in the U.S., with 7,100 active wells in Pennsylvania alone (Amico et al. 2015). Daily oil production nationwide is estimated at 5,486 thousand barrels with the Permian, Eagle Ford, and Bakken regions leading the way (US EIA 2015a). Future energy forecasts suggest increased unconventional natural gas production will almost double by 2040, while unconventional oil production will increase by 36% over the same time frame (US EIA

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2015b). Directional drilling along with hydraulic fracturing (together called "fracking") have significantly increased the natural gas and oil production potential from shale and have made the extraction process economically feasible.

BENEFITS OF HYDRAULIC FRACTURING

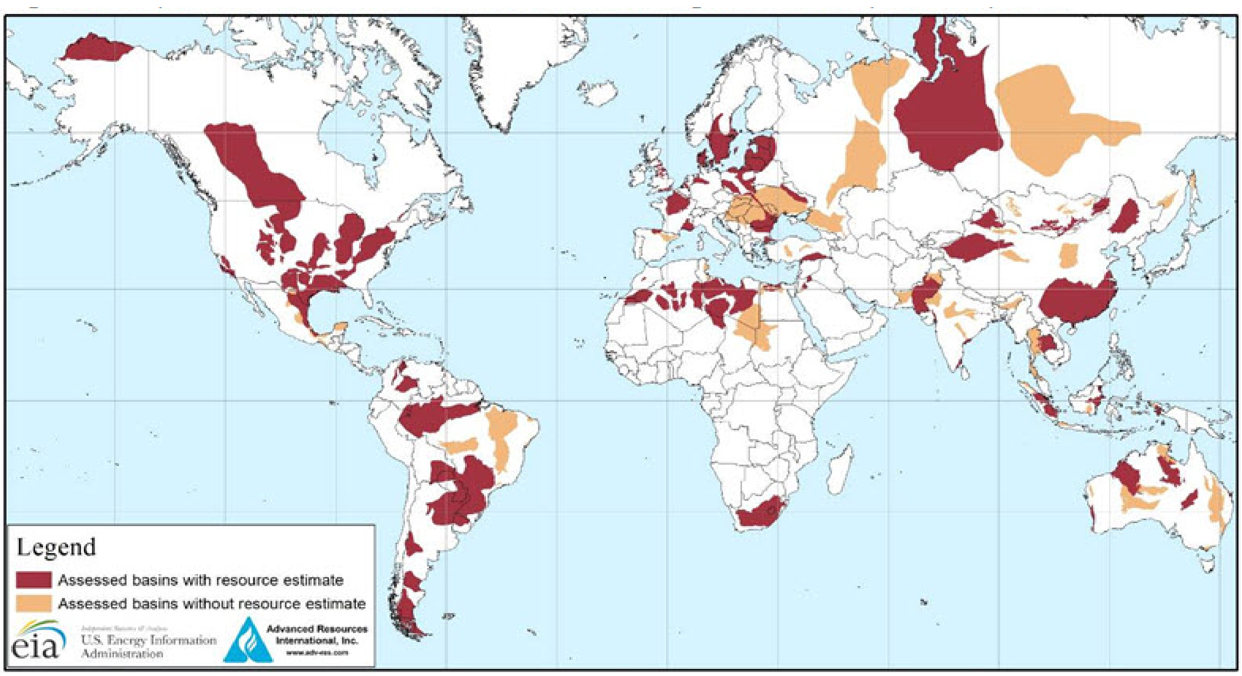
There are a number of benefits to hydraulic fracturing, notwithstanding environmental effects that warrant further investigation. While hydraulic fracturing is used to obtain both oil and gas reserves, much of the benefit is derived from the transition from liquid petroleum to natural gas as a primary energy source. This transition to an abundant energy source (from oil to gas) has led proponents to espouse the benefits of hydraulic fracturing for economic prosperity, energy security, and environmental improvements.

Economic Prosperity. Many of the benefits of hydraulic fracturing are attributed to economic prosperity. The economic value of natural gas in some areas has quadrupled in recent years, a clear indication that the industry has reached a boom status (Weber 2012). The rise of influence of natural gas has led to lower domestic natural gas prices, and the unconventional hydraulic fracturing technology has been behind the reduction (Sovacool 2014*)*. Some local areas welcome the industry (Sontag and Gebeloff 2014), while others do not (Sovacool 2014). The industry has brought wealth to some regions; an influx of skilled workers can lead not only to an increase in the local service economy, but can lead to more permanent economic improvements, such as increases in housing prices due to an inelastic supply (Weber 2012).

On the other hand, energy booms are often short-term, and cycles of boom and bust are rarely managed in advance. Economists offer the concept of a "resource curse" where reliance on natural resources is inversely correlated to economic growth, and the relationship has both political and economic underpinnings (Weber 2012). Hydraulic fracturing has allowed large increases in gas production which have led to modest increases in median household income, employment, and salary and wage income, but wage increases are dependent upon local factors such as commute time/distance, existing wage rate, and worker skill set. Economic benefits tied to hydraulic fracturing can also extend beyond the immediate locality of drilling activity in stimulating manufacturing activities that support drilling and other products that rely on inexpensive natural gas (e.g. plastic, agrochemicals, pharmaceuticals; Sovacool 2014). Gas extraction taxes can also be used to support statewide initiatives (Weber 2012).

The resource curse was not evidenced in an analysis of labor markets in the south-central US; however, sources of public revenue and expenditures may not yet be apparent (Weber 2014). Often absent in this calculation are negative externalities, which must be incorporated and assessed to the entity responsible for creating impacts. Of course, proving causality of an individual entity without a baseline is difficult if not impossible; thus, calculations neglect the cost for any negative by-products of the technology. Policies currently in place for the unconventional extraction are more closely aligned with conventional gas policies, but the consequences are more akin to those of non-point source

FIGURE 1.
Global assessed shale oil and gas formations as of May 2013. (Image courtesy US EIA)



Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.

pollution; hence, appropriate future policy measures might take a different approach than those currently in place (Holahan and Arnold 2013).

Energy Security. At current extraction and consumption rates (including extensive exports), U.S. estimates suggest that hydraulic fracturing provides a lifespan of natural gas at 45 years from the Marcellus play alone (Sovacool 2014) to 65 years nationwide (Howarth et al. 2011). U.S. government projections suggest that oil production from tight oil plays (e.g., shale) will substantially rise over the next decade and thus allow the U.S. to reduce the need for imports (US EIA 2015). The abundance of the resource lessens the source country's dependence on imports, thus reducing the likelihood of conflict over an energy source. It might be an interesting analysis to calculate the resource lifespan if exports slowed, allowing a concomitant delay in production. Presumably, if the hydrocarbon remained in the country of origin for longer term use, energy security would extend to greater timeframes than current estimates.

Environmental. Unlike the combustion of coal and petroleum, use of natural gas does not emit carbon dioxide (CO_2). Thus, natural gas potentially removes CO_2 as a by-product of energy generation, so long as renegade emissions are prevented (Sovacool 2014). Shale gas also has lower emissions of other gases, including sulfur oxide, nitrogen oxide and mercury relative to its fossil fuel counterparts (Sovacool 2014). If completed properly without any leaks, proponents argue that the transition to a gas-based fossil fuel could be a step toward lowered atmospheric greenhouse gases, but renegade methane leaks remain a concerning greenhouse gas emission.

GENERAL ENVIRONMENTAL IMPACTS

Few data-driven studies on the impacts of hydraulic fracturing have been published, and virtually none address wetlands specifically. We review the limited existing scientific literature on environmental impacts of hydraulic fracturing that might affect wetlands and then draw on those impacts to extend the risks to wetlands in the subsequent section. Given the landscape positions of many wetlands (in drainage depressions or at the interface between groundwater and the land surface), they are particularly vulnerable to all impacts to water resources, thus research in water quantity and quality are presented. Wetlands also serve as habitat to wildlife species, of course, so we consider wildlife impacts. We do not include other important effects that are not relatable to wetlands; thus induced seismicity, air quality, and human health are excluded from this report.

FIGURE 2.
The hydraulic fracturing process. (Image courtesy Al Granberg/ProPublica)

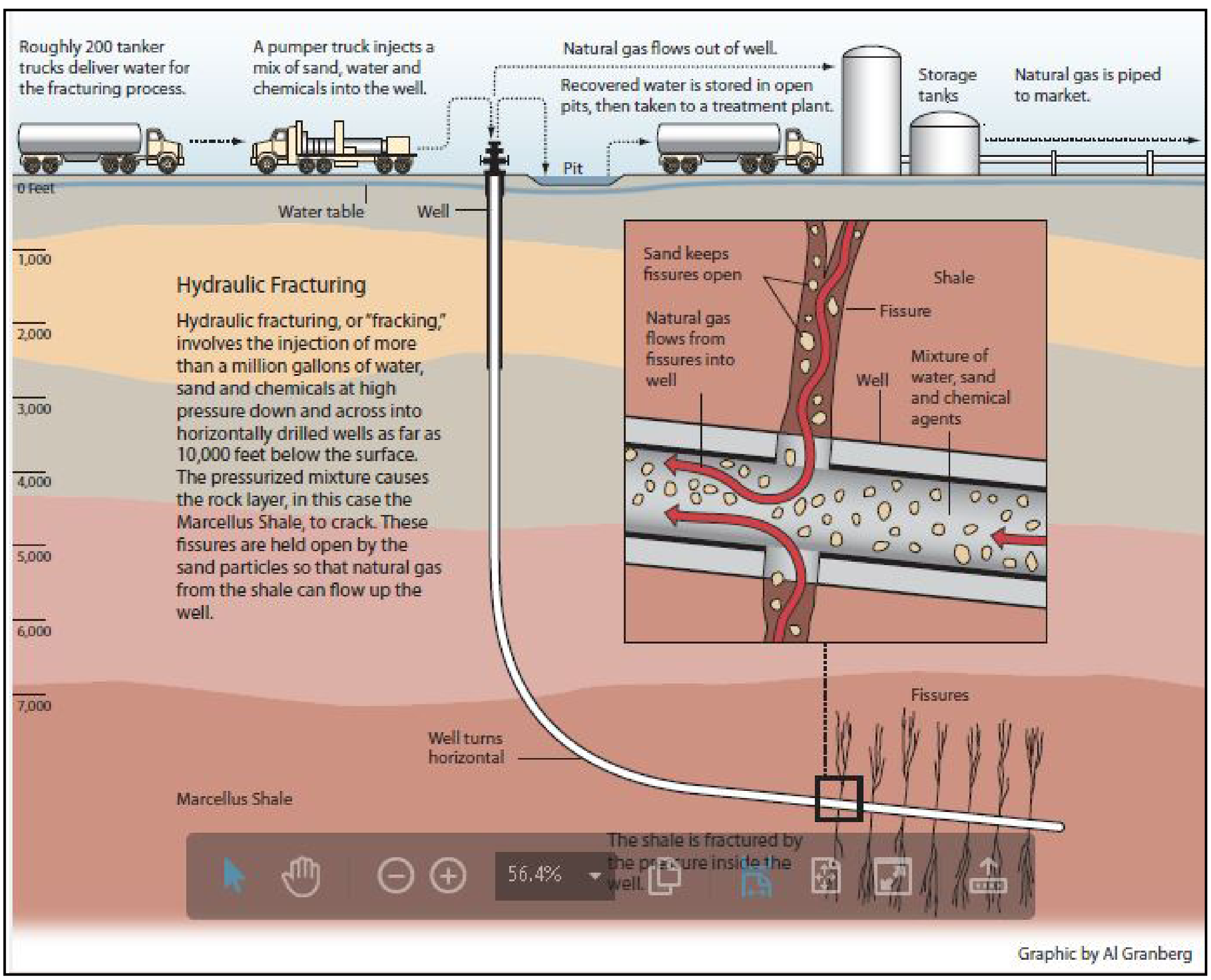


FIGURE 3.
Shale plays in North America as of May 2011. (Image courtesy US EIA)

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

Water Quantity. Estimates of water volumes used in the hydraulic fracturing process vary from ~8,000 to 80,000 m^3 (2–20 million gallons) per well each time it is fractured (Jackson et al. 2014). An additional 25% of that water volume can be used for other steps in the hydraulic fracturing process (Nicot and Scanlon 2012). Water volumes vary geographically and are a function of the hydrocarbon of interest as well as its relative depth and/or extent below the surface. For example, hydraulic fracturing in the Marcellus region requires about 17,000 m^3 (~4.5 million gallons) of water per well, whereas Texas' Eagle Ford Shale uses up to 50,000 m^3 (~13 million gallons) of water per well (Beauduy 2011). The water used during injection is withdrawn from local surface water or groundwater, though increasingly injection water is being reused. Much of the water injected remains greater than one kilometer underground (e.g., 60-90% of the water in the Marcellus Shale in PA and WV), effectively removed from the surface hydrologic cycle.

Using Pennsylvania as an example, water requirements for the total number of wells since 2007 indicate that 100.7 million – 134 million m^3 (26.6 - 35.4 trillion gallons) of water were removed from the surficial hydrologic cycle. These values likely represent a minimum as they do not take into consideration how many times each individual well has been pressure-injected, or fractured ("fracked"). Although Pennsylvania is generally considered a water-rich state, in 2012 the Susquehanna River Basin Commission temporarily suspended hydraulic fracturing water withdrawal permits in five counties due to low stream levels (NPR 2012). The fact that the region was not experiencing a drought during this time suggests that natural gas operations are creating conflicts with other users under normal conditions. The Susquehanna River Basin currently contributes over 98 million m^3 (26 billion gallons) of water to the Chesapeake Bay daily (Drohan et al. 2012b). Withdrawal is expected to increase to over 113 million m^3 (30 million gallons) needed when peak gas production is reached (Drohan et al. 2012b). Given the proposed expansion and growth of drilling in PA, conflicts between natural gas companies and other water users are likely to intensify.

Water Contamination. The injection fluid used for hydraulic fracturing is a mixture of solids and chemicals added prior to injection, which becomes further mixed with brine (ancient seawater) associated with shale deposits during fracturing. The injection fluid is water (generally > 90%), a proppant (used to keep the fissures open; usually sand), and chemicals to adjust the properties of the injection fluid. The volume of the added chemicals is generally <2% of the injection fluid volume, though with the large volumes of water required for hydraulic fracturing the total volume of chemicals used would typically be in the thousands of gallons per well. There have been more than 1000 unique chemicals used in hydraulic fracturing operations nationally, with typically <30 unique chemicals per well; the specific composition of injection fluid varies widely. Voluntary self-reporting of hydraulic fracturing fluids have shown they can include acids (*e.g.,* hydrochloric acid), friction reducers, and corrosion inhibitors designed to protect pipe integrity (e.g., ammonium persulfate, ethylene glycol, and isopropanol), and anti-scalents and biocides to prevent the build-up of bacteria and chemical precipitation in pipes and pores (e.g., acrylic and carboxylic polymers, and glutaraldehyde (see www.fracfocus.org for more complete synopsis of fracturing fluids as well as examples of specific compounds). The voluntary nature of the reporting as well as the lack of reporting of chemicals deemed propriety has led to complaints regarding the transparency of the true composition of injection fluid.

Once injected during the hydraulic fracturing process, the injection fluid comes into contact with the shale rock and mixes with brine confined within the shale. As the acidic injection fluid interacts with the shale and brine, the resulting fluid can become enriched with salts (e.g., sodium, chloride, and sulfate; Haluszczak et al. 2013), heavy metals (notably arsenic and selenium; Balaba et al. 2012), and radionuclides (radium; Warner et al. 2012). The returned water, or flowback water, from hydraulic fracturing activities, therefore, is a variable mixture of high total dissolved solids (TDS), organic compounds, major ions, trace metals, and radionuclides, which depends on the chemicals added to the injection fluid, the chemistry of the shale deposit and brine, and the interactions between the two sources during the fracturing process.

Once a well has been fractured, some portion of the injection fluid returns to the surface, along with the produced gas (largely methane) and/or oil. Eventually, ancient, naturally occurring water previously held deep in the Earth ("produced water") also makes its way to the surface. This combined flowback and produced water, if not properly collected, stored, and treated, can contaminate aquatic resources. Returned water is often temporarily stored in surficial lined pits designed to let evaporation reduce the overall quantity for off-site disposal. Increased storage time, however, runs the risk that improperly constructed pits may leak or that tears in pit linings could contribute to localized groundwater impacts. This avenue of delivery along with leaks from poorly constructed and/or maintained gas well casings has also been tentatively linked to negative impacts in private drinking water wells. Impacts associated with individual spills and well disasters have been reported, but research has not identified wide-scale degradation to surface or ground water resources, in part because of the unpredictable timing of such events.

Wells often are drilled through shallow aquifers to reach shale deposits thousands of meters below the surface. At shallow depths, multiple layers of well casing with cement between each layer are intended to isolate the injection fluid, flowback, and produced gas or oil from the surrounding lithology and groundwater. However, faulty well construction, inadequate layers of casing or cement, or failure of the well casing can lead to the leakage of fluids and gases from the well into shallow groundwater resources. Migration of fluid or gas from the shale production zone up along the outside of the well or through existing or newly created fractures into shallower groundwater or surface water also is a concern. These possible routes of contamination are controversial, remain relatively undocumented, and are the focus of active research (Vengosh et al. 2014).

