Opportunities and Challenges of Integrating Ecological Restoration into Assessment and Management of Contaminated Ecosystems

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EDITOR’S NOTE:
This article represents 1 of 6 articles in the special series “Restoration of Impaired Ecosystems: An Ounce of Prevention or a Pound of Cure?” The articles result from a Technical Workshop organized by SETAC and the Society for Ecological Restoration, held June 2014 in Jackson, Wyoming, that focused on advancing the practice of restoring ecosystems that have been contaminated or impaired from industrial activities.

ABSTRACT
Ecosystem restoration planning near the beginning of the site assessment and management process (“early integration”) involves consideration of restoration goals from the outset in developing solutions for contaminated ecosystems. There are limitations to integration that stem from institutional barriers, few successful precedents, and limited availability of guidance. Challenges occur in integrating expertise from various disciplines and multiple, sometimes divergent interests and goals. The more complex process can result in timing, capacity, communication, and collaboration challenges. On the other hand, integrating the 2 approaches presents new and creative opportunities. For example, integration allows early planning for expanding ecosystem services on or near contaminated lands or waters that might otherwise have been unaddressed by remediation alone. Integrated plans can explicitly pursue ecosystem services that have market value, which can add to funds for long-term monitoring and management. Early integration presents opportunities for improved and productive collaboration and coordination between ecosystem restoration and contaminant assessment and management. Examples exist where early integration facilitates liability resolution and generates positive public relations. Restoration planning and implementation before the completion of the contaminated site assessment, remediation, or management process (“early restoration”) can facilitate coordination with off-site restoration options and a regional approach to restoration of contaminated environments. Integration of performance monitoring, for both remedial and restoration actions, can save resources and expand the interpretive power of results. Early integration may aid experimentation, which may be more feasible on contaminated lands than in many other situations. The potential application of concepts and tools from adaptive management is discussed as a way of avoiding pitfalls and achieving benefits in early integration. In any case, there will be challenges with early integration of restoration concepts for contaminated ecosystems, but the benefits are likely to outweigh them. Integr Environ Assess Manag 2016;12:296–305. © 2015 The Authors. Integrated Environmental Assessment and Management published by Wiley Periodicals, Inc. on behalf of Society of Environmental Toxicology & Chemistry (SETAC)

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INTRODUCTION
The goal of the Society of Environmental Toxicology and Chemistry/Society for Ecological Restoration (SETAC/SER) workshop on Restoration of Impaired Ecosystems was to advance the practice of restoration of ecosystems that have been contaminated or impaired by bringing together ecotoxicologists and risk assessors with restoration ecologists (Farag et al. this issue). A common practice in contaminated site management is to assess and remediate contaminant impacts and then restore ecological structures and function in a sequential manner (Farag...
et al. this issue). Planning for restoration near the beginning of this process (termed here “early integration”) and actually implementing restoration actions before the assessment and remediation activities are complete (termed here “early restoration”) both have challenges but numerous potential benefits.

Aside from being encouraged in some regulatory environments (e.g., in the United States: 40 CFR §11.23 (f); 15 CFR §990.14), there are practical benefits for stakeholders in any nation in integrating the assessment and restoration processes. Response agencies, parties legally responsible for cleanup and restoration, agencies with statutory responsibility for public trust, natural resources and services (trustees), and other parties can benefit. For example, portions of or all aspects of legally motivated instruments for restoration such as a formalized Natural Resource Damage Assessment and Restoration (NRDAR) process can be avoided. When conducted in parallel, there is also great potential for expedited restoration delivery and return of natural resource services, reduction of interim natural resource losses, facilitated liability resolution, and positive public relations. These are all incentives for stakeholders to commit to early integration and early restoration.

Other articles in this series explore the links between ecological risk assessment and restoration (Kapustka et al. this issue), restoration goals (Wagner et al. this issue), and design (Rohr et al. this issue), and monitoring for restoration efficacy (Hooper et al. this issue) and all reinforce the need for integration and early restoration. These are all incentives for stakeholders to commit to early integration and early restoration.