Certain vulnerabilities to groundwater do exist and have been reported in the scientific literature. Several published studies have used a variety of tracers to confirm the presence of fugitive or stray methane gas emissions in shallow aquifers. Using a dataset of 60 drinking water wells in Pennsylvania and New York, for example, Osborn et al. (2011) identified methane concentrations approximately 17 times higher in active extraction areas. The authors used stable carbon isotopes of methane as well as ratios of methane to higher-chain hydrocarbons to suggest input from deep thermogenic methane. Additional studies have used chemical fingerprints of gas (e.g., ethane and propane not found in biogenic methanogenesis) as well as select noble gas concentrations to confirm shallow aquifer contamination was occurring as the result of stray gas migration of deep thermogenic methane (Jackson et al. 2013; Darrah et al. 2014). Interestingly, evaluation of major elemental concentrations (Br^-, Cl^-, Na^+, Ba^{+2}, Sr^{+2}, and Li^+) and isotopic ratios ($^{87}Sr/^{86}Sr$, $^{2}H/H$, $^{18}O/^{16}O$, and $^{228}Ra/^{226}Ra$) in these same wells revealed no distinctive input of Marcellus brine (Warner et al. 2012). However, a more recent study conducted in Bradford County, PA confirmed the presence of the hydraulic fracturing chemical 2-n-Butoxyethanol in a drinking water well located over a kilometer from a nearby hydraulic fracturing well (Llewellyn et al. 2015). Additional studies from Wyoming also confirm the presence of organic compounds, such as benzene, toluene, ethylbenzene, and xylenes, and elevated concentrations of TDS, methane, and ethane in monitoring wells located in regions of active hydraulic fracturing that have experienced known spills (DiGiulio et al. 2011; Wright et al. 2012).

Surface water contamination from hydraulic fracturing activities also has been documented in the literature. Studies in the Marcellus region have identified the presence of significantly higher concentrations of Cl^- and Br^- in stream water (Olmstead et al. 2013; Warner et al. 2013) as well as ^{226}Ra levels downstream of industrial wastewater facilities that treat hydraulic fracturing wastewater (Warner et al. 2013). It follows that landscape disturbance associated with well pad construction will also exhibit an impact on stream water quality just as any other industrial disturbance or construction activity. An initial survey of watersheds in the Fayetteville shale by Entreken et al. (2011) found a link between well density and stream water turbidity values during high flow periods. Interestingly, this study was performed early during the hydraulic fracturing boom and does not take into consideration disturbances associated with the construction of pipelines or compressor stations.

While evidence of surface and groundwater contamination in the scientific literature is primarily limited to these aforementioned studies, it is safe to conclude that the number of documented releases and/or violations, particularly those associated with cementing, casing, and well construction, have likely influenced water quality in some capacity.

Wildlife. Flora and fauna in the proximity of a surface or groundwater spill risk exposure to contamination. Species susceptible to chloride, heavy metals and sedimentation that have been found in some local studies are at particular risk. Vegetation sprayed with hydraulic fracturing fluid in an experimental forest displayed severe damage and mortality within 10 days of application; soil sodium and chloride increased 50 fold and became more acidic with over 50% tree mortality after two years (Adams 2011). Fish and possibly aquatic invertebrates in southeastern Kentucky were adversely affected by unauthorized disposal of hydraulic fracturing fluids (Papoulias and Velasco 2013). Certain species may also have aversion to light and sound affiliated with unconventional drilling installations during active periods.

More widespread effects occur with the conversion of forested or other undeveloped land to industry, and the fragmentation that results when constructing well pads, pipeline corridors and compressor stations. An assessment of the central U.S. estimates that approximately 3 million ha were converted to drilling installations between 2000-2012 (Allred et al. 2015). In the Marcellus Shale, one estimate suggests that each installation (including well pad, access road, storage area, compressor station, and collector pipeline) affected 12-15 ha and led to 80% of land being fragmented to the point of harming interior species that require a minimum of 100 m of connected forest (Johnson 2010; Kiviat 2013). Drohan and colleagues (2012a) predicted approximately 650 km of roads would be installed based on permitted activity in the summer of 2011.

Fragmentation (i.e., the breaking up of contiguous blocks of undisturbed habitat) has been shown to have many adverse effects on wildlife, including the loss of core/interior habitat (thus changing patch size and connectedness to other patches), and changes in light, moisture, and temperature (Harper et al. 2005). Fragmentation disrupts pollination, dispersal, herbivory and predation and may lead to greater invasion of nonnative plants, introduction of songbird nest predators, severed migratory pathways, and altered wildlife behavior and mortality (Kiviat 2013; Allred et al. 2015). The warming and drying associated with fragmentation also is suspected in the decline of certain amphibians (Brand et al. 2014). Preliminary results of research in Pennsylvania's Marcellus Shale indicate that specialist avian species are more affected by the installations than are generalists; synanthropic species (those associated with humans) are highest nearest installations; whereas, interior forest species decline less than 150 m from the pads (Brittingham et al. 2014a). As might be expected, forest interior species decreased in abundance with increasing well pad density (Thomas et al. 2014).

Globally, shale gas resources are extensive and often intersect with areas of high biodiversity, such as northern South America and the western Pacific Ocean (Butt et al. 2013). This combination points to the importance of protecting biodiversity when gas development begins in earnest outside of North America. Regional plans for drilling might consider consolidating infrastructure and balancing what will likely be a wider footprint with fragmentation in each specific area. To date, restoration from abandoned drilled areas in central North America has not replaced what has been destroyed (Allred et al. 2015). Restoration of sites after drilling is complete will be critical in all areas subjected to unconventional drilling, and preparations should be required at the time of installation to ensure site-specific coarse woody debris and migration corridors are in place (Northrup and Wittemyer 2013). Vegetation that supports targeted fauna should be seeded/planted to kick start the return to baseline function.

Cumulative Impacts. Landscapes can be resilient, but the impacts of unconventional drilling coupled with climate change and other land use changes may lead to unexpected consequences. The scale of environmental degradation suggests that the loss of many ecosystem services is being overlooked. This may be due, in part, because most studies focus on smaller areas (Allred et al. 2015). In Pennsylvania alone, unconventional drilling permits issued by June 2011 could lead to development of 1180-1966 ha, degrading 45-62% in agricultural lands and 38-54% in forested lands (Drohan et al. 2012). Evans and Kiesecker (2014) predicted energy developments would impact upwards of 440,000 ha of forest and over half a million hectares of impervious surface in modeled build-out scenarios within the Marcellus Shale. It follows that this large-scale alteration of the landscape will alter the local hydrology in these settings similar to what is experienced via stormwater runoff in more developed settings.

Many processes within and among ecosystems – whether producer-based ("green") or detritus-based ("brown", like many wetlands) trophic webs – are regulated by the amount of biomass produced as a result of net primary production (NPP). Allred and colleagues (2015) found that the estimated loss of NPP to hydraulic fracturing in 2000-2012 from rangeland and cropland is ~4.5 Tg of C (10 Tg dry biomass) across Central North America

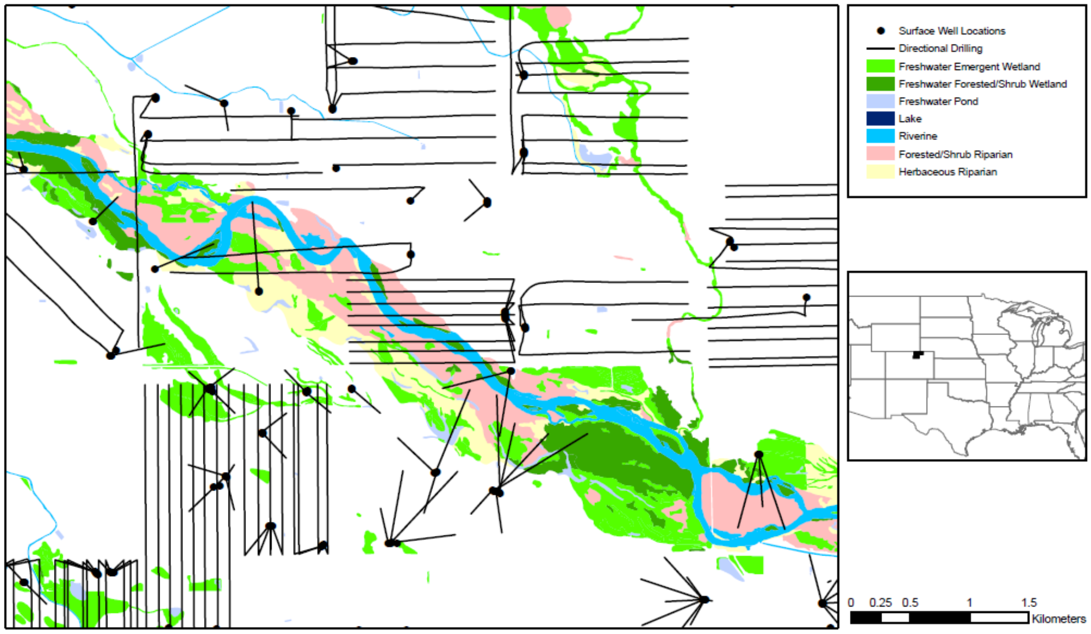


FIGURE 4.
Portion of the South Platte River in Weld County, CO (indicated on inset map) showing wetlands (from National Wetlands Inventory) and oil and gas wells with subsurface horizontal directional drilling lines indicated (Colorado Oil and Gas Commission; data for active wells and wells in production, drilling, or injection stage as of 9 June 2015).

Note that only wells with directional drilling were included here, as presumably these sections were hydraulically fractured (specific data on hydraulic fracturing activity was not available), and that a single surface well location may host numerous subsurface directional wellbores. Many other vertical-only wells (some of which may have been fractured) are not included here.

(U.S. and Canada) alone. The lost rangeland is the equivalent forage that would feed 5 million animals for a month; the cropland loss is equivalent to 120.2 million bushels of wheat (Allred et al. 2015). The rapid installation of drilling infrastructure, therefore, has potential ramifications throughout the food web, suggesting the importance of building regional planning and monitoring networks. The conversion of agriculture to unconventional drilling installations (Drohan et al. 2012a; Allred et al. 2015) also has the potential to place important land uses in competition with one another as the energy industry approaches maximum build-out in future years.

Cumulative impacts are difficult to assess: scales can be broad, baseline data may be difficult to obtain, and causality is challenging to establish. As a result, few data-driven, published studies exist in the literature. As Allred and colleagues (2015) point out, a perfect storm may be brewing between agriculture, environmental conservation, and energy demands on the remaining undeveloped landscape. The last time the U.S. saw conflicts of this scale led to the Dust Bowl (1930s). With an abundance of data on related activities currently available and the lessons learned from history, we have an opportunity to act now to prevent such catastrophic events.

CONCERNS FOR WETLAND IMPACTS

Concerns about drilling and hydraulic fracturing activities have focused largely on the human health consequences of water and air pollution, though the impacts of changes in water quality and quantity and land-use associated with natural gas and oil extraction on ecosystems are receiving increasing attention. Here, we outline the threats that hydraulic fracturing might pose to wetland systems.

Land Use Change. The installation of new unconventional wells and related infrastructure each year drives substantial change in land use. Transformation of wetlands for other uses has long been the leading cause of wetland loss (Dahl 1990). Before new gas or oil wells are drilled and hydraulically fractured, land is cleared for the construction of a well-pad at the site of the drilling. In addition, pipelines are installed, new roads are built (in most cases), and supporting infrastructure such as natural gas compression stations are erected. While proportionally little of the land used for hydrocarbon extraction activities has directly impacted wetlands (<1% in North America; Allred et al. 2014), wetlands occupy a relatively small footprint on the landscape and even that small presence makes a large contribution to ecosystem health. It is likely that the most common wetland type impacted is the important headwater forested wetland. In Pennsylvania approximately one quarter of all well pads occur in core forest areas where many headwater streams are located (Drohan et al. 2012a).

In addition to direct loss of wetlands from land use change, the process of constructing well-pads, roads, and pipelines may indirectly impact wetlands through an increased area of impervious surfaces (Allred et al. 2014) and the mobilization of sediments and other materials (e.g., Entrekin et al. 2011; Vengosh et al. 2014). These activities may lead to deterioration in water quality (see *Water Quality*, following section), delivery of sediments and pollutants to depositional wetland environments, and changes in hydrology with increased impervious surfaces (along with water extraction; see *Water Usage*, following). The impacts of land use change associated with gas and oil drilling on wetlands remains unclear.

Water Usage. Vengosh and others (2014) estimated that approximately 300 million m^3 (>79 trillion gallons) of water has been used for hydraulic fracturing over the last decade, which represents about 1% of the water lost from evaporation during thermoelectric generation. On a national scale, then, hydraulic fracturing does not substantially alter water usage. Water withdrawals may have greater influence on water resources at the local level, however, that may impact wetland ecosystems. Several of the oil and gas plays in the Central and Western U.S. (for example the Niobrara, Hilliard-Baxter-Mancos, and Mancos plays in CO, NV, WY, and UT, the Barnett and Eagle-Ford plays in TX, and the Monterey play in CA) are situated beneath relatively arid regions. Freyman and Salmon (2013) estimate that about half of the shale gas and oil wells in the nation have been developed in areas with high to extremely high baseline water stress. Surface water or groundwater withdrawals for hydraulic fracturing in these areas may compound agricultural and municipal withdrawals further exacerbating water stress, potentially leading to water shortages for wetland habitats. For example, much of northeast Colorado positioned over the Niobrara shale play is classified as high or extremely high water stress (Freyman and Salmon 2013; Freyman 2014). Directional drilling and hydraulic fracturing activity is rapidly expanding in this a region (Figure 4). This is also a region with abundant freshwater wetland ecosystems (Figure 4). Much of the South Platte River is bounded by extensive riparian meadows and woodlands, and there are wet meadows, freshwater marshes, and submerged aquatic wetland ecosystems found in this region. Many wetlands in this area have been altered by development and agricultural activities, and water availability is a concern in this relatively arid region. Irrigation for agricultural use in the South Platte River basin exerts substantial pressure on the region's water resources. Water withdrawals for hydraulic fracturing activity may further exacerbate depletion of local water resources, creating water stress for wetland ecosystems in the region. The impact of water withdrawals on wetland ecosystems requires further attention.

TABLE 1.
Potential sources of water contamination from unconventional drilling

Standard Operations
On-site spills of chemicals used for injection, and/or spills of produced water
Failed well casing allowing leakage to water table or surface waters
Migration from production zone to water table or surface waters
Improper storage and/or treatment of flowback/produced water
Less Common Scenarios
Well explosions [*examples from Sontag and Gebeloff (2014)*] • North Dakota (2006): 1 environmental incident for every 11 wells • North Dakota (2013): 1 environmental incident for every 6 wells • Well blow outs often withheld from public (e.g. Skurupey in North Dakota)
Incidents during transport • Transmission pipelines leaks • Compressor stations explosions (e.g. Appomattox, VA) • Ports • Nearshore - ships awaiting port entry to load/unload because ports are over capacity or awaiting more favorable market prices • Greatest concern where hydraulic fracturing collects both oil and gas

Water Quality. Hydraulic fracturing for gas and oil carries the potential to contaminate shallow groundwater aquifers and surface water resources at several steps in the process that has the potential to impact wetland ecosystems (Table 1). Since large quantities of the chemicals used to create the injection fluid are transported, stored, and mixed during hydraulic fracturing activities, there is a risk of spillage and/or leakage during each of these steps. In their recent draft assessment, the U.S. EPA (2015b) found that between 0.5 and 12% of wells had reported spills/leaks, yet this is likely underreported, and the volume of unplanned releases are generally not known.

Concerns about pollution from hydraulic fracturing have understandably been focused largely on surface water quality and human health (Olmstead et al. 2013; Vengosh et al. 2014), and, to our knowledge, there has been no research on wetland-specific response to changes in water quality associated with drilling. Wetland ecosystems are likely resilient to low concentrations of many of the chemicals that might be released into surface waters or shallow groundwater, except in the case of acute events. We suggest that the largest widespread concern specifically for wetlands – outside of individual spills – is the potential for an increase in dissolved salts (mainly Cl^-) that might accompany any contamination of water resources. The shale brine contains very high concentrations of salts, and chloride is often added to drilling fluid in the form of hydrochloric acid (US EPA 2015b). Van der Burg and Tangen (2015) identified chloride contamination in many wetlands throughout the Prairie Pothole Region of the U.S. likely associated with unconventional gas drilling. Drilling and hydraulic fracturing activities may, therefore, further exacerbate the general salinization of freshwater systems nationally (Kaushal et al. 2005). Increasing salinity in freshwater wetlands may adversely impact plant growth and alter ecosystem function (Neubauer 2013).

Challenges. The challenges facing quantifying impacts of hydraulic fracturing on wetlands hinge on the many unknowns, which may remain unstudied for some time because of the controversial nature of the topic and/or lack of funding sources. Until baseline data can be obtained, attributing impacts to hydraulic fracturing will remain difficult. Requiring baseline data for drilling on public lands would be a responsible strategy for the publicly held common good, but it would not be adequate as a sole measure since most hydraulic fracturing occurs on private lands (e.g., in the U.S. Great Plains as much as 90% occurs on private lands; Allred et al. 2015). Additionally, a lack of transparency regarding the chemical composition of the injected fluids has impeded the targeted testing for impacts in areas where drilling is already underway. Furthermore, a lack of regulatory inspections in areas of active drilling, suspected under-reporting of known releases, and lack of stream and groundwater monitoring networks in areas of active drilling has not allowed for a full quantification of water quality impacts. Finally, given the relatively new arrival of this technology, we simply do not yet have a handle on the failure rate of well integrity over time.

RECOMMENDATIONS FOR FUTURE INVESTIGATION

The position of wetlands in the landscape suggests that impacts to water resources (both quantity and quality) will be magnified in these valuable and vulnerable systems. Any data-driven research would be a significant contribution to the current level of understanding. Until a systematic monitoring program is in place, there is no way to truly know the impacts of fresh water withdrawals from these systems or the probability of well leaks. It is possible that required routine installation of groundwater monitoring systems analogous to that instituted for underground storage tanks in the mid-1980s would allow for the earlier detection of leaks. In light of the concerns presented herein, we recommend the following research priorities targeting wetlands.

- Determine water budgets in impacted watersheds, especially in high water stress areas to ascertain impacts that water withdrawal may have on aquatic and more particularly wetland resources.
- Create an integrated monitoring system within each shale play to capture long-term responses of targeted contaminants (e.g., salts, metals, and organics) both at individual wells and downstream.
  - Prioritize monitoring in watersheds with spills to see if impacts attenuate, especially organics and metals.
  - Determine the transport and potential accumulation of appropriate contaminants through the food web.
- Discriminate the role of water and/or sediments to wetland long-term survival in heavily impacted watersheds, especially during initial sediment flux during construction and during high runoff events.
- Institute regional siting planning to consolidate infrastructure, thus avoiding wetlands and minimizing fragmentation.
- Design effective restoration and monitoring to ensure sites are returned to functioning areas reaching targeted ecosystem services and species. ■

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Application of International Water Law in Eden: Environmental Protection of the Mesopotamian Marshes in Southern Iraq

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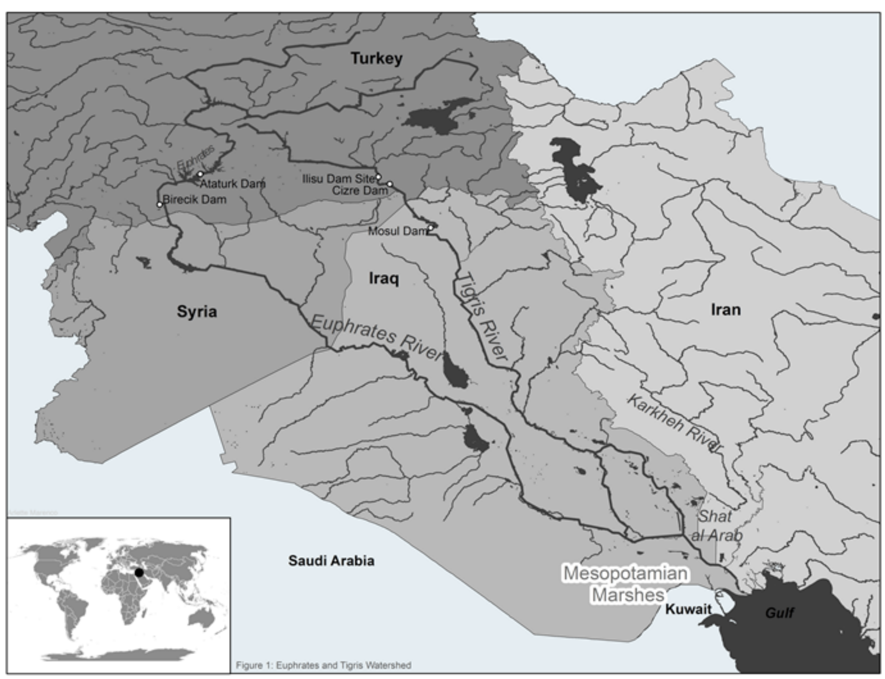
INTRODUCTION

Southern Iraq's Mesopotamian Marshes are fed by the Tigris and Euphrates watercourses. Conflicts in the Tigris-Euphrates Basin over water use and quality are among the most contentious in the world. Increased upstream water withdrawals exacerbated by desertification and regional changes in precipitation and temperature have created a serious water shortage that is becoming increasingly severe. These wetlands need cooperation, reasonable use, and no harm by all watercourse states, especially Turkey, in order to guarantee their survival and conservation. Recent history has not been kind to the Mesopotamian Marshes of southern Iraq or the people that inhabit them. The area has been the scene of three wars and military conflicts over water. The Iran-Iraq War (1980–1988) was fought over international borders, ending where it began at the thalweg of the Shatt-al-Arab. After the Gulf War (1990–1991), over 90% of the marshes were destroyed for military purposes by diverting the Tigris and Euphrates Rivers to destroy the wetlands and indigenous Marsh Arab inhabitants, who became internally displaced persons during this time period (UNEP 2001; Brasington 2002; Naff and Hanna 1993). In 2003, the demise of the previous regime brought renewed flooding to the marshes (Stevens 2011). From 2004-2008, good water years and Iraqi restoration efforts reflooded approximately 58% of the marshes, and many Marsh Arabs returned with their water buffalo (*Bubalus bubalis*) to life in the marshes (Stevens 2011; Al-Handal and Hu 2015). Sadly, the marshes are again desiccated to 2003 levels due to upstream dam construction in Turkey and drought. Civil unrest continues and is escalating with tragic consequences.

Application of international water law by water managers and policy makers may help prevent harm to the human and ecological health indigenous to the Mesopotamian Marshes of southern Iraq, sustained by the Tigris and Euphrates watersheds (Figure 1). Environmental protection is accomplished through application of the 1997 United Nations (UN) Convention on the Law of Non-Navigational Uses of International Watercourses, the Ramsar Convention, and customary principles of international water law. As with other international transboundary rivers—the Nile, Zambezi, Mekong, Amazon, and Colorado—upstream water diversions, dams for irrigation and hydroelectric development, and increasing human populations and related water consumption result in loss of downstream water for human welfare, biodiversity and ecosystem function.

The purpose of this article is to describe the physiographic and socioeconomic conditions that characterize the Mesopotamian Marshes and demonstrate how upstream water diversions are harming downstream ecosystems, biodiversity, and human well-being. The discussion includes background on the past failures of water agreements, clarifying the root causes and national perspectives of each co-riparian state over the flows of the Euphrates and Tigris Rivers and emphasizes the importance of using

FIGURE 1.
Tigris and Euphrates Basin. (Arlette Marenco 2015)



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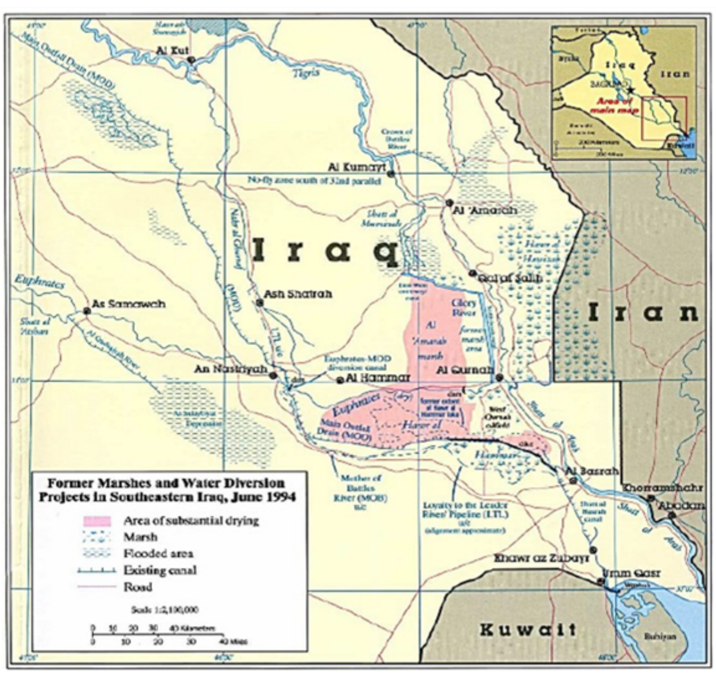
international water law to protect, preserve, and conserve the Mesopotamian Marshes and Gulf. The Tigris-Euphrates Basin is an analog for other international transboundary river systems and should be viewed as a prequel for the need to assess current water management practices and implement a wiser approach.

PHYSIOGRAPHIC BACKGROUND / HYDROLOGIC CONSIDERATIONS

The headwaters of the Euphrates and Tigris Rivers form in the Taurus Mountains of southeastern Turkey (Figure 1). The 2,700 km Euphrates River and 1,900 km Tigris River flow through Syria and Iraq, joining together in the 193 km Shatt al Arab, then discharging into the Gulf (FAO 1999; El-Fadel et al. 2002). The headwaters of the Tigris-Euphrates watershed in Turkey, Syria and Iran support approximately 70% of the water entering the basin. Historically, the downstream Mesopotamian Marshes thrived from pulsed flood flows in the spring that renewed soil fertility, deposited sediment, and eliminated concentrated salts at the marsh surface. Unfortunately, upstream water diversions now eliminate the seasonal flooding that drove the ecological dynamics of the marshlands (Al-Ansari et al. 2012, 2013).

External water sources are critical to maintain marshes in southern Iraq, which is a desert with an average annual rainfall of 154 mm. Precipitation ranges from less than 100 mm over 60% of the country in the south to 1200 mm in the northeast. Evaporation and evapotranspiration vary depending on temperature and wind velocity, with overall evapotranspiration and transpiration losses averaging 1900 mm per year (Al-Ansari 2013).

FIGURE 2.
Mesopotamian Marshes in southern Iraq. (US-AID Report 2004)



At one time, the Mesopotamian Marshes of southern Iraq (*Al-Ahwar*[2] in Arabic) were the largest wetland ecosystem in the Middle East, covering 15,000–20,000 km^2 (UNEP 2001). This area has been inhabited since the dawn of civilization by ancient agricultural and civilized communities, including the Sumerians and Akkadians during the period 4000–6000 BCE (Ochsenschlager 2004; Hritz et al. 2012). The marshes are a cultural heritage center of global importance, having supported the traditional lifestyles of approximately 500,000 indigenous people — the Marsh Arabs (Stevens et al. 2011).

Wetlands within the Mesopotamian Plains of Iraq form an island of vegetation within a matrix of desert vegetation and dunes (Al-Hilli et al. 2009). These wetlands play a vital role in the maintenance of biodiversity in the Middle East primarily because of their large size, the richness of their aquatic vegetation, and their isolation from other comparable systems (Stevens 2011; Douabul et al. 2013). The marshes form a river of very tall grass dominated by the common reed (*Phragmites australis*), an ecological and cultural keystone species (Stevens 2007). A total of 371 plant species were recorded by Al-Hilli et al. (2009), of which approximately 40% were wetland obligate or facultative species. Tall emergent plant communities define the marshes, and are dominated by *P. australis, Typha domingensis*, *Scirpus littoralis*, and *Cyperus papyrus* (Al-Hilli et al. 2009). The marshes have become more saline and biodiversity has declined with reduced inflows.

The wetlands of Lower Mesopotamia comprise shallow lakes and marshes, formed on two large, flat, and active fan deltas fed by the flows and floods of the Tigris and Euphrates Rivers and their distributaries (Al-Ansari et al. 2012). Figure 2 illustrates the three geographic areas of the Mesopotamian Plain: the Hammar wetlands to the west of the Euphrates; the Central Marshes; and the Al-Hawizeh and Al-Azim transboundary marshes straddling the Iran-Iraq border. Conditions that shape the biotic communities of the Mesopotamian Marshes include 1) fluvial flood pulses and sediment deposition, 2) influences from the distributary rivers, 3) tidal estuarine mixing of salt-and freshwater in the Shat al-Arab, and 4) groundwater in the southern marshes (Altinbilek 2004).

The marshes are legendary for their birdlife. In the fall months up to 10 million migratory waterfowl and shorebirds make their way from Siberian nesting grounds to the Mesopotamian Marshes and northern Africa (Scott 1995; Stattersfield et al. 1998; Porter and Aspinall 2010). Surveys by Nature Iraq from 2005 confirmed 190 breeding bird species for Iraq (Nature Iraq 2010b; Ararat et al. 2011). This area supports 22 globally endangered and 66 at-risk avian species (Birdlife International 2010). The endemic Iraq babbler (*Turdoides altirostris*) and the Basra reed-warbler (*Acrocephalus griseldis*) breed only in the marshes.

[2]The term "al ahwar: is derived from Aramaic meaning "whiteness" or "the illumination of sunlight on water".

The marsh ecosystem sustains an economically important local and regional fishery, providing spawning habitat for migratory finfish and penaid shrimp from the Gulf (Salman 2011b). Over 58 freshwater fish species occur in Iraqi inland waters, whereas 53 marine species frequent both estuarine and fresh water (Coad 1996, 2010), and 125 fish species and five species of shrimp reside in the Iraqi marine waters (Mohamed et al. 2001).

Fish populations are diminishing and habitat is being lost from enormous hydrologic modifications from the Tigris and Euphrates rivers (Mohamed et al., 2012). Dampening of annual high-water flood pulses has removed natural spawning cues of fishes and reduced the annual deposition of silt-borne nutrients to the floodplains. Within the marshlands, manmade canals exclude the natural habitats required by fish for their reproduction and growth. Remaining marsh habitats have been embanked and partitioned, restricting the connections between the various habitats required by fish for their different life stages.

SOUTHEASTERN ANATOLIA PROJECT (GAP PROJECT)

In 1977, the Turkish Government started the GAP Project, one of the largest river basin development projects in the world. The GAP Project includes 22 dams and 19 hydraulic power plants that are to irrigate 17,103 km^2 of land with a storage capacity of 100 km3, three times more than the capacity of Iraq and Syrian reservoirs (Al-Ansari and Knutsson 2011). The GAP Project will reduce the Euphrates River water flow to Syria by 40–50%, leaving Syria and Iraq in conflict over the residual water. The estimated water reduction to Iraq is approximately 80% (Bagis 1997).

A regional crisis occurred with the building of Ataturk Dam in 1990 and Birecik Dam in 1996, resulting in reduced flows and impaired water quality in the Euphrates River (Kibaroglu and Unver 2000). In 1998, Turkey pledged a release of an amount of 500 m^3/s to the Euphrates River at the Syrian border (Bagis 1997). In April 2009, only 230 m^3/s were trickling through the Euphrates River at Iraq's northern border (Alwash 2013).

Prior to 1972, the mean water discharge of the Euphrates River at Hit and Haditha cities was 967 m^3/sec and dropped to 553 m^3/sec after 1985 (Figure 3), resulting in a 43% decrease in river water discharge (Al-Ansari and Knutsson 2011). The decrease is attributed to the construction of the Ataturk and Birecik Dams. Note that flood pulses were also dampened.

Reduced flows of the Tigris River is of even more cultural and political significance to the Iraq. Historically, the Tigris River carried an average of 22 BCM (billion cubic meters) annually into Iraq, and its tributaries within Iraq contributed an additional 28 BCM (Alwash 2013). The proposed Ilisu Dam on the Tigris River is one of the world's most controversial hydropower projects. Ilisu Dam will create an 11 billion m^3 reservoir with a surface area of 31 km^2, providing 2% of Turkey's electricity needs (Scheumann et al. 2011; UN-ESCR 2011). Unfortunately, the Ilusu Dam will internally displace an estimated 55,000 Anatolian people in 199 settlements, creating human rights violations in southeastern Turkey (Ibid.). The Ilusu Reservoir will also flood more than 30,000 hectares of land (74,000 acres), destroying archaeological sites and regional biodiversity. Of particular concern is the inundation of the 10,000-year-old proposed World Heritage Site of Hasankeyf.