**EARLY INTEGRATION OBSTACLES**

Methods or tools to expedite the assessment and management of contaminated sites have been promoted for decades. Challenges to early integration have been recognized previously and actions taken to advance response practices. For example, one tool, a Streamlined Approach for Environmental Restoration (SAFER) (Gianti et al. 1993), was developed for the US Department of Energy (USDOE) to address waste sites under their management in a more comprehensive manner that would result in time and cost savings in implementation of the response. SAFER built on the Observational Approach and the Data Quality Objectives (DQO) process developed by the US Environmental Protection Agency (USEPA) and formed an integrated and collaborative methodology for addressing the cleanup of hazardous waste sites through the use of expedited data collection and consensus building among stakeholders. The methodology was deemed effective at reducing costs and expediting the remedial design and implementation of site restoration (USDOE and USEPA 1996) and continues to be used on certain USDOE sites. Arguably, SAFER helped advance use of an integrated and expedited approach but is primarily focused on remedial action (i.e., the removal of contaminants) and does not fully embrace ecological restoration as discussed as part of this workshop (i.e., restoration of ecological structure and function). Notably, at the time SAFER was being developed, the National Research Council (NRC 1992) issued its report entitled Restoration of Aquatic Ecosystems that strongly encouraged early integration, detailed institutional barriers to attaining ecological restoration and provided substantial recommendations to achieve desired restoration. SAFER and the 1992 NRC report provide evidence that early integration of restoration planning has historically been an issue of concern but a challenge as yet not fully met. The limited availability of both precedent and guidance for early integration presents some real or perceived risks for the proponents of restorative measures, oversight agencies, responsible parties, and other stakeholders.

Why, then, is the practice of early integration not embraced more widely? Challenges to early integration may be divided into 5 categories: 1) divergent stakeholder objectives, 2) timing incongruence, 3) conflicting stewardship criteria, 4) locational obstacles, and 5) limited guidance. First, a significant institutional barrier to achieving stakeholder objectives is the function of varied responsibilities of decision makers. Some decision makers are engaged in only the remedial process, whereas many participants are stakeholders in both the remedial and restoration processes. Opportunities for early integration are diminished when differences in endpoint objectives, authority, and responsibilities pose limitations on willingness or capacities to expand data collection, assessment, planning, etc., beyond narrowly prescribed roles. Second, although multiple parties involved in a project may express interest in timing that advances ecosystem restoration early in the process, perceptions often persist that such efforts may delay or prolong the determination and/or implementation of remedial action. Third, responsibility for long-term stewardship may pose challenges for some stakeholders when such obligations extend well beyond remedial performance periods. Fourth, the term “reverse NIMBY” (i.e., preference for restoration and/or conservation in close proximity to one’s location) may be attributed to D.E. Willard and J. Klarquist as introduced in Rehabilitating Damaged Ecosystems (Cairns 1995). Those preferences, along with potential equity challenges posed by environmental justice issues, continue to contribute to the hurdles for siting restoration and engaging parties in early integration. Fifth, the paucity of applicable guidance or methodology (e.g., an expanded SAFER-type program) has resulted in inconsistency in approaches toward early combination of assessment with restoration and may be a reason for the shortage of precedent-setting examples of successful early integration. Institutional barriers to early integration of restoration practices, similar to those noted herein and presented in Table 1 for combining assessment with restoration, continue to obstruct progress toward restoration of impaired environments. These categories are not exclusive and may be considered to include similarities to those raised more than 2 decades ago by others (NRC 1992). Raising these challenges anew herein demonstrates that the ongoing implications of these issues are numerous and require additional consideration, which in turn may serve to advance the application of early integration.

How then can early integration practices be advanced? There are considerable time and cost savings that may be realized and the recognition of these potential benefits is key to understanding why both processes can and, in some cases, should move forward contemporaneously.
Table 1. Early integration of restoration: Opportunities, challenges and implications with assessment and remediation of contamination

| Early integration | Implications |
|-------------------|--------------|
| Opportunities     |              |
| Expedites restoration delivery |  ● Faster return of ecosystem function and services  |
|                    |  ● Reduced interim losses  |
| Incorporates enhanced ecological value to onsite remedies when clean-up protective |  ● Appropriate selection of species  |
|                    |  ● Avoids attractive nuisance  |
|                    |  ● Meet habitat provisions  |
| Incentivizes offsite (compensatory) restoration when ecorisk reduction insufficient or restoration onsite impractical |  ● Provide natural resource injury offsets  |
|                    |  ● Mitigation of natural resource injuries that result from response activities  |
| Data collection and implementation harmonization |  ● Ability to use ecorisk data for injury assessment and restoration planning and design  |
|                    |  ● Coordinated or contemporaneous approach to data collection additional to ecorisk  |
|                    |  ● Concurrent implementation of clean-up or remedial and restoration actions  |
| Cost and time efficient |  ● Reduced mobilization equals economies of scale  |
|                    |  ● Time savings (technical vs legal solution, staff efficiency)  |
| Expedited stakeholder engagement |  ● Increased input into restoration planning  |
|                    |  ● Greater acceptance of remedy and restoration outcome  |
| Meet regulatory mandates for coordination |  ● Upfront and iterative communication of different obligations and objectives  |
| Natural resource liability resolution |  ● Complete resolution of liability if NRDAR avoided  |
|                    |  ● Increased chance of a restoration-based settlement  |
|                    |  ● Potential to streamline ultimate NRDAR (if warranted)  |
| Creative options for parties responsible for natural resource liability where remediation does not achieve primary restoration |  ● Address preexisting regional restoration priorities  |
|                    |  ● Leverage additional partnerships and geographic scope  |
|                    |  ● Restoration banking  |
|                    |  ● Novel ecosystems  |
|                    |  ● Ecosystem service considerations and markets  |
|                    |  ● Promote positive public relations  |
| Challenges         |              |
| Diverse group of stakeholders with varied objectives |  ● Response agencies and natural resource trustees have different authorities and responsibilities  |
|                    |  ● Constraints, perceived or real, on limited funding and stakeholder capacity for assessment and restoration planning  |
|                    |  ● Public input and engagement requirements are less clear outside of a formal NRDAR  |
|                    |  ● Decreased likelihood of success without motivated responsible party  |

(Continued)
ECOSYSTEM SERVICES AND INCENTIVES FOR EARLY INTEGRATION

One major opportunity provided by early integration is increased ability to take advantage of ecosystem service benefits. Ecosystem service benefits are those benefits provided by ecosystems that support, enrich, and sustain human life, and which are often improved when restoration goals are met (Palmer and Filoso 2009). Kaputska et al. (this issue) highlight opportunities to incorporate ecosystem services in the ERA and restoration planning process. Thorough consideration of ecosystem services with early integration of restoration design into remedial assessment has many benefits (Table 1).

Communicating planning goals among site assessment, management, and restoration stakeholders can inform remedial and restoration processes and shape desired outcomes of both, thereby addressing one of the challenges to early integration (i.e., divergent stakeholder objectives). Ecosystem services provide a good framework for this communication. Remedial decision makers should be aware that the remedy can be an instrumental part of developing restoration options, particularly onsite primary restoration actions. The goal of early integration is to concurrently achieve cleanup goals, enhance ecological value, and reduce environmental liability. Remedial targets that are protective of the environment create preferred options for onsite, in-kind actions or opportunities to restore nearby degraded areas, directly benefitting resources that have been negatively affected. Where cleanup targets are not protective of the environment or onsite natural resource injuries result from the cleanup, the remedy may drive compensatory restoration (offsets) elsewhere (Figure 1).

With early integration, there is an expanded opportunity for a crediting framework. Ecosystem service credits for restoration can be quantified to achieve 1) internal (NRDAR restoration scaling, offsetting impacts of business operations beyond hazardous substance releases), and 2) external (trading restoration credits as a commodity) stakeholder interests as described below.

There is the potential for revenue in emerging markets from ecosystem service benefits realized in excess to the release-specific need. This can counterbalance the real or perceived risks associated with “over-investment” in early restoration to offset contamination effects without fully understanding the nature and extent of those injuries and associated liability (challenges of timing incongruence and limited precedent).