The Tigris River, unlike the Euphrates, has several tributaries. Prior to 1984, Iraq received 20.9 km^3/year of water from the Tigris River (a discharge rate of 701 m^3/sec

FIGURE 3.
Water discharge of River Euphrates at Haditha Dam for the period 1960-2008. (Al-Ansari and Knutsson 2011)

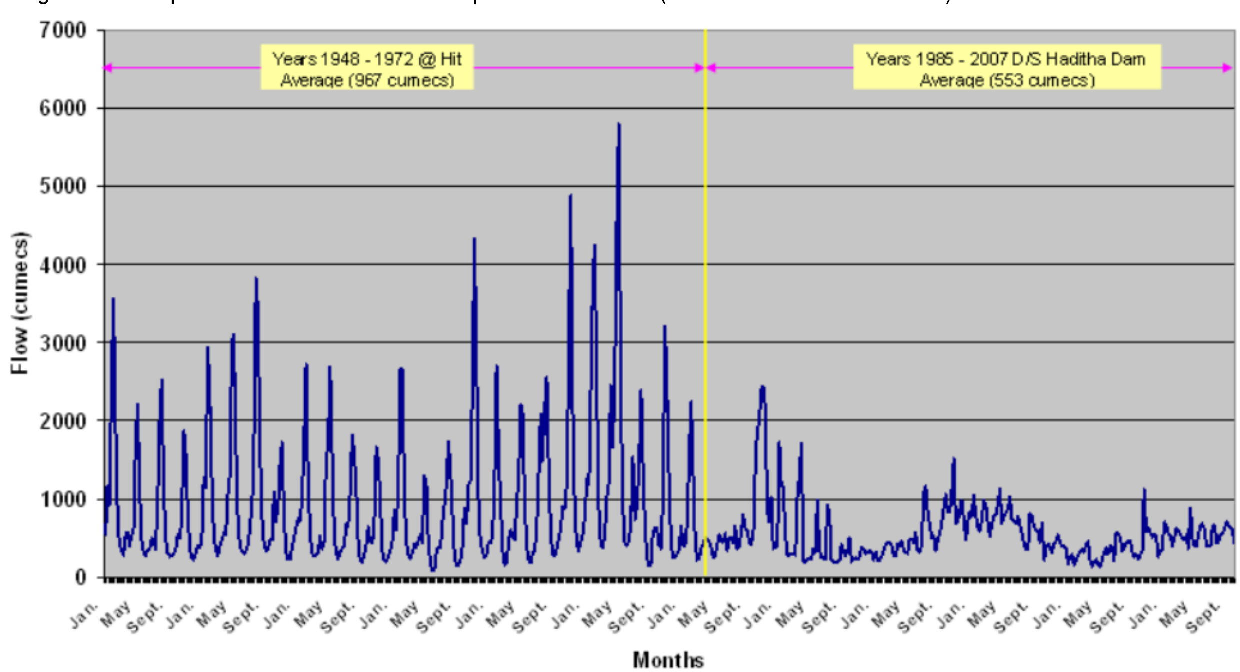
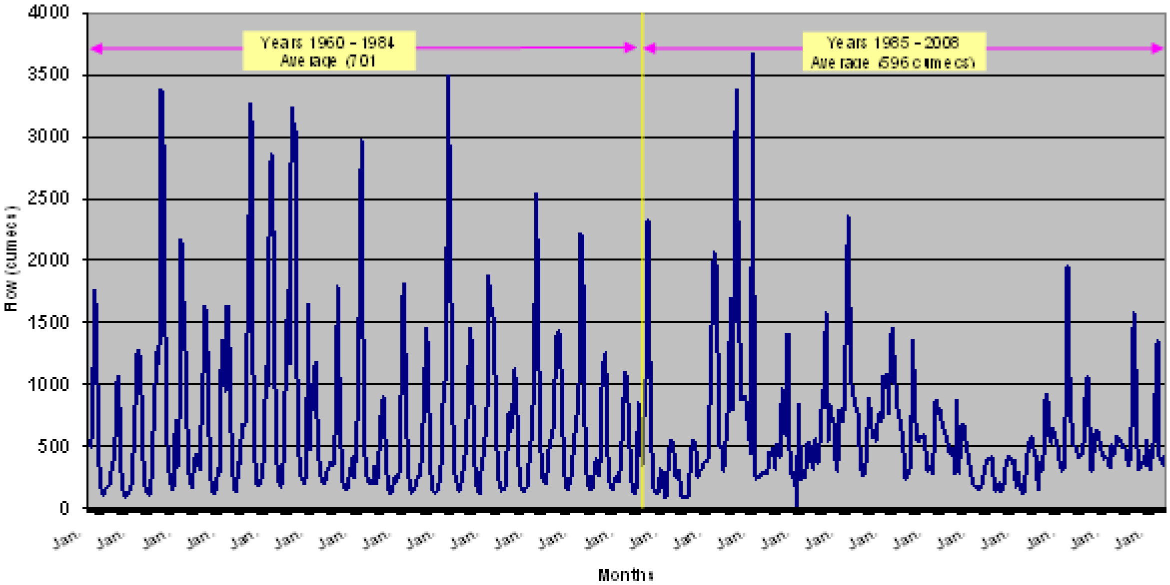


FIGURE 4.

Water discharge of River Tigris at Mosul City for the period 1960-2008. (Al-Ansari and Knutsson 2011)



at Mosul City). After 1984, this rate dropped to 596 m^3/sec (Figure 4) for a decrease of 15% (Al-Ansari and Knutsson 2011). Once Ilisu and Cizre Dams are constructed, flows are likely to drop to 9.7 km^3, a reduction of 47% (Al-Ansari and Knutsson 2011), affecting some 670,000 hectares of arable land in Iraq.

Without an effective international water management strategy, Turkey is free to act unilaterally; as the upstream water user, dams and diversions will determine downstream flows of the Tigris and Euphrates Rivers (Salman 2004; Wolf and Newton 2007; UNEP 2008). Downstream users, with little available surface water, are forced to deplete their non-renewable groundwater reserves, intensifying saltwater intrusion from the Shat al-Arab and contamination of freshwater.

The Gravity Recovery and Climate Experiment (GRACE) satellite mission evaluated freshwater storage in the Tigris and Euphrates River Basins and western Iran from 2003 to 2009 and provided a tool for water management decision-making at a transboundary scale (Rodell et al. 2004; Voss et al. 2013). Water storage in the region shows a clear decline after 2007 which marked the beginning of a regional drought and upstream water diversions. The GRACE model showed that the rate of water loss in the Euphrates River is among the largest liquid freshwater losses in the world. The 143.662.8 km^3 loss during the 7-year study is nearly equivalent to the volume of the Dead Sea (Voss et al. 2013). Between 2003 and 2009, groundwater use increased in response to the drought and declining surface water availability (Famiglietti et al. 2011).

Climate change models project lower water availability in the future. By the end of this century, mean temperatures in the Middle East North African (MENA) region are projected to increase by 3° to 5°C, while precipitation will decrease by about 20% (Elasha 2010). By 2050, water runoff will decline by 20% to 30% in most of the MENA region, and water supply might decline by 10% or more (Milly et al. 2005).

The goal of the Iraq Ministry of Water Resources (MOWR) and Center for Restoration of Iraqi Marshes and Wetlands (CRIMW) was originally to restore 75% of the original area of the marshes (UN-IWTF 2011). This translates into an area of 1,800 km^2 for Al-Hammar Marsh; 1,800 km^2 for the Central marshes; and 2,425 km^2 for the Al Hawizeh and Central Marshes, respectively (Al-Ansari et al. 2012). Therefore, the quantity of water required for each marsh is 3,262 m^3, 5,495 m^3 and 4,128,106 m^3, respectively (Al-Ansari et al. 2012). There is not enough available water to meet restoration goals, necessitating revision to reflect reduced water supply (Salman 2004; Chenoweth et al. 2011).

WATER SUPPLY AND WATER QUALITY

Water quality degradation throughout the Mesopotamian marshes is caused by reduced flows, saline drainage from direct discharge of irrigation return flows, retention of sediment and nutrients behind dams, and discharge of industrial waste and raw sewage to surface waters (UNEP 2001). The heavy use and contamination of water by the oil industry has exacerbated water quality problems (Rubec 2013). Salinity of the Chubayish marshes increased from 0.4–0.6 g/dm^3 in the 1970s (Al-Saadi et al. 1981) to 6.3 g/dm^3 during 2008–2009 (Abd 2010). Increased salinity correlates to reduced vegetation productivity and decreased biodiversity (Hamdan et al. 2010).

The depletion of water flow and poor-quality water in Iraq (unusable for agriculture or homes) is a national tragedy. Over one third of the population of Iraq has no access to potable water and the quantity of water production is decreasing to 53% of the demand (Al-Ansari 2013). Alleviation of this environmental crisis can only be achieved by an internationally facilitated accord and legal agreement between the transboundary countries on the Tigris and Euphrates Rivers.

IMPACTS ON FISH PRODUCTION AND BIODIVERSITY

The Mesopotamian Marshes and its fisheries have suffered from the enormous hydrologic modifications summarized above (US-AID Report 2004). The fisheries productivity of healthy floodplain rivers is roughly proportional to the total area of the waters in the high-water flood season (US-AID Report 2004). In 2000, the total post-drainage flooded area of the Mesopotamian Marshes was only 14.5% of the pre-drainage marsh area in 1973–1976 (UNEP 2001). Most of the remaining wetland area was in Hawizeh Marsh, with 3% in Central Marsh, and 6% in Hammar Marsh. Even if there had been no other influences on the system, the fisheries productivity of these areas has declined in approximate proportion to this loss of floodplain areas.

Fish productivity was greatly reduced by impaired water quality, overharvesting, and loss of habitat (Richardson et al. 2005, 2006; Mohamed et al. 2012). Altered military diversions during the 1990s resulted in stagnation, lower water quality, lower dissolved oxygen levels, increased salinity, and low water elevation (FAO-Iraq 2010; Mohammed et al. 2012). Eutrophication has resulted in large fish kills, particularly during low-flow periods in summer and fall. The Tigris River is more vulnerable to salinity impacts than the Euphrates River due to lower dissolved mineral content (Hamdan et al. 2010).

Deterioration of water quality led to the disappearance of several cyprinid species even before desiccation (Coad 2010). Economically important fish species substantially decreased in number or became locally extirpated (e.g., gattan - *Barbus xanthopterus*, giant biz - *Barbus esocinus*, and shabout - *Barbus gyrpus*). Bunni (*Barbus sharpeyi*) - historically the most important endemic fish species with the highest commercial value – has greatly declined in numbers and size. The most abundant fish are now non-commercial, small-sized fish species (such as *Liza abu*), representing a serious deterioration of fish resources.

Marsh Arabs estimate that four truckloads of fish were sent daily to urban areas north of Al-Chubayish, the largest town in the marshes, until 1991 (US-AID Report 2004). Fish were originally caught with tridents and nets, with mesh sizes getting smaller as fish catches decreased. Fishing practices were non-sustainable. Some fishers used mesh or cloth from which nothing escaped; others used poisons and electric shocking to take the final fish remaining in the drying ponds. Environmental assessments detected many cases of toxicity in the water, plants, and fish (Salman 2011a). Many chronic effects of toxicity-related factors have been detected among fish populations.

The Al-Hawizeh Marsh provides a specific case study. During last the two decades, 65% of the permanent Al-Hawizeh Marsh was drained, which led to a substantial loss of native aquatic flora and fauna (Abdul-Razak et al. 2008; Abd 2010; Mohamed et al. 2012). The marsh was re-flooded in 2003. Fish assemblage characteristics were sampled from 2005-2006: a total of 4,715 fish representing 15 species were caught. Several cyprinid species disappeared from the restored marshes or decreased in abundance due to increased salinity, scarcity of benthic food resources, and competition with alien/introduced fish species.

FAO (1990) estimated that the total inland catch of fish in Iraq was 23,600 tonnes, with over 60% of this coming from the Mesopotamian Marshes (UNEP 2001). Fish production in the Iraq inland waters declined from an average of 21,000 tonnes during 1994-1997, to an average of 11,000 tonnes during 1998-2002 (FAO-Iraq 2010). Per capita fish supply (including marine fisheries and aquaculture) is 0.8 kg (in 2005) - very low compared to 14 kg internationally (FAO-Iraq 2010).

The loss of marshlands as fisheries habitat and a natural water quality filter between the Shat al- Arab and the Gulf has resulted in noticeable degradation of water quality along the coast of Kuwait (Al-Ghadban et al. 1999; Saeed et al. 1999; Al-Yamani et al. 2007). Several marine fish species of great economic importance in the Gulf are dependent on the estuarine systems and marshes for spawning (Hussain et al. 1994) or feeding (Hussain et al. 1987; Hussain and Ahmed 1995). The penaid shrimp (*Metapenaeus affinis*) migrates seasonally between spawning grounds in the Gulf and the nursery and feeding grounds of the East Hammar Marsh (Mathews et al. 1986).

ADVERSE SOCIOECONOMIC IMPACTS

Adverse socioeconomic impacts to marsh inhabitants demonstrate "harm" under international water law from upstream water diversions, reduced water supply and impaired water quality. The Mesopotamian Marshes are a landscape sustainably managed for thousands of years (Stevens 2011). To support a sustainable harvest of culturally important resources, the indigenous residents of the marshes, called Marsh Arabs, actively managed resources such as gathering reeds, fishing, bird hunting, and caring for water buffalo (Figure 5; Salim 1962; Ochsenschlager 2004; Jwaideh 2007; Stevens 2007). Water buffalo have played a cultural role similar to that of the camel in Bedouin Arab culture (Thesinger 1964). Agricultural activities included seasonal work growing grain and field crops, and date palm plantations. Without water, the Marsh Arab way of life and the marsh fauna and flora will end.

In the 1950s and 1960s, the main elements of the marshlands economy in southern Iraq were based on their biological diversity. Subsistence fishing was practiced widely, and fish were a major food item for people inhabiting the marshes (US-AID Report 2004). Although only a small number of tribes utilized fishing as a primary economic livelihood, fishing played an important role in the local economy when fishing markets were accessible.

FIGURE 5.
Marsh Arab women collecting reeds. (M. Stevens photo)

Most inhabitants of the Al-Huweiza Marsh today work as fishermen or with animal husbandry; few have other temporary jobs (FAO-Iraq 2010). The most serious problems are high unemployment and lack of job opportunities to earn a livelihood. Transportation to jobs is lacking. Most Al-Huwiza Marsh inhabitants lack financial ability to build suitable housing. Marsh inhabitants have a very low education level, likely related to lack of access to schools. In addition, poverty forces all individuals over 6 years old to work to support their families rather than attend school. The lack of basic services, such as potable water and regular supply of electricity, creates hardships and suffering (FAO-Iraq 2010).

Social instability, disintegration of community linkages, and direct dependence on diminishing local natural resources increases the vulnerability and insecurity of marsh inhabitants. (FAO-Iraq 2010). Marsh inhabitants face many health problems, and there is a shortage of nearby health clinics. Increased social and environmental instability has led to an increase in violence. A combination of conflicts, lack of water, and lack of jobs cause inhabitants to become internally displaced and flee their villages.

INTERNATIONAL WATER LAW

For over 4,000 years, the lands irrigated by the Tigris and Euphrates Rivers have been the scene of conflicts to divide and exploit them (Bagis 1997; Al-Ansari et al. 2012). International water law has the potential to develop a communication nexus to discuss water scarcity and regional water management in order to avert ecological and socioeconomic crises, and reduce the potential for conflict (McCaffery 2007). These laws and agreements can be used to develop a basin-wide planning instrument that protects the downstream co-riparian state's claim to the use of water.

The most significant transboundary issue in the Tigris-Euphrates watershed that needs to be resolved between the neighboring countries of Turkey, Syria and Iraq is declining water supply and water quality, with increased severity progressing downriver. Viable tools for the protection of the Mesopotamian Marshes include the UN 1997 Convention on the Law of Non-Navigable Uses of International Watercourses (UN-WC 1997) and the 1971 Ramsar Convention on Wetlands of International Importance (Ramsar Convention) (Ramsar 2013; UN-ECE 1992). Also, renewing or adapting a Joint Trilateral Committee between co-riparian countries on water allocation will do a great deal to promote communication and data sharing between countries, serving as de facto hydro-diplomacy (El-Fadel et al. 2002; Al-Ansari and Knutsson 2011; Kibaroglu and Scheumann 2013).

Traditional Islamic law has treated water as a communal resource since the Code of Hammurabi (pre-1750 BCE). *Al-Hima (*meaning protected area or place) is a traditional Islamic system of resource tenure, and is the most widespread and long-standing indigenous conservation institution in the Middle East (Kilani et al. 2007; Stevens 2013). The *al-Hima* tradition has the potential to promote sharing and allocation of water for the benefit of the whole society. The recently established Mesopotamian Marshlands National Park is a successful example of well-planned conservation and water use. Local stakeholder involvement is promoted for capacity building, education, health, and wise use.

The first treaty that established harmonious relations among the co-riparian states was the 1946 Treaty of Friendship and Good Neighbourly Relations. In the 1950s, management plans were developed (mainly between Iraq and Turkey) to control flooding and provide water storage (Carkoglu and Eder 2001; Kibaroglu 2007). This simplified the path toward developing major water and land resources projects. Since the 1960s, major developments in the region include Turkey's development of the Southeastern Anatolia Project (GAP), Syria's development of the Euphrates Valley Project, and Iraq's development of the Thartar Canal Project (Kibaroglu 2007).

Co-riparian states hold conflicting positions on international water law and terminology that have prevented a basin-wide agreement, with the exception of the 1987 Protocol for Technical and Economic Cooperation (PTEC) (Altinbilek 2004). The PTEC is an interim agreement on water quantity, which states that an annual 16 BCM (500 m^3/s) is to be released at the Syrian-Turkish border. This was the only agreement achieved by the Joint Technical Committee (JTC), which met continuously from 1981 to 1992. The substantive issue at stake that defeated the JTC negotiations was that Turkey considers the Tigris and Euphrates Rivers a single transboundary river, and refuses to consider co-sovereignty with downstream countries. Iraq and Syria consider the Euphrates River to be an integrated system that should be shared.

Turkey's claims on the Euphrates and Tigris Rivers are based on the acknowledgement that the headwaters are located in Turkey and, therefore, it has the sovereign right to utilize water resources in any way it desires (Kibaroglu 2007). Turkey considers the Euphrates and Tigris Rivers as a single transboundary river system that crosses a common political border (Kibaroglu and Unver 2000), and emphatically does not consider downstream countries as having the rights of co-sovereignty. Turkey says that under international water law, each co-riparian state of the transboundary watercourse has the sovereign right to make use of the water that flows through its borders, and that each co-riparian state has the option of "equitable and optimal utilization" of such waters provided that such utilization does not create appreciable harm to other co-riparian states. Turkey states that building dams, including diversion of irrigation water for agriculture and hydroelectric generation, constitutes equitable utilization (Kibaroglu and Scheumann 2013).

It is Iraq's position that the Euphrates and Tigris Rivers are "international watercourses," and they have special "acquired rights" relating to its ancestral irrigation practices, with special emphasis on the Tigris River (Kibaroglu and Unver 2000). Iraq argues that for thousands of years these rivers have given life to Mesopotamia, and thus represent an acquired or "historical" right of the Iraqi people. Iraq regards the Tigris River as their sovereign right and rejected the Turkish offer to compensate for scarcity of water in the Euphrates River by surplus in the Tigris River. Therefore, Iraq believes Turkey should neither obtain nor decide alone on the quantity of water that should flow to Iraq and Syria. Iraq's second argument for acquired rights is the presence of prior use of existing water development projects, such as dams, irrigation systems, and water installations. Turkey argues against the waste, antiquity, and poor repair of the existing Iraqi water systems. Iraq does have a problem with inefficient and antiquated infrastructure.