Credits for ecosystem services have potential to satisfy regulatory demands, but lack of consensus on implementation has hindered acceptance. There are several examples of where the developer of the restoration project can hold credits for ecosystem services (excess to those required to offset contamination injuries) that could potentially be used to satisfy internal operational or environmental performance needs. An incentive-based approach built on the structure of crediting and capturing benefits from early restoration was first developed in the early- to mid-2000s (NOAA 2007). The “Prospective Restoration/Restoration Up Front” concept of early restoration provided a framework for determining and banking durable credits for restoration conducted proactively in advance of known or assessed injuries to natural resources (Stahl et al. 2008). The concept could be applicable to crediting restoration conducted for, or that may be required for, settlement of NRDAR claims or other compensatory obligations (Rapp 2009). However, challenges with the framework and functionality of the concept have hampered its acceptance and impeded its implementation as proposed. For example, the concept was intended to facilitate willingness of entities to conduct early restoration with confidence that credit for such efforts would be awarded in a structured and formalized manner. However, there is as yet no consensus about the appropriate framework for implementation.

When a framework for implementation does exist, it can provide incentive for early restoration. Commencement Bay, Washington, USA is a NRDAR remediation and/or restoration project (NOAA 2011a) for which an early restoration-type crediting program was developed. The Hylebos Creek Estuarine Project is a 2.7-ha site within the broader Commencement Bay project. This unique, third party-implemented restoration was conducted jointly between entities with liability and natural resource agencies, under an agreement that the third party assumes both site cleanup and restoration responsibilities (Wildlands 2009). Natural resource agencies involved allowed

Table 1. (Continued)

| Early integration | Implications |
|-------------------|--------------|
| Potential for timing incongruence | • Perceived of slowing remedial process |
| Long-term stewardship | • Restoration horizon may exceed remedial performance period |
| Compensatory restoration or offset projects conducted off-site | • Reverse NIMBY |
| Limited guidance/precedent | • Perceived or real inflexibility to incorporate innovative approaches to enhancement beyond source control and remedy |

NIMBY = Not In My Back Yard; NRDAR = Natural Resource Damage Assessment and Restoration.
trading or selling of excess ecosystem service credits between entities with liability (NOAA 2002). The Hylebos Creek project was completed ahead of final settlement of ecological damages and is therefore considered an example of successful early restoration. However, the NRDAR was initiated in 1991 with a second phase that was not implemented until 2009 (NOAA 2013). In this case, early restoration did not necessarily equate to expedited implementation and recovery of ecosystem services. Clearly, barriers still exist to advancing the schedule for restoration.

The framework for implementation can take many forms. At least in the United States, collaborations between trustees and entities with liabilities are emerging wherein the 2 work cooperatively to identify approaches to integrate restoration. For example, the Commencement Bay federal trustees and a proactive corporate party signed a memorandum of agreement that allowed early restoration projects to be initiated by the responsible party, and acknowledged that such projects may provide credits or offsets. Although all of the specifics of the agreement have not been made public, this action can serve as the basis to expedite similar actions in the future (NOAA 2011b).

Figure 1. Linkages between an ecological risk assessment conducted for a contaminated site, remediation, restoration, and offsetting.

Novel, market-based restoration approaches with demonstrated ecosystem service benefits can provide additional incentives to all parties. Novel, as used herein, refers to actions not typically considered to represent “in-kind” compensation (e.g., replacement of emergent marsh with similar habitat), but that can be demonstrated quantitatively to provide specific ecosystem services. For example, preventative measures (Chapman and Julius 2005) are now considered as compensatory restoration. These efforts include such simple means as signage that demonstrably prevents injury to natural resources or executing land conservation measures to avoid imminent habitat or resource losses. Opportunities for acceptance of these restoration actions and the realization of potential ecosystem service contributions toward the management of contaminated ecosystems can be achieved through early integration of restoration planning (e.g., restoration is achieved sooner), particularly given the simultaneous planning and design needs for restoration and ecosystem service crediting.

Regardless of crediting requirements, a net increase in benefits can stem from focusing on restoration actions that yield marketable services, even though they are additional to actions needed to address liability alone. For example, although restoration to address contamination impacts will often be designed first and foremost to redress ecosystem injuries, there may also be opportunities to expand planning and design to optimize C sequestration capacity and concurrently mitigate greenhouse gas emissions (Rohr et al. 2013).
This approach is capable of generating credits compatible with voluntary or compliance market standards and certifications (such as the Verified Carbon Standard, the Climate Action Reserve and American Climate Registry, the Climate Community and Biodiversity Alliance, and the Gold Standard). The developer may also have the capacity to sell or trade such credits to others, similar to established ecosystem service markets such as wetland mitigation banks (USEPA 2014). The concept holds promise for providing many of the benefits presented in Table 1.

When considered in concert with other creditable services (e.g., water filtration, nutrient sequestration) surplus to those necessary for offsets, there may be future opportunities for parties requiring offsets to “stack” or secure multiple ecosystem service payments for services produced by a single project on a fixed area (Cooley and Oleander 2011). These incentives underscore the opportunities provided by early coordination and integration of restoration goals with site assessment planning and present fertile ground for additional consideration among all parties of potential offset trading implications.

**REGIONAL COORDINATION AND OFFSITE RESTORATION OPPORTUNITIES**

The ability to consider offsite restoration is another key opportunity presented by early integration. Although onsite restoration is often the preferred option, offsite restoration is also an important tool to compensate for lost natural resources and the ecosystem services they provide (“compensatory restoration” or “offsets”; Text Box 1; Figure 1) and can be considered during early integration. There are circumstances where it is either not feasible to do remediation, rehabilitation or restoration onsite (Chapman and Julius 2005; Figure 1) or where additional restoration beyond what can be accomplished at the site is required to compensate the public for loss of ecological services from the time of impact (resource injury) until recovery is completed (NOAA 1996). There also may be circumstances where it may be desirable for stakeholders to deliver ecosystem services that may not be achievable locally, for example, by leveraging or collaborating with larger-scale ecosystem restoration efforts already underway. Kaputksa et al. (this issue) note that a regional/landscape/seascape focus in assessing contaminated sites allows restoration efforts to deliver more substantial ecosystem services. Likewise, in many ecosystems, habitat fragmentation or pressures resulting from changing climatic conditions (e.g., sea level rise, habitat transition) are stimulating strategic identification of areas of higher priority and greater potential for restoration permanence. These opportunities may be more apparent or available when considering early integration or restoration into the site management process (Table 1). The geographic scope of such actions can vary from localized (near-field) to far-field (e.g., watershed or basin) and beyond, all of which may be considered regional actions. Regional, as used herein, may be applicable to locations where actions are connected to impacted areas through natural and/or administrative boundaries.

Under such a regional viewpoint, one of the first ecological restoration issues that could or should be evaluated at a contaminated site is the potential opportunity for restoration to influence or be integrated with adjacent lands or waters extending beyond the remedial footprint. Consideration of near-field restoration opportunities beyond the scope of the remedy allows parties legally responsible for cleanup to potentially achieve economies of scale and localized “co-benefits” (e.g., improved biodiversity, conservation and/or ecosystem services). Notably, implementation of early restoration with demonstrably positive influence on a local scale may functionally reduce the magnitude of compensatory restoration needed by immediately jump-starting recovery and reducing the overall extent of the injury.

Benefits for pursuing localized restoration on areas adjacent to contaminated sites may also include improved environmental justice, by targeting delivery of restored resources and services in areas meaningful to local communities affected by the release.

Emerging restoration opportunities on a large geographic scale may depend on appropriate restoration species selection (Text Box 2), and may include developing refugia or movement corridors for vulnerable species, restoring habitats projected to be more resilient or supportive, and enhancing riparian habitat and marshes to buffer against erosion and storm surges (Harris et al. 2006; Rohr et al. 2013).

If parties legally responsible for contamination cleanup also have influence over restoration of adjacent lands or waters, there are real time- and cost-savings to be realized through integrated efforts. Duplicative actions can be prevented and opportunities will be enhanced to capitalize on shared findings. For example, during planning and implementation, field work conducted to assess, cleanup, rehabilitate, conserve, or restore an area could be consolidated and synchronized. Potential cost savings exist in collection of field data, ecological assessments, on-site construction, operations and maintenance, and monitoring as well as long-term stewardship. Additionally, regula-