Both Syria and Iraq consider the Euphrates River as an "international river" that should be treated as an integrated system that is to be shared (Kibaroglu and Unver 2000). Both Iraqi dams (at Haditha and Mosul) function at reduced capacity due to upstream dams on the Euphrates River. Mosul Dam was built on highly soluble, fractured, and jointed gypsum beds; it is in a high risk condition and close to complete collapse (Al-Ansari et al. 1997; Muir 2007). Three Syrian dams on the Euphrates River have flaws in construction and operation, leading to reduced water availability and power generation.

Mosul Dam is also the staging area for recent conflicts with ISIS, making either engineering or political solutions impossible at this time. Another variable has entered the equation: security analysts say the outcome of the Iraq and Syrian conflicts may rest on who controls the region's dwindling water supplies, which are now military targets. Wars of the next century may be over water, which is at the top of the international political agenda (Berman and Wihbey 1999; Samson and Charrier 1997).

Unfortunately, there is no formal agreement between all three countries concerning the Euphrates and Tigris Rivers. The Euphrates River is subject to two bilateral accords: 1) an agreement between Syria and Turkey specifies the minimum average flow of 500 m3/sec at the Syrian-Turkish border, and 2) the 1990 Syrian-Iraqi Water Accord - Iraq is supposed to receive 58% of the Euphrates River flow, which crosses the Turkish-Syrian border, while Syria is to receive 42% (Al-Ansari 2013). Turkey promised minimum flows of 9 km^3/year to Iraq; however, only 0.03 km^3/year is available (Al-Ansari and Knutsson 2011).

Most recently, the 2009 Iraq-Turkey Memorandum of Understanding (MOU) established an accord to improve water quality and the number of shared water pumping stations and dams (Al-Ansari 2013). Syria and Turkey agreed to cooperate in controlling pollution of common Euphrates River waters and to decide on methods to determine the reasonable and appropriate water flow that each country needs. Syria and Turkey also agreed to share hydrological and meteorological data and expertise (Kibaroglu 2007). These agreements did not include Iraq. The current civil war in Syria, and resulting refugees flooding across the borders into Turkey has created an impasse to water allocation discussions.

1997 UNITED NATIONS WATERCOURSE CONVENTION

The 1997 UN Watercourse Convention on the Law of the Non-Navigational Uses of International Watercourses is the most comprehensive, authoritative, and universally applicable framework of international water law. It pertains to the uses and conservation of all waters that cross international boundaries, including both surface and groundwater (UNWC 1997; Milanes Murcia et al. 2013; Kibaroglu et al. 2013). Entered into force on August 17, 2014, the convention has been ratified by 36 states, including Iraq, Syrian Arab Republic, Jordan, Lebanon, and the State of Palestine. Unfortunately the key upstream states on the Tigris and Euphrates Rivers of Turkey and Iran are not signatories.

The principles codified in the 1997 UN Watercourse Convention provides a management approach to apply to each watercourse, requiring all watercourse states to ensure the protection and preservation of ecosystems through cooperation, reasonable utilization, and causing no harm along the entirety of each basin (UNWC 1997; Murcia Milanes et al.2013). The Convention emphasizes cooperation between co-riparian states toward achieving a regime of equitable and reasonable utilization for the international watercourse system as a whole. An analysis of these instruments reveals the best practices to sustainably manage the Tigris and Euphrates transboundary basin.

The Convention sets forth "limited territorial sovereignty" as the international standard and seeks to prevent significant harm to downstream co-riparian states while allowing equitable utilization by upstream coriparian states.

International water laws propose the equitable and reasonable allocation of water, taking into account various factors including: natural physiographic factors; socioeconomic needs of each water course state; population; past and present utilization; existing and potential use of water; and the extent to which the needs of each coriparian state can be met without damage to the needs of other states (El-Fadel 2002). International water law often fails to include ecological functions and services, biodiversity, culturally significant resources, and social justice in consideration of equitable and reasonable allocations of water.

INSTRUMENTS FOR WETLAND PROTECTION

The Ramsar Convention (formerly called the Convention on Wetlands of International Importance, especially as Waterfowl Habitat) focuses on wetlands protection and conservation. The mission of the Ramsar Convention is "the conservation and wise use of all wetlands through local and national actions and international cooperation" (Ramsar 2013).

Hawizeh Marsh, the largest wetland in the region, was Iraq's first Wetlands of International Significance in 2007 for its historical, cultural and environmental legacy (Nature Iraq 2010a, 2010b, 2012).

In June 2010 due to disruption of water inflows, the Hawizeh Ramsar Site was placed on the Montreux Record - a list of Ramsar sites where changes in ecological character have occurred or are likely to occur (Rubec 2013). Reduced inflows and impaired water quality have had a significant negative impact on the Hawizeh Marshes and the northern Gulf marine environment (UN-IWTF 2011). Inflows from the Karkheh River into the southern marshes were diverted via construction of an upstream dam and dike inside Iran, effectively bisecting the transboundary marshes (see Figure 1; Al-Handal and Hu 2015). Inflows from the Tigris River into the northern marshes are threatened by construction of Ilusu and Cizre Dams in Turkey. In January 2009, the Key Biological Area assessment team found a total of 49 avian species and over 25,000 individuals in a single site in the northern marshlands (Nature Iraq 2010b; Alwash 2013). By the fall of 2009, the southern Hawizeh Marsh had completely disappeared, and the habitats for thousands of waterfowl were gone—a clear tragedy under the Ramsar convention.

As of this date no urgent action has been taken to save the Hawizeh Marsh wetlands, the southern Hawizeh remains dry, and northern section is threatened with destruction. In January 2014, CRIMW and MOWR invited the Ramsar Secretariat to review the status of the Hawizeh Marsh Ramsar site (Rubec and Young 2014). A meeting was held with representatives from Iraq government ministries, governorates, non-profit organizations, Nature Iraq, the oil sector, academics, and local stakeholder's organizations (Nature Iraq 2010a; UN-IWTF 2011; Rubec 2013; Rubec and Young 2014). The key recommendations from the 2014 meeting were to implement the Hawizeh Marsh Management Plan and to improve collaboration and communication among stakeholder groups. Upstream water withdrawals and oil development in the Majnoon oilfields adjacent to the southern marshes makes it unlikely that the marshes will ever be flooded to their original area.

Rubec and Young (2014) recommend that Turkey and Iraq find an economic model that both countries could agree on to facilitate the sale of oil to turkey in exchange for water for Iraq. They also recommend that small steps be taken to build trust and cooperation between relevant agencies in Iraq and the Islamic Republic of Iran to promote the conservation of both the Al-Hawizeh Marsh (Iraq) and the Al-Azim Marsh (Iran).

While Ramsar designation does not provide legal protection for the Hawizeh Marsh Ramsar Site, the advantages to Iraq for designating the Wetlands of International

Significance include increased community engagement, improved management planning and scientific research, access to funding and capacity building, and increased public visitation and appreciation (Rubec 2013). At some point in the future, the Hawizeh Marsh Ramsar site may provide public focus for conservation and "green tourism." Hope remains for a peaceful future, where the legacy and heritage of the Hawizeh Marsh Ramsar Site may be enjoyed by future generations.

MESOPOTAMIAN MARSHLANDS NATIONAL PARK

Iraq's first National Park, designated in 2013, not only represents history as Iraq's first national protected area, but also serves as an inspiring solution for people and nature in an area once decimated by conflict and destructive policies. Azzam Alwash, founder of Nature Iraq, said:

With this action, Iraq has acted to preserve the cradle of civilization. It is now the duty of the world to help Iraq maintain these wetlands for the future generations by helping Iraq, Turkey, Syria, and Iran to reach an equitable agreement on the sharing of the waters in the basin of the Tigris and Euphrates.

CONCLUSION

The application of international water law is essential to sustain human well-being, biodiversity, and ecosystem functions in the Mesopotamian Marshes (Eden) and northwestern Gulf. Application of the standards of international water law includes cooperation, reasonable use, and no harm by all watercourse states in the Tigris-Euphrates Watershed. Implementation of the 1997 UN Convention on the Law of Non-Navigational Uses of International Watercourses, the Ramsar Convention, and customary principles of international water law will contribute to water resource and wetlands conservation, and improve regional security in transboundary river systems. International rivers and wetlands are at risk for the causal factors of upstream water diversions, increasing water consumption, and impacts of climate change resulting in the loss of life-giving waters. The most important first step is renewing a Joint Technical Committee with co-riparian countries to promote regular communication, exchange of data and expertise, determine reasonable and appropriate water flows to meet each country's needs, and to move toward creation of a legally binding agreement for fair and equitable water use of the transboundary river waters. ■

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Notes on the Third Edition of the Floristic Quality Assessment of Michigan

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OVERVIEW AND FLORISTIC SUMMARY

In fall 2014, we released the 3rd Edition of the Floristic Quality Assessment of Michigan (MFQA) (Reznicek et al. 2014), replacing the 2nd Edition released in 2001 (Herman et al. 2001). For the first time, the MFQA coincides with a complete revision of the Michigan Flora (Reznicek et al. 2011; Voss and Reznicek 2012), resulting in the same list of taxa and consistent nomenclature for both products. The list of taxa, including wetness coefficient values (*W*) and coefficients of conservatism (*C*), will be periodically uploaded to the open source, online *Universal FQA Calculator* (Freyman and Masters 2013) to facilitate quick calculation of FQAs. As of July 2015, *Michigan Flora Online* (Reznicek et al. 2011) treats 2,873 vascular plant taxa at the specific level, including 1,808 native species (Table 1), compared to 2,729 taxa and 1,815 native taxa treated in Herman et al. (2001). Slight differences between lists in *Michigan Flora Online* and the *Universal FQA Calculator* are expected as updates are made to the former page, but periodic reconciliation of the lists will ensure no significant divergence.

TABLE 1.
Summary of vascular plant taxa included in Michigan Flora Online as of July 2015 (Reznicek et al. 2011).

	Native		Non-Native	
Physiognomic Class	#	% of cohort	#	% of cohort
Trees	106	5.9	62	5.8
Shrubs	146	8.1	94	8.8
Vines	47	2.6	52	4.9
Annual	*12*	*0.7*	*22*	*2.1*
Biennial	*1*	*0.1*	*0*	*0.0*
Perennial	*18*	*1.0*	*13*	*1.2*
Woody	*16*	*0.9*	*17*	*1.6*
Ferns and Fern Allies	107	5.9	1	0.1
Forbs	992	54.9	724	68.0
Annual	*127*	*7.0*	*300*	*28.2*
Biennial	*46*	*2.5*	*67*	*6.3*
Perennial	*819*	*45.3*	*357*	*33.5*
Grasses	155	8.6	113	10.6
Annual	*51*	*2.8*	*26*	*2.4*
Perennial	*129*	*7.1*	*62*	*5.8*
Sedges	255	14.1	17	1.6
Annual	*26*	*1.4*	*3*	*0.2*
Perennial	*229*	*12.7*	*14*	*1.3*
Total	**1808**	**62.9**	**1065**	**37.1**

COEFFICIENT OF CONSERVATISM (*C*) VALUES

For this 3rd Edition of the MFQA, a significant number of coefficient of conservatism (*C*) values were updated to reflect recent collections and sight records. In particular, we focused on species that were previously assigned high *C* values (8-10) that have since been found to occur more frequently in disturbed habitats (Figure 1). The distribution of Michigan *C* values for native taxa is similar to that of other Midwestern states and regions (e.g., Swink and Wilhelm 1994; Rothrock 2004; Ladd and Thomas 2015; although see Parker et al. 2014 for a slightly different distribution),

FIGURE 1.
The state threatened *Asclepias purpurascens* (purple milkweed) occurs in high quality upland and wetland habitats, but also persists and sometimes thrives in disturbed thickets and along roads. Its *C* value was tweaked from 10 to 9 in the 3rd Edition of the MFQA to reflect its sporadic presence in degraded habitats.

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with one peak near the middle of the distribution (*C*= 5) and another at *C*= 10 (Figure 2). The distribution of native wetland plant *C* values mirrors the overall distribution. The median and mean *C* values for native taxa are 6 and 6.5, respectively; wetland taxa specifically have a slightly higher median (7) and mean (6.9) *C* value.

WETNESS COEFFICIENT (*W*) VALUES

Wetness coefficient (*W*) values are assigned on a five-point scale: Upland (UPL; *W*= 5); Facultative Upland (FACU; *W*= 3); Facultative (FAC; *W*= 0); Facultative Wetland (FACW; *W*= -3); and Obligate Wetland (OBL; *W*= -5). For this update of the MFQA, previously assigned intermediate values (e.g., FACU+; FACW-) were eliminated in keeping with the recently updated National Wetland Plant List (NWPL; 2012). We provide a single wetness coefficient (*W*) for each taxon that we believe best captures its habitat preferences within the state as a whole. However, Michigan spans portions of two geographic regions defined by the NWPL, the Northcentral and Northeast Geographic Region and the Midwest Region (Lichvar 2012). For most taxa, the assigned *W* value corresponds to the value for the Northcentral and Northeast NWPL, which characterizes most of the state outside a small area in southeastern Lower Michigan coinciding with the Jackson Interlobate (Albert 1995; Lichvar 2012). Users of the MFQA are encouraged to consult the NWPL *W* values for both regions, which will be particularly important for assessments of sites falling within the small part of the state mapped within the Midwest Region. In a few cases, species that have greater wetland fidelity in Michigan than reflected in either regional list were assigned *W* values appropriate for the state (Figure 3). In contrast, *W* values for species that with us are more characteristic of upland habitats than reflected in the regional lists were not adjusted so as to conform to national regulatory standards (Figure 4).

The distribution of *W* values differs for native vs. nonnative taxa (Figure 5). Native taxa are fairly evenly distributed across the wetness spectrum, with approximately equal numbers of upland species ($n_{UPL+FACU}$=803) and wetland species ($n_{OBL+FACW}$=763), and a mean of FAC (*W*= 0). On the other hand, non-native taxa of upland affinity vastly outnumber wetland taxa, by a nearly 10:1 ratio ($n_{UPL+FACU}$=876 vs. $n_{OBL+FACW}$=91) (Figure 5). Although Michigan supports relatively few non-native wetland plant species, several of those that do occur are among our most pernicious, destructive invasive taxa, including *Lythrum salicaria*, *Myriophyllum spicatum*, *Phragmites australis* subsp. *australis*, and *Typha ´glauca*.

FIGURE 2.
Michigan *C* value distribution for all taxa and for wetland taxa (facultative wetland or obligate wetland species).

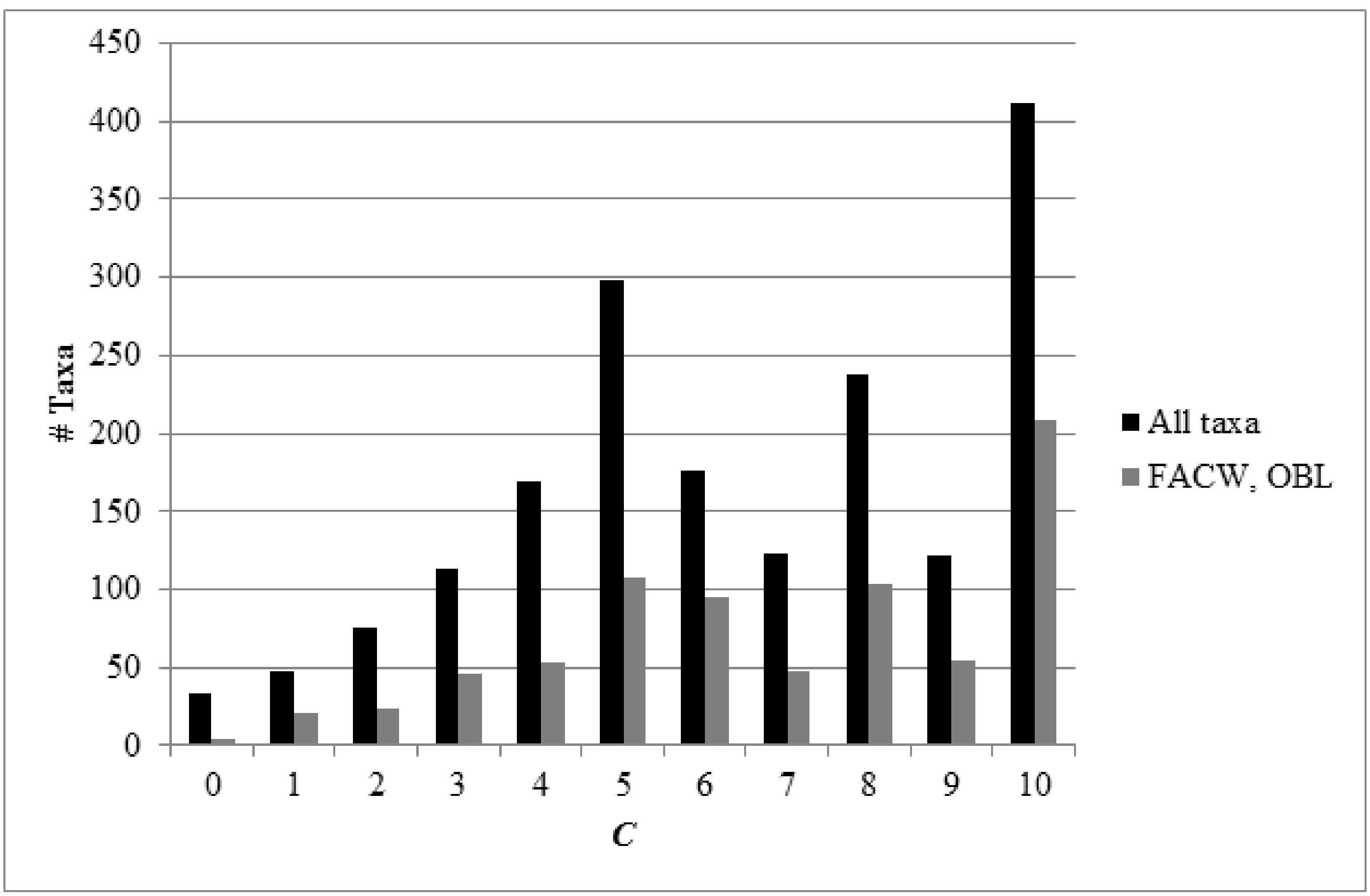
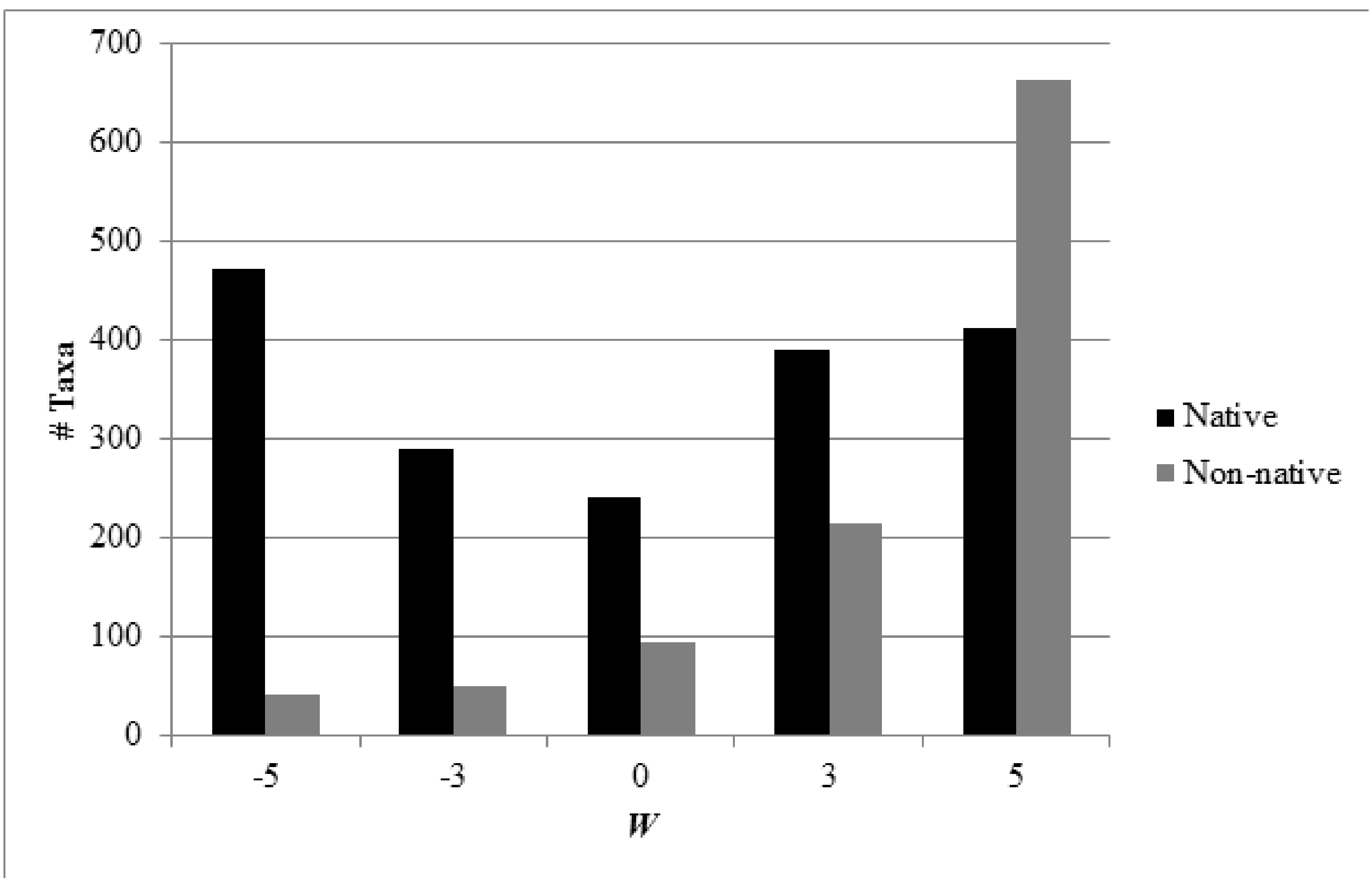


FIGURE 3.
The state threatened *Myrica pensylvanica* (northern bayberry) is apparently native in a few calcareous fens and adjacent tamarack swamps in southern Lower Michigan. It was assigned OBL wetland status in Michigan, but occurs on sandy beach ridges and other upland habitats east of Michigan and is considered FAC in both the Northcentral & Northeast and the Midwest Geographic Regions of Lichvar (2012).

FIGURE 4.
The state special concern *Cypripedium arietinum* (ram's head lady-slipper) is assigned FACW wetland status in Michigan to conform to Lichvar (2012), but it is here primarily a species of upland, partially wooded dunes and beach ridges along the northern Great Lakes shoreline (Reznicek et al. 2011).

FIGURE 5.
Michigan *W* value distribution for native and non-native taxa.



INTERPRETATION AND APPLICATION

In addition to its traditional, widespread use in identifying wetlands and in assessing success of wetland mitigation activities (Herman et al. 2001) (Figure 6), there is continued interest in and adoption of the tool for evaluations of ecological integrity (Herman et al. 2001; Mack 2009; Bried et al. 2012; Spyreas et al. 2012; Bried et al. 2013, 2014; DeBerry and Perry 2015; Matthews et al. 2015). Herman et al. (2001) suggest that Michigan sites with a Floristic Quality Index (*FQI*; calculated as *FQI* = $\bar{C}$n) of 35 or greater "possess sufficient conservatism and richness that they are floristically important from a statewide perspective," and that sites with *FQI* of 50 or greater are "extremely rare and represent a significant component of Michigan's native biodiversity and natural landscapes." However, *FQI* scores are sensitive to area, landscape patterns, and physiognomy (Matthews et al. 2005), limiting their usefulness in assessing the relative conservation value of different sites. Indeed, sites of sufficient size that support primarily degraded habitats such as old field or cleared, grazed wetlands often approach or exceed *FQI* scores of 50 (Michigan Natural Features Inventory [MNFI], unpublished data).

Mean *C* values have been suggested as a less biased indicator of relative site conservation value (Matthews et al. 2005). An analysis of species lists taken during single-day meander surveys by MNFI scientists in several natural community types demonstrates modest within-type variance of $\bar{C}$ values, but significant differences in between-type $\bar{C}$ values (Figure 7), consistent with findings by Andreas et al. (2004). We suggest the collection of standardized plant lists to derive statistically robust $\bar{C}$ reference values for all 77 natural community types described by MNFI (Cohen et al. 2014). In the absence of systematically collected vegetation data and statistically robust benchmarks, reported FQI and $\bar{C}$ scores should be used carefully as but one component of an ecological integrity assessment. ■

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FIGURE 6.

Distribution of $\overline{W}$ scores for northern fen (NF; *n*=17); bog (BOG; *n*=25); and hardwood and hardwood-conifer swamps (SF; *n*=27) based on unpublished MNFI data. $\overline{W}$ values for all of these natural communities strongly indicate wetland conditions. The higher average $\overline{W}$ value and broader distribution of values for swamp forests may indicate overall drier conditions and greater biotic and abiotic heterogeneity among these sites compared to northern fen and bog. ♦ indicates overall $\overline{W}$ (NF, $\overline{W}$ = -3.3±0.1; BOG, $\overline{W}$ = -3.7 ± 0.1; SF, $\overline{W}$ = -2.0±0.2).

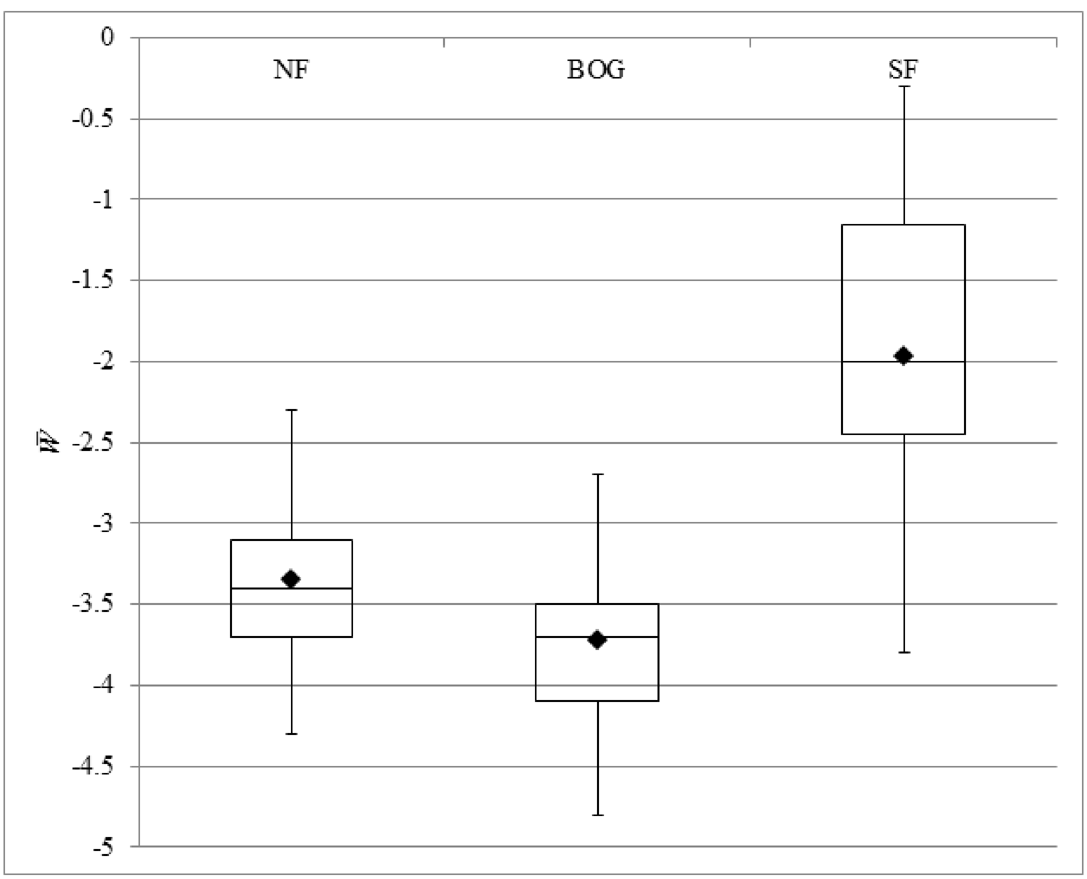

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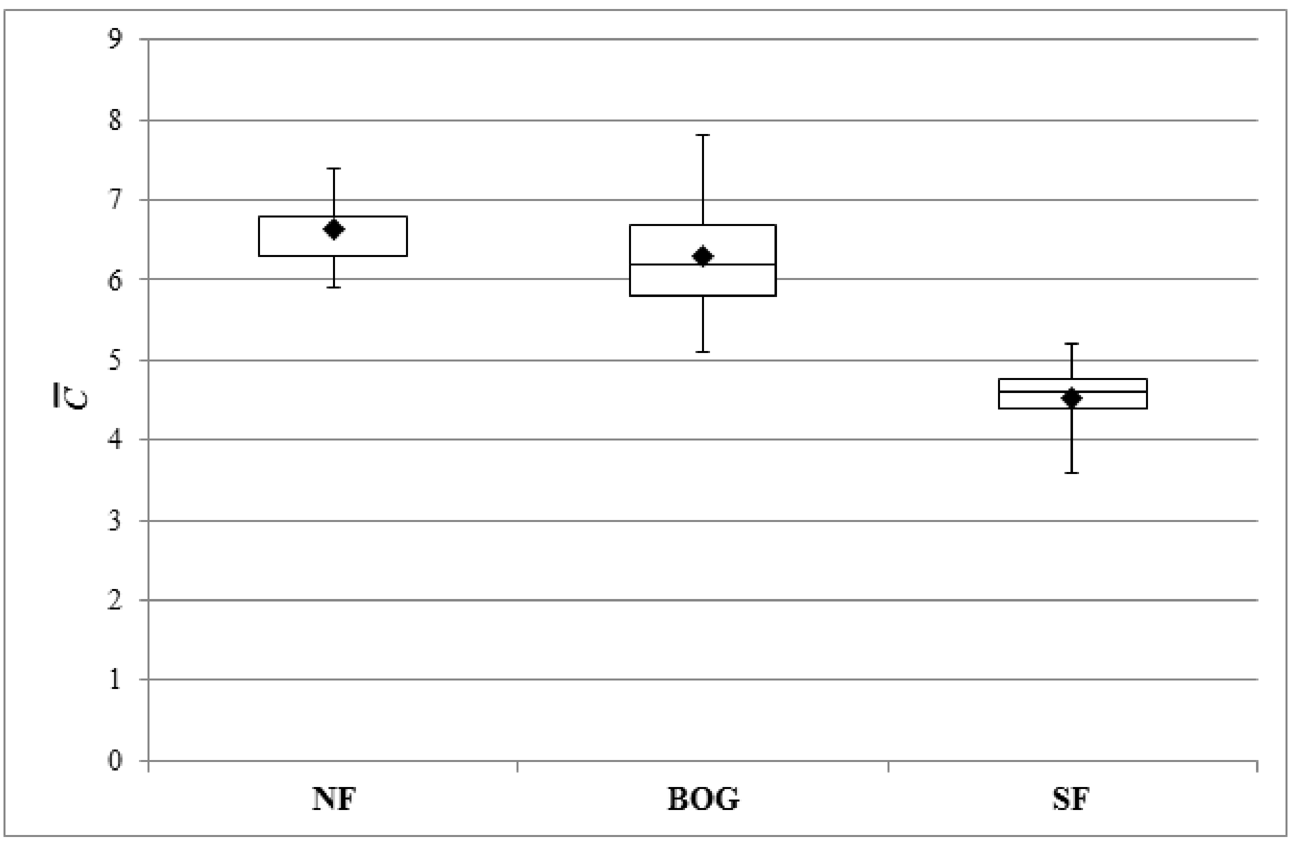
FIGURE 7.

Distribution of $\overline{C}$ scores for northern fen (NF; *n*=17); bog (BOG; *n*= 25); and hardwood and hardwood-conifer swamps (SF; *n*=27) based on unpublished MNFI data. Northern fen and bog are characterized by many specialist taxa restricted to low-nutrient, alkaline or acidic wetlands, whereas swamp forests tend to support higher species richness but more habitat generalists. ♦ indicates overall $\overline{C}$ (NF, $\overline{C}$ = 6.6±0.1; BOG, $\overline{C}$ = 6.3±0.2; SF, $\overline{C}$ = 4.5±0.1).



Clean Water Rule Temporarily Blocked in 13 States by Federal Judge

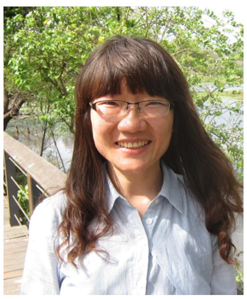
The Clean Water Rule defining "waters of the United States" published in the Federal Register on June 29, 2015, was scheduled for implementation on Friday August 28 (http://www2.epa.gov/cleanwaterrule/final-clean-water-rule). Announcement of the rule back in June created controversy over federal vs. state controls of water resources. Thirteen states led by North Dakota filed a lawsuit against EPA and the Corps claiming an infringement on state sovereignty. The Federal government claims it is simply trying to clarify the existing law and protect the nation's waters from pollution, especially headwater streams. On Thursday (August 27), U.S. District Judge Ralph Erickson (Fargo, ND) issued a preliminary injunction against the rule preventing the rule from taking effect in thirteen states: Alaska, Arizona, Arkansas, Colorado, Idaho, Missouri, Montana, Nebraska, Nevada, New Mexico, North Dakota, South Dakota and Wyoming. EPA says the rule will take effect in other states. Overall more than half of the states plus farm and business groups have sued EPA over this rule (http://www.usnews.com/news/us/articles/2015/08/28/epa-clean-water-rule-in-effect-despite-court-ruling?page=2). Federal judges in some other districts (e.g., West Virginia and southern Georgia) have declined to block the rule stating that they lacked jurisdiction. EPA has requested that the cases be consolidated into a single case. A federal judicial panel is scheduled to hear the arguments on October 1 in New York. ■

New Mexico mountain stream (R. Tiner photo)

This section is intended to inform readers about ongoing wetland research by various universities, government agencies, NGOs and others. When studies are completed, WSP invites short articles that address key findings, while more technical papers are submitted to Wetlands or other peer-reviewed journals. Researchers interested in posting short or more detailed summaries of their investigations are encouraged to contact the WSP editor (please include "WSP Research News" in the email subject box).