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**Text Box 1: Offsets**

Best-practice guidance exists for frameworks, principles, and criteria that define the use of offsets (BBOP 2012). Key considerations include (BBOP 2012): landscape context, inclusion of stakeholders in the process, use of sound science and incorporation of monitoring, evaluation, and an adaptive management approach. Other practical considerations include cost, likelihood of success, and effect on public health and safety (NOAA 1996). Offsite options for restoration present an opportunity for a collaborative, coordinated, regional approach to restoration. This can result in greater overall benefits than consideration of onsite restoration only. It also meets regulatory requirements in those jurisdictions where compensatory restoration is needed to address residual injury or loss of ecological services. A challenge with integration of restoration early in the site management process is insuring against failure and dealing with uncertainty (BBOP 2012). Uncertainty sometimes is dealt with by using multipliers; the quantity of offsite restoration is multiplied beyond estimates of that required to compensate for onsite losses, in case restoration goals are not fully realized. However, it is often difficult to define a multiplier that will be adequate and appropriate to ensure no net loss. Alternatives to multipliers include investing in rigorous methods to estimate losses and gains, inclusion of multiple and complementary offset activities, and employment of an adaptive management approach to review and modify activities if the expected gains are not realized (BBOP 2012).
Revegetation of contaminated lands is one aspect of restoration that can benefit from early integration, as the ability to achieve benefits while avoiding pitfalls depends substantially on species-selection decisions. When revegetating contaminated land, “workhorse” species that perform well under the adverse conditions typical of rehabilitated sites should be selected (Harris et al. 1996; Whisenant 1999). Where there is residual contamination, further criteria include avoiding species likely to elevate risk of off-site or trophic transfer of contaminants, avoiding species easily replaced by exotic invasive species (Cox 2004) and/or selecting species able to provide beneficial contaminant-related services such as phyto-remediation, stabilization, and degradation (Bini 2010).

Contaminated sites can rapidly select for populations of toxicant-adapted organisms (Wu 2004). Such sites can serve as natural laboratories, offering opportunities for collection and study of novel populations that can potentially be used in other contaminated systems. To realize such opportunities, care should be taken to not eliminate potentially desirable “volunteers” that colonize contaminated systems on their own.

Another benefit of contaminated systems is their potential to support biodiversity and serve as refugia for rare species. The presence of contamination can eliminate other highly disturbing anthropogenic land uses. The resulting, often long-term removal of human pressures can lead to strong recovery of biological diversity. For example, ecosystems surrounding the decommissioned nuclear Hanford Site in the northwestern United States support over 30 plant and animal species classified as Special Concern, Threatened, or Endangered (Duncan et al. 2007).

Text Box 2: Challenges and opportunities in selecting species for revegetation

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In context of the need for broader regional restoration, parties responsible for planning and implementing remediation and restoration may be afforded greater opportunity for developing more creative offsets or addressing restoration needs of regional importance when an expanded set of stakeholders, representing different yet overlapping interests, are brought early into the restoration planning process. Such efforts may be expedited when there are pre-existing watershed and regional restoration frameworks where potentially appropriate restoration activities have already been identified, vetted, and prioritized by diverse groups of stakeholders, including the public. The Louisiana Regional Restoration Planning Program, Final Regional Restoration Plan, Region 2 (LLRP), is one such example in which the program structure was developed to establish efficient decision-making processes, restoration project selection criteria, and lists of acceptable projects for implementation under the NRDAR process (LLRP 2007).

Confounding the above opportunities, the potential challenges with pursuing an integrated approach at a regional scale (be it near-field or far-field) are similar to those on a site-specific scale (Table 1) but with potentially greater impact on: 1) increased time and front-end costs for data collection, which can be even greater when developing and implementing regionally-expanded collection efforts; 2) time delays for the increased number of partners on a regional scale who may not be vested in both the remedial and restoration processes; and 3) overcoming capacity issues relative to increased spatio-temporal effort. Moreover, at a regional scale, all 3 of these challenges are often interrelated. For example, characterizing an expanded assessment footprint sufficiently to satisfy due diligence requirements for restoration may be complicated and/or delayed if partners are not willing to expeditiously contribute to the process or relinquish decision making to others, which may be related to limited funding and/or staffing capabilities or capacities. Programs such as the LLRP can serve to diminish these time, cost, and capacity impacts by providing vetted regional opportunities that preclude the need for additional characterization. Lessons learned during SAFER pilot projects can be applied to overcome challenges and advance an integrated regional approach. These include the need for a “champion” for each project to coordinate and move the process forward, the early and active contributions of regulators, investing in consensus building at the forefront and progress documentation throughout, and commitment to not only expediting investigation and assessment processes, but to accelerating remedial and restoration schedules (USDOE and USEPA 1996). On this last point, the continuation of efforts such as those by many risk assessment and restoration practitioners over the past several decades to develop processes by which integrated approaches may be realized (e.g., 2014 SETAC/SER workshop key messages [Farag et al. this issue]) may be further reduced if there is a continued unwillingness or inability to demonstrate advancements that result in expedited ecosystem service gains and tangible benefits for all parties involved.

**MONITORING AND ADAPTIVE MANAGEMENT**

Including restoration planning early in the risk assessment and/or remediation process can facilitate an integrated means to evaluate not only chemicals but also other stressors that often accompany contamination. Monitoring outcomes from such an integrated approach could provide welcome relief from conflicts over which stressor is most important. Even if there are greater costs in addressing multiple stressors at once, those might be mitigated by reducing the inefficiencies and high costs of litigation (at least in the United States) and remediation of stressors (e.g., chemicals) that may not be the primary cause of the observed impacts.

Early integration provides opportunities for efficiency and cost-savings in monitoring and adaptive management. Monitoring is a critical component of the early integration of the assessment, management and restoration of a contaminated site, to be able to identify important site-specific data to
be collected that will address key chemical and ecological parameters, to track change and to allow for program modification through adaptive management. Monitoring also is an opportunity to learn from successes and failures (Hooper et al. this issue). Remediation and restoration are both long-term and uncertain processes, particularly at larger sites, and therefore, adaptive management has been recognized as a best practice (NRC 2005). The science-driven adaptive management often promised when a restoration and/or remediation program begins is not possible without a robust program of ongoing monitoring and assessment.

Early integration requires monitoring throughout the site assessment and management process, and therefore helps secure funding for this critical activity. Despite obvious benefits, monitoring and assessment are too often under-funded or the first thing to be cut if support dwindles (Hooper et al. this issue). Research linked to monitoring is almost never funded, even though the combination of both can help explain causes of environmental change (Luoma et al. 2010). In the absence of data, adaptive management is based on intuition (best professional judgment), if it occurs at all. If restoration planning is integrated with risk assessment and remediation early in the process, then planning for adequate resources for integrated monitoring, assessment and reporting on performance is a critical component of the integration.

Integrated monitoring across remediation and restoration goals does present challenges, particularly due to the lack of guidance available. Water and soil quality measures often are given the highest priority in traditional monitoring of remediation in contaminated aquatic and terrestrial ecosystems, respectively, largely because most environmental quality regulations or guidelines are based on water or soil concentrations of the contaminant. Recovery from adverse effects of contamination depends on reducing bioavailability, bioaccumulation at the base of food webs and food web transfer. The traits of organisms that occupy the food web and the characteristics of the contaminant influence the impacts (Luoma and Rainbow 2005). These complexities often decouple water or soil contaminant concentrations from ecological change. Similarly, traditional restoration monitoring assesses ecological change but not necessarily changes in environmental (i.e., chemical) conditions. Ecological change alone is not sufficient to link restoration of the ecosystem to remediation of the contamination; some measure of exposure is essential. Therefore, monitoring when conducting early integration of restoration at a site should include both contaminant and ecological parameters.