Post-Project Appraisal of Wetland Restoration; Seeking Improvements in Mangrove Restoration

by Po-Hsiu Kuo, hopebartken@gmail.com



I am currently working on my Doctorate in wetland restoration with Dr. Hsiao-Wen Wang at the Department of Hydraulic and Ocean Engineering, National Cheng Kung University, Taiwan. My current PhD research originated from my graduate student project in a Restoration of Rivers and Streams course. In the project I applied the Post-Project Appraisal method (PPA; Kondolf et al. 2000, 2002, and 2007) to determine what lessons were learned from the mangrove restoration project in Jhongdou Wetlands Park near by the Love River in Kaohsiung City in southern Taiwan.

Through an urban renewal process Jhongdou Wetlands Park (hereafter referred to as the Park) was restored from an abandoned plywood factory capped with landfill to a multi-functions eco-park. It is now a green park combining ecological and social functions including landscaping, recreation, habitat restoration, environmental education and flood detention The coastal area of Kaohsiung once had the oldest and most diverse mangrove community in Taiwan, Consequently the landscape designer proposed restoring six native species of mangroves to the Park, including *Lumnitzera racemosa*, *Avicennia marina*, *Kandelia obovata*, *Rhizophora stylosa*, *Ceriops tagal* and *Bruguiera gymnorrhiza* (Figure 1).The latter two species have been extirpated from Taiwan in the past several decades due to habitat loss.

Some monitoring of biodiversity and water quality was conducted in the Park after construction was completed. However, there was no follow up concerning mangroves species survival, distribution, and optimal habitats. My research will perform PPA on the restored mangrove wetlands of Jhongdou Wetlands Park to determine if the original ecotone planting design was successful in assigning the correct species to the correct elevation and, therefore, assuring optimum survival, distribution, and growth.

My work began with a survey of mangrove distribution at the site at low-tide to map the current distribution of mangroves. Mangrove species, growth status, and abundance were recorded. Individuals of *L. racemosa* and *A. marina* taller than one meter were recorded and mapped. *Kandelia obovata*, *R. stylosa*, and *B. gymnorrhiza* above 0.5 meter were recorded and mapped (Figure 2) since they grow relatively slower than the former two species. Water quality (temperature, electrical conductivity, salinity, pH, dissolved oxygen and turbidity) at nine selected locations (Figure 3) was measured in December 2013. The data were analyzed and compared with the data from other monitoring reports to help determine how water quality influenced each species of mangroves.

Preliminary results indicate that planted saplings of *L. racemosa* had the greatest range of elevation distribution and grew under the largest range of water quality parameters. *Avicennia marina* had the second most widely distribution and tolerance to water quality variation. Both of these species grew well, but, interestingly, their dominant distribution varied from the original design plan. Specifically, the *A. marina* saplings was originally planted in a circle around the eco-island in the center of the Park (Figure 1), but after two years, it grew naturally to the nearby bank, the education center and culverts. Surprisingly, *L. racemosa* established itself around the edges of the eco-island, replacing the planted *A. marina* saplings (Figure 2). Water quality survey data conducted monthly from March 2012 to September 2013 by the Kaohsiung Wild Bird Society showed that the salinity in the Park ranged from 11‰ to 31‰. As expected the salinity was lower during the rainy season from June to August (11‰ to 15‰) and higher during September to May (23‰ to 31‰). Water quality data during high-tide on December 2nd, 2013 showed that the salinity measured at the nine locations in the Park ranged from 27‰ to 30‰ (Figure 3). Interestingly, mangroves in Taiwan are normally found in lower salinity usually only as high as 15‰ (Fan 2006) and 22‰ (Huang and Shih 2007), respectively.

Therefore, it appears that the high salinity of the Park may have limited the distribution and growth of some of the planted mangroves species. This study hypothesized that salinity was one key factor that influenced the distribution and growth condition of mangroves in the Park. It is likely that the mangroves that have survived were merely doing so on the upper limit of their salinity range. It might be that during rainy season, lowered salinity acted as a decreased stressor for the mangroves saplings and, therefore, may allow for certain mangrove saplings to not only adapt to the changes in salinity but also allow them to get strong enough to tolerate future increased stress (i.e., higher salinity).

By performing Post-Project Appraisal to review the project goals, two major lessons were learned:

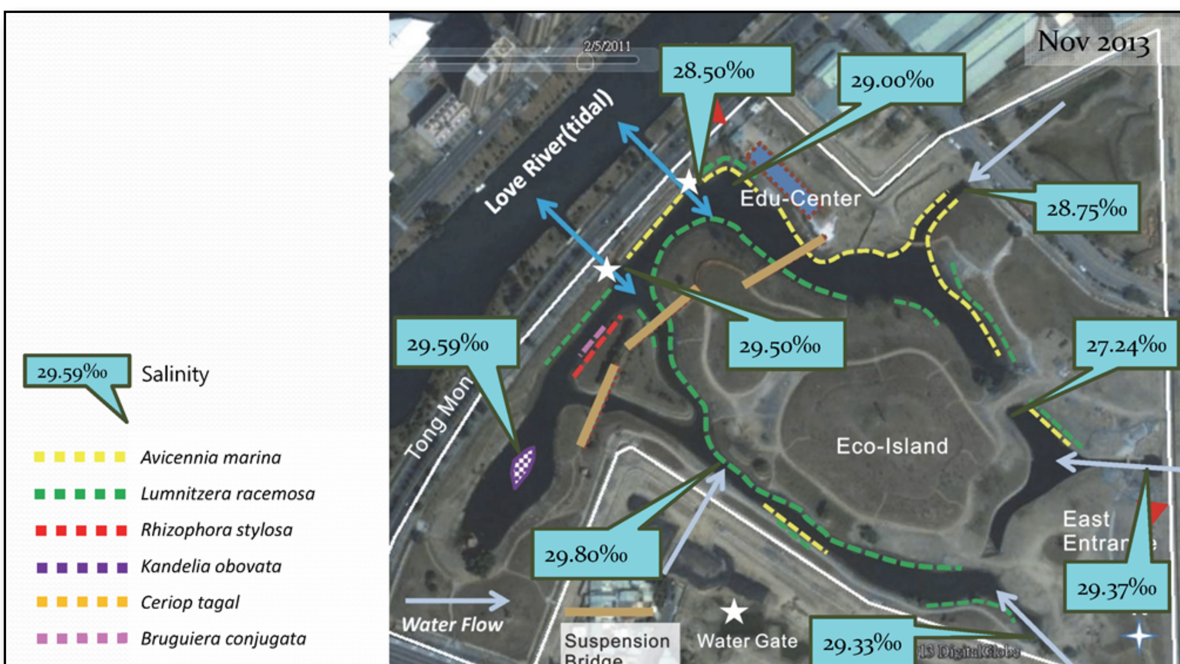
It was critical to have clearly stated project objective with specific success criteria. The concept of Adaptive Management and communication with stakeholders needed to be included in the process when setting these objectives. Furthermore, the project objectives should had been continually re-evaluated throughout the entire restoration project. Stakeholders should include the conservation NGOs, planners and designers, scientists, managers and government authorities. The conservation NGOs and the government authorities can collaborate to create a forum involving the public concern and promoting the communication between stakeholders. Scientists can contribute their research evidence to improve the design. Planners and designers should make efforts to integrate opinions from different aspects developing a scientific-based project. If the designer of the original project had collaborated more effectively with other key players and used scientific hydrology/ ecology monitoring information to create specified attainable success criteria to reach the goal of '*optimal conditions for mangrove growth*', and not just followed the original objective to '*enhance nature and build landscape,'* she may have been able to find alternative fresh water resources to avoid the high salinity or low dissolved oxygen causing by misjudging the quality and quantity of the water resource.

There is a need for park designers to account for river restoration schemes in terms of geomorphic compatibility, watershed hydrology and sediment transport processes. If

FIGURE 1.
Original design plan of mangrove distribution in Jhongdou Wetlands Park. Arrows present the flow directions. Dash lines in different colors illustrate different mangrove species. The original goal is to restore six native species in Taiwan, including *Kandelia obovata, Rhizophora stylosa, Lumnitzera racemosa, Avicennia marina, Ceriop tagal and Bruguiera conjugata.*

FIGURE 2.
Current distribution of mangroves in Jhongdou Wetlands Park. From 2011, five species were planted, including *Kandelia obovata, Rhizophora stylosa, Lumnitzera racemosa, Avicennia marina, and Bruguiera conjugata.* The distribution of *L. racemosa* and *A. marina* switched banksides naturally, totally differed from the original design plan.

FIGURE 3.
The result of salinity survey on December 2, 2013 at nine selected locations



a designer can involve specialists in these areas that deal with restoration schemes, including those from disciplines of hydrology, geomorphology, and ecology, the success of mangrove restoration, and therefore possibly their sustainability, would be more effective. To ensure effective and sustainable growth of mangrove species in the future, it is important to use management techniques adapting the dynamic changes within the restoration project. To achieve the goals making mangroves not only survive but to also thrive, managers should monitor changes within the restoration site and take action to respond to changes within the watershed and between the ecosystems. By doing so, we may have been able to ensure the environmental connection of the Park as a sustainable stepping stone of the Kaohsiung Wetlands ecological corridor.

When evaluating a construction project, most people considered the Wetlands Park a successful project. For it turned the site from "brown to green" and made the Park into a popular recreational space. People were aware that all objectives were executed, but they do not fully understand to what extent the ecological goals were achieved. From the ecological perspective it is important to monitor the continuing evolution of the mangrove swamp relative to the restoration goal, especially whether the mangroves thrive or not, so we can learn from this project and adapt lessons learned to improve the management of Jhongdou Wetlands Park and the design of other mangrove restoration projects. The future goals of my research are to determine the hydrology pattern and the hydro-geomorphology process, and to clarify the key factors that influence the ecology, growth, and survival of mangroves in the Park so that we may be able to develop an eco-hydraulic model for mangrove restoration in Taiwan. The main objective is to improve the practice and enhance the use of adaptive management in mangrove restoration. ■

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Student Research Grant Projects Underway

Every year, the Society awards grants through a competitive process to partially support student research in wetlands. For information on the program, visit: http://www.sws.org/Awards-and-Grants/student-research-grants.html. In this issue and the next issue, ongoing student projects funded in 2015 will be summarized. For more information on these project, contact the student investigator.

AMPHIBIAN COMMUNITY COMPARISON BETWEEN CONSTRUCTED AND NATURAL WETLANDS IN THE DANIEL BOONE NATIONAL FOREST, KENTUCKY

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Isolated, ephemeral wetlands are a natural feature of the ridge-top ecosystem in the Daniel Boone National Forest (DBNF), Kentucky. They support a rich and diverse amphibian species assemblage, characterized by species with short larval periods. However, hundreds of hydrologically permanent ponds intended for game use have been constructed within the ridge-top system in the last 50 years. These ponds provide suitable habitat for amphibian predators with long larval periods or aquatic adult stages, which has promoted their movement from Kentucky's lowland basins into the ridge-tops where they were historically absent or in low abundance. In the Cumberland Ranger District of the DBNF, eastern newts and green frogs have been found to predate eggs of traditional ridgetop amphibians, such as wood frogs, suggesting that these permanently constructed ponds act as ecological sinks for historical species. The objective of this research is to further elucidate the impact constructed ponds have on the ridgetop ecosystem in the southern London Ranger District. Specifically, this project will address the following questions: 1) do natural wetlands differ from constructed wetlands in amphibian community composition in the London Ranger District? and 2) What habitat characteristics predict presence and abundance of amphibian species? Twenty-eight natural and constructed wetlands will be surveyed within the London Ranger District of the DBNF. Each wetland assessment will include both dip netting and visual encounter surveys to resolve any differences in community composition between the wetland types. Habitat characteristics will also be measured to better assess what factors influence amphibian community composition. These characteristics include: percent aquatic vegetation, canopy closure, depth of littoral zone, water quality measurements, and amount of coarse woody debris. Additionally, each site will also be scored for wetland quality according to the Kentucky Wetland Rapid Assessment Method. Although previous studies in the northern Cumberland Ranger District have been instrumental in prompting research in the area, they do not directly apply to other districts as the construction methods, wetland numbers, and habitat characteristics vary greatly from one district to the next. Research within the London Ranger District is the next step in furthering our understanding of the DBNF ridge-top system.

IMPACTS OF HYBRID CATTAIL (*TYPHA* X *GLAUCA*) INVASION AND MANAGEMENT ON METHANOGENIC MICROBIAL COMMUNITIEIS IN GREAT LAKES COASTAL WETLANDS

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Great Lakes coastal wetlands (GLCW) are biologically diverse ecosystems that provide many important ecosystem services. Over the past several decades, many of these wetlands have been increasingly dominated by the hybrid cattail (Typha x glauca). As Typha persists and expands, a thick layer of leaf litter accumulates in invaded wetlands. Wetlands where this species is dominant have extremely reduced plant diversity, increased concentrations of sediment carbon, and increased soluble nutrients. Invasion also impacts the structure of microbial communities that mediate biogeochemical processes. An increase in methane production has been recently documented when comparing sediments from invaded and un-invaded sections of a wetland. These differences were not correlated to soil organic matter, available nitrogen, or redox levels, which suggests that these changes are tied to changes in microbial community composition. It is important to understand methane production of these microbial communities, because as Typha increases in dominance, shifts in microbial community structure may lead to increased methane production. The Tuchman lab has been investigating biomass harvesting as an innovative method for restoring GLCW function and plant community diversity. While the potential of harvesting to restore floral biodiversity has been demonstrated, it is unknown how wetland microbial communities or the biogeochemical processes they mediate are influenced. For my undergraduate thesis research, I am comparing the microbial community structures in T. x glauca-dominated sites, un-invaded wetland sites, and restored wetland sites. I will collect sediment samples from 4 replicate plots from each treatment type, and use next-generation gene sequencing to evaluate the microbial community structure and methanogen abundance. My hypotheses are as follows: 1) Typha-dominated and un-invaded sites will have microbial communities that differ significantly from each other, and restored sites will have microbial communities that are have similarities to both Typha-dominated sites and un-invaded sites. and 2) Typha-dominated sites will have greater abundance and diversity of methanogenic archaea than non-invaded sites, and restored sites will have an intermediate methanogenic community.

PHENOLOGY OF COASTAL MARSHES IN LOUISIANA FROM 1984-2014: LONG- AND SHORT-TERM VARIATIONS ASSOCIATED WITH CLIMATIC AND ENVIRONMENTAL EVENTS

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Coastal ecosystems face a variety of threats ranging from global climate change to in situ human interventions. Coastal marshes in Louisiana are inherently vulnerable to these threats as they are microtidal marshes and inhabit a narrow portion of the intertidal zone. This study attempts to decipher the multitude of stresses by studying the marshes' phenology, their timing of growth activities within a year, i.e. green up, maturity, senescence, and dormancy. The study area consists four major basins of Louisiana, the Barataria, Breton Sound, Pontchartrain, and Terrebonne basin, where marshes are classified into four types, freshwater, intermediate, brackish, and saline marsh. This study will use moderate-resolution remote sensing data, i.e. Landsat-derived Normalized Difference Vegetation Index to create a long-term phenological record of the marshes from 1984 to 2014. Phenological patterns of each marsh types for each year will be modeled by a nonlinear mixed model. Phenological changes concurrent with climate change will be investigated by correlating phenological metrics and environmental conditions (including sea-level, annual temperature and precipitation, atmospheric CO_2 level, etc.) using multivariate statistics. Phenological variations associated with disastrous events, such as hurricanes and drought, will be analysis using multiple analysis of variance. The goal is to compare and identify the key stressors of Louisiana coastal marshes, and to provide insights for predicting and managing the marshes' responses to current and future environmental changes and events.

UNDERSTANDING WETLAND VULNERABILITY TO ENDOCRINE DISRUPTING CHEMICALS THROUGH AMPHIBIAN SEXUAL DEVELOPMENT

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Wetlands occur throughout a variety of landscapes that occur along a gradient of human environments including undeveloped, natural landscapes like forests to human developed landscapes like urbanization. In amphibians, patterns of altered sex ratios and abnormal sexual development, such as feminization of males, are correlated with increasing suburban land use intensity around wetlands. This feminization has been found to be associated with endocrine disrupting chemicals (EDCs) but impacts throughout wetland communities have been predominantly unexplored. These chemically-induced effects on amphibians can be indicative of wetland vulnerability to human land use. The goal of my research is to understand whether suburbanization has pervasive impacts on sexual development throughout amphibian communities. This research will help us to understand how ubiquitous endocrine disruption might be within amphibian communities and to estimate relative vulnerability of different species to landscape change and associated changes in chemical pollution. I will be sampling from at least 10 local wetlands along a suburban-to-forest landscape gradient. I will use four different species of frogs that commonly breed along this gradient and differ in their larval period. A longer larval period a means longer exposure time and thus could indicate increased vulnerability to such suburban contaminants. The data from this project could help develop a biologic diagnostic to understand wetland vulnerability to EDCs and which wetlands are most impacted by developed landscapes.

BIODIVERSITY IN THE CONTEXT OF CLIMATE CHANGE: IMPLICATIONS OF ALTERED WETLAND EPHEMERALITY AND WATER QUALITY IN PRAIRIE WETLANDS

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Climate change, a major landscape stressor, is predicted to substantially alter ecosystem characteristics. In semi-arid regions where water availability is a crucial concern, wetlands constitute a critical, though highly dynamic, ecosystem component. Altered temperature and precipitation regimes under climate change may affect wetland ephemerality, or the persistence of wetlands across the growing season. My research will develop a novel, cost-effective, and large-scale method for relating climate change effects to wetland ephemerality and biodiversity. Using a combination of field observations and remotely sensed data, I will study the Plains and Prairie Pothole Region (PPPR), a highly productive yet sensitive ecosystem. By using field observations to train remotely sensed data, I will classify wetland ephemerality under a range of climatic conditions representing potential changes to temperature, and precipitation amount and timing. Further, I will use environmental DNA assays from water samples to estimate current amphibian and microbial diversity across the PPPR. By relating these measures to projected ephemerality, this research will enable me to link biodiversity to a range of future climate projections. Ultimately, the model I develop in the PPPR will yield a rapid assessment tool capable of aiding land managers in other regions to project future wetland ephemerality and biodiversity.

PHYTOREMEDIATION OF HEAVY METAL POLLUTED AQUATIC ENVIRONMENT (OLOGE LAGOON) BY WATER HYACINTH (*EICHHORNIA CRASSIPES*) AND WATER LETTUCE (*PISTIA STRATIOTES*)

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The indiscriminate discharge of industrial effluents containing harmful substances such as heavy metals has become a global problem because of the negative effects of these substances on humans. Water hyacinth has been considered a menace since it entered Nigerian inland waters through neighbouring Republic of Benin in the 80's. Water lettuce has also been a serious problem to Nigerian inland water fisheries. Attempts to eradicate these aquatic plants has not been successful. Thus, the need to explore their useful potentials especially water hyacinth. Water hyacinth is used in paper production, feed formulation, phytoremediation etc. Phytoremediation is a bioremediation process that uses plants to remove, transfer, stabilize, and/or destroy pollutants in the soil and water. The objectives of the study are: 1) to investigate the heavy metal content of water, sediment and water hyacinth from Ologe Lagoon, 2) to study the phytoremediation of heavy metals in Ologe Lagoon by a resident aquatic macrophytes (water hyacinth and water lettuce), and 3) to study the effects of water hyacinth invasion on the socio-economic lives of the inhabitants of Ologe Lagoon. The study would be conducted over a period of 18 months and 5 sampling stations will be used. Stations would be chosen based on their nearness to effluent discharge points, presence of water hyacinth and water lettuce and human activities. Water, sediment water hyacinth and water lettuce samples would be collected monthly from each sampling station and analyzed for heavy metals (Cu, Fe, Pb, Zn, Cd, Cr, Co and As). A questionnaire will be administered for socio-economic impact analyses. The study is expected to throw more light on passive phytoremediation of heavy metal by water hyacinth and its socio-ecological and economic implications. ■

NOTES FROM THE FIELD

While I did not receive any notes from others, I thought readers might be interested in viewing a few photos from a field trip in Rocky Mountain National Park (west side near Grand Lake). In the landscape views notice all the dead trees due to mountain pine beetle infestation. ■

Sloping fen

Seepage from this sloping fen discharging into Colorado River

Monkshood (*Acontium columbianum*)

Yellow Paintbrush (*Castilleja sulphurea*)

Shrubby Cinquefoil (*Dasiphora fruticosa ssp. floribunda*)

Fringed Willow-herb (*Epilobium ciliatum*)

Western Fringed Gentian (*Gentianopsis thermalis*)

Water Avens (*Geum rivale*)

Fringed Bluebells (*Mertensia ciliata*)

Elephant's Head (*Pedicularis groelandica*)

Yellow Monkeyflower
(*Mimulus guttatus*)

Fringed Grass-of-Parnassus
(*Parnassia fimbriata*)

White Bog Orchid
(*Platanthera dilatata*)

Western Polemonium (*Polemonium occidentale, formerly P. caeruleum*)

American Bistort
(*Polygonum bistortoides*)

Hooded Lady's Tresses
(*Spiranthes romanzoffiana*)

Star Gentian (*Swertia perennis*)

Streamside Fen

Fen with small pond

Wet meadow and streambank along Colorado River

Rosecrown Rhodiola
(*Sedum rhodantha*)

Forested wetland, wet meadow, and old beaver pond

The following are a list of some recent publications that may be of interest. If you know of others please send the information to the WSP Editor (rtiner@eco.umass.edu) for inclusion in future editions of Wetland Science and Practice.

BOOKS

- Salt Marsh Secrets. Who uncovered them and how? http://trnerr.org/SaltMarshSecrets/
- Remote Sensing of Wetlands: Applications and Advances. https://www.crcpress.com/product/isbn/9781482237351
- Wetlands (5th Edition). http://www.wiley.com/WileyCDA/WileyTitle/productCd-1118676823.html
- Black Swan Lake – Life of a Wetland http://press.uchicago.edu/ucp/books/book/distributed/B/bo15564698.html
- Coastal Wetlands of the World: Geology, Ecology, Distribution and Applications http://www.cambridge.org/us/academic/subjects/earth-and-environmental-science/environmental-science/coastal-wetlands-world-geology-ecology-distribution-and-applications
- Florida's Wetlands http://www.pineapplepress.com/ad.asp?isbn=978-1-56164-687-6
- Mid-Atlantic Freshwater Wetlands: Science, Management, Policy, and Practice http://www.springer.com/environment/aquatic+sciences/book/978-1-4614-5595-0
- The Atchafalaya River Basin: History and Ecology of an American Wetland http://www.tamupress.com/product/Atchafalaya-River-Basin,7733.aspx
- Tidal Wetlands Primer: An Introduction to their Ecology, Natural History, Status and Conservation https://www.umass.edu/umpress/title/tidal-wetlands-primer
- Wetland Landscape Characterization: Practical Tools, Methods, and Approaches for Landscape Ecology http://www.crcpress.com/product/isbn/9781466503762
- Wetland Techniques (3 volumes) http://www.springer.com/life+sciences/ecology/book/978-94-007-6859-8

ONLINE PUBLICATIONS

U.S. ARMY CORPS OF ENGINEERS

- Wetland-related publications:
  -http://acwc.sdp.sirsi.net/client/en_US/default/search/results?te=&lm=WRP
  -http://acwc.sdp.sirsi.net/client/en_US/default/search/results?te=&lm=WRP
- National Wetland Plant List publications: http://rsgisias.crrel.usace.army.mil/NWPL/
- National Technical Committee for Wetland Vegetation: http://rsgisias.crrel.usace.army.mil/nwpl_static/ntcwv.html
- U.S. Environmental Protection Agency wetland reports and searches: http://water.epa.gov/type/wetlands/wetpubs.cfm
- A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Forested Wetlands in Alluvial Valleys of the Coastal Plain of the Southeastern United States ERDC/EL TR-13-1
- Hydrogeomorphic (HGM) Approach to Assessing Wetland Functions: Guidelines for Developing Guidebooks (Version 2) ERDC/EL TR-13-11
- Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing the Functions of Flat and Seasonally Inundated Depression Wetlands on the Highland Rim ERDC/EL TR-13-12

U.S. FISH AND WILDLIFE SERVICE, NATIONAL WETLANDS INVENTORY

- Wetland Characterization and Landscape-level Functional Assessment for Long Island, New York http://www.fws.gov/northeast/ecologicalservices/pdf/wetlands/Characterization_Report_February_2015.pdf or http://www.aswm.org/wetlandsonestop/wetland_characterization_long_island_ny_021715.pdf
- Also wetland characterization/landscape-level functional assessment reports for over 12 small watersheds in New York at: http://www.aswm.org/wetland-science/134-wetlands-one-stop/5044-nwi-reports
- Preliminary Inventory of Potential Wetland Restoration Sites for Long Island, New York http://www.aswm.org/wetlandsonestop/restoration_inventory_long_island_ny_021715.pdf
- Dichotomous Keys and Mapping Codes for Wetland Landscape Position, Landform, Water Flow Path, and Waterbody Type Descriptors. Version 3.0. U.S. Fish and Wildlife Service, Northeast Region, Hadley, MA.
- Connecticut Wetlands Reports
  - Changes in Connecticut Wetlands: 1990 to 2010
  - Potential Wetland Restoration Sites for Connecticut: Results of a Preliminary Statewide Survey
  - Wetlands and Waters of Connecticut: Status 2010
  - Connecticut Wetlands: Characterization and Landscape-level Functional Assessment
- Rhode Island Wetlands: Status, Characterization, and Landscape-level Functional Assessment http://www.aswm.org/wetlandsonestop/rhode_island_wetlands_llww.pdf
- Status and Trends of Prairie Wetlands in the United States: 1997 to 2009 http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Prairie-Wetlands-in-the-United-States-1997-to-2009.pdf
- Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States 2004 to 2009. http://www.fws.gov/wetlands/Documents/Status-and-Trends-of-Wetlands-In-the-Coastal-Watersheds-of-the-Conterminous-US-2004-to-2009.pdf

- The NWI+ Web Mapper – Expanded Data for Wetland Conservation http://www.aswm.org/wetlandsonestop/nwiplus_web_mapper_nwn_2013.pdf
- Wetlands One-Stop Mapping: Providing Easy Online Access to Geospatial Data on Wetlands and Soils and Related Information http://www.aswm.org/wetlandsonestop/wetlands_one_stop_mapping_in_wetland_science_and_practice.pdf
- Wetlands of Pennsylvania's Lake Erie Watershed: Status, Characterization, Landscape-level Functional Assessment, and Potential Wetland Restoration Sites http://www.aswm.org/wetlandsonestop/lake_erie_watershed_report_0514.pdf

U.S. FOREST SERVICE

- Historical Range of Variation Assessment for Wetland and Riparian Ecosystems, U.S. Forest Service Rocky Mountain Region. http://www.fs.fed.us/rm/pubs/rmrs_gtr286.pdf
- Inventory of Fens in a Large Landscape of West-Central Colorado http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5363703.pdf

U.S. GEOLOGICAL SURVEY, NATIONAL WETLANDS RESEARCH CENTER

- Link to publications: http://www.nwrc.usgs.gov/pblctns.htm (recent publications are noted)
- A Regional Classification of the Effectiveness of Depressional Wetlands at Mitigating Nitrogen Transport to Surface Waters in the Northern Atlantic Coastal Plain http://pubs.usgs.gov/sir/2012/5266/pdf/sir2012-5266.pdf
- Tidal Wetlands of the Yaquina and Alsea River Estuaries, Oregon: Geographic Information Systems Layer Development and Recommendations for National Wetlands Inventory Revisions http://pubs.usgs.gov/of/2012/1038/pdf/ofr2012-1038.pdf

U.S.D.A. NATURAL RESOURCES CONSERVATION SERVICE

- Link to information on hydric soils:http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/hydric/

PUBLICATIONS BY OTHER ORGANIZATIONS

- The Nature Conservancy has posted several reports on wetland and riparian restoration for the Gunnison Basin, Colorado at: http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/Colorado/science/climate/gunnison/Pages/Reports.aspx (Note: Other TNC reports are also available via this website by looking under different regions.)
- Book: Ecology and Conservation of Waterfowl in the Northern Hemisphere, Proceedings of the 6th North American Duck Symposium and Workshop (Memphis, TN; January 27-31, 2013). Wildfowl Special Issue No. 4. Wildfowl & Wetlands Trust, Slimbridge, Gloucestershire, UK.
- Report on State Definitions, Jurisdiction and Mitigation Requirements in State Programs for Ephemeral, Intermittent and Perennial Streams in the United States (Association of State Wetland Managers) http://aswm.org/stream_mitigation/streams_in_the_us.pdf
- Wetlands and People (International Water Management Institute) http://www.iwmi.cgiar.org/Publications/Books/PDF/wetlands-and-people.pdf

ARTICLES OF INTEREST FROM VARIED SOURCES

- Comparative phylogeography of the wild-rice genus Zizania (Poaceae) in eastern Asia and North America; American Journal of Botany 102:239-247. http://www.amjbot.org/content/102/2/239.abstract

LINKS TO WETLAND-RELATED JOURNALS AND NEWSLETTERS

JOURNALS

- Aquatic Botany http://www.journals.elsevier.com/aquatic-botany/
- Aquatic Conservation: Marine and Freshwater Ecosystems http://onlinelibrary.wiley.com/journal/10.1002/%28ISSN%291099-0755
- Aquatic Sciences http://www.springer.com/life+sciences/ecology/journal/27
- Ecological Engineering http://www.journals.elsevier.com/ecological-engineering/
- Estuaries and Coasts http://www.springer.com/environment/journal/12237
- Estuarine, Coastal and Shelf Science http://www.journals.elsevier.com/estuarine-coastal-and-shelf-science/
- Hydrobiologia http://link.springer.com/journal/10750
- Hydrological Sciences Journal http://www.tandfonline.com/toc/thsj20/current
- Journal of Hydrology http://www.journals.elsevier.com/journal-of-hydrology/
- Wetlands http://link.springer.com/journal/13157
- Wetlands Ecology and Management http://link.springer.com/journal/11273

NEWSLETTERS

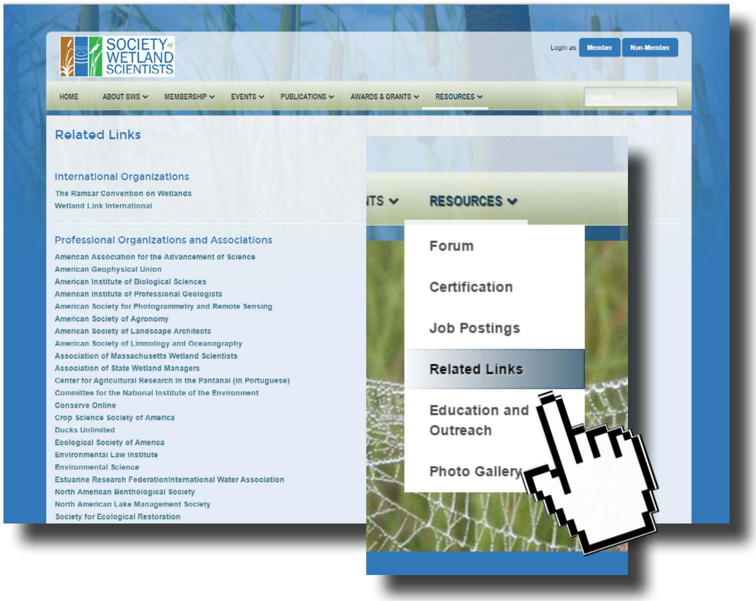
- Biological Conservation Newsletter (this monthly newsletter contains a listing of articles that include many that address wetland issues – current and others back to 1991 in the "Archives") http://botany.si.edu/pubs/bcn/issue/latest.htm#biblio
- Wetland Breaking News (Association of State Wetland Managers) http://aswm.org/news/wetland-breaking-news
- National Wetlands Newsletter (Environmental Law Institute) http://www.wetlandsnewsletter.org/welcome/index.cfm

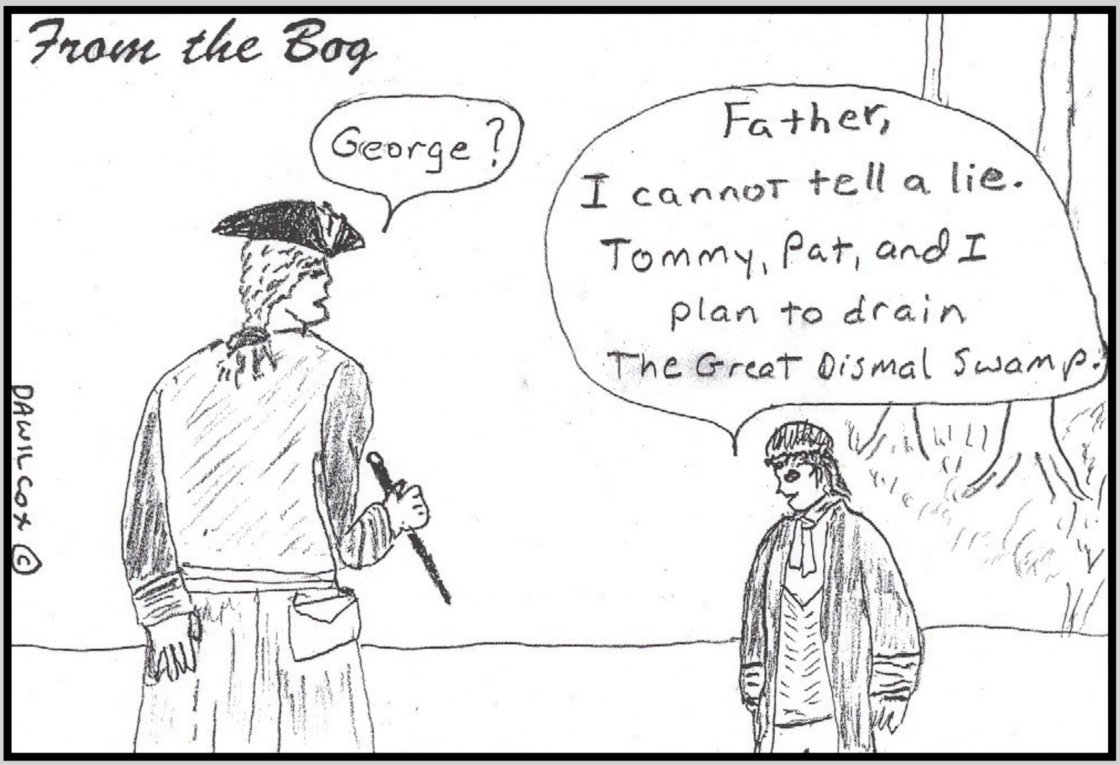
WEB TIP

Resources at your fingertips!

For your convenience, SWS has compiled a hefty list of wetland science websites, books, newsletters, government agencies, research centers and more, and saved them to sws.org.

Find them on the Related Links page **at sws.org.**





Young Forefathers

wetland & science practice

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