A robust integrated monitoring program should simultaneously track restoration progress and contaminant remediation. Decades of research in contaminated environments illustrate several kinds of ecological change that accompany recovery from contamination (Luoma and Rainbow 2008). Similarly, ecological change associated with restoration can affect the fate and effects of contaminants. The challenge is to combine this knowledge into an integrated monitoring program. Candidates for such a program in aquatic environments, for example, might include environmental concentrations of the contaminant of concern and/or bioaccumulated concentrations in indicator species (Hornberger et al. 2009), changes in the expression of sublethal signs of adverse effects in resident species (Hornberger et al. 2000; Farag et al. 2003), changes in benthic populations (Clements et al. 2002; Luoma et al. 2010), or changes in functional aspects of the ecosystem known to be affected by contaminants (Carlisle and Clements 2005). For example, long-term monitoring of metal concentrations in fine-grained sediments and bioaccumulated metal concentrations in a resident benthic species were employed in the Clark Fork River, Montana. Together these measures successfully tracked the degree to which remediation activities reduced exposure to Cu and Cd from mine waste deposits in the river (Hornberger et al. 2009). Declining exposures to metals in the biomonitored species were then calibrated against changes in benthic community structure. Abundance of sensitive invertebrate species (heptageniid mayflies) was one particularly sensitive measure of recovery in the benthic community with potential benefits for fish and wildlife (Luoma et al. 2010).

Simple approaches can improve evaluation of broader ecological implications of restoration and remediation activities. Conclusions about links between exposure and effects can be reinforced by laboratory and field experiments. In streams, for example, there is a progression of sensitivities that determines the sequence of recovery among aquatic insect larvae (Clements et al. 2002), as contamination recedes. Periodic monitoring of fish populations, biomarkers of fish health (Farag et al. 2003), or measures of ecological function known to be affected by metals (Carlisle and Clements 2005) could be added to the integrated monitoring program.

It is widely recognized that development of a convincing set of performance measures is essential to science-based adaptive management of both restoration and remediation. Identification of an integrated set of performance measures should be a part of the early integration of restoration and risk assessment. Identifying and implementing these measurements is more challenging than is widely recognized, however, due to factors such as divergent stakeholder objectives, and limited guidance and precedence. Often the choices are either too narrow in scope (e.g., water quality measurements only), too broad to implement (vague indicators that cannot be directly measured), too many to support financially (every aspect in the conceptual ecosystem model) or are not feasible (measures that are not fully developed). In both restoration and remediation, many examples exist of lists of indicators that languish unmaintained. Choosing performance measures at an early integration site would necessitate integrating the expertise of restoration ecologists and contaminant experts, 2 fields where experts often do not work together. There are examples of formal performance measures implemented in association with large ecosystem restoration projects (Dennison et al. 2007) that have overcome these challenges, although ecotoxicology was not an issue at these sites.

Adaptive management deals with recurrent decision making over time in the context of uncertain science (Williams et al. 2007) that clearly applies to the restoration of contaminated lands and especially when integrating restoration early in the site assessment and management process. Although a powerful tool, adaptive management is a complex, challenging, sometimes contentious process that requires skilled leadership and strong buy-in from stakeholders, even when the goals are simple. Although there is a lack of guidance for implementing adaptive management for ecological restoration of contaminated lands per se, there is guidance for adaptive management related to management of natural resource systems (Allan and Stankey 2009) and there is specific guidance developed for the remediation phase.
The broader decision science literature for ecological and environmental management also contains useful guidance (Linkov and Moberg 2011). Integrating restoration thinking with risk assessment and remediation planning can provide an excellent setting for both analysis of benefits from learning and conflict resolution. A positive outcome can provide both explicit justification and incentives for investments in the monitoring, assessment and feedback to decision making that is so often lost in the traditional linear approach to risk assessment, remediation, then restoration.

CONCLUSIONS

Integrating restoration into the assessment and management of contaminated sites involves consideration of restoration goals from the outset and in developing solutions for contaminated ecosystems. Opportunities and challenges will accompany this new way to view restoration of contaminated environments. Challenges arise due to institutional barriers arising from divergent stakeholder objectives, timing incongruences, long-term stewardship issues, locational obstacles, and limited availability of guidance with few successful precedents. Notwithstanding the opportunities described above, running remedial and restoration planning processes concurrently may not be appropriate at all sites. There are circumstances where critical decisions regarding the type, magnitude and placement of restoration projects to offset natural resource injuries cannot be fully considered without access to results that may not be available until remedial investigations and injury assessments are more mature. Postponing restoration decision making to more fully consider results of remedial and injury studies may sacrifice the benefits of a concurrent approach. Although finding a restoration opportunity in proximity to a remediation action may yield maximum integration benefits from a certain perspective (e.g., regulatory, environmental justice), this will not always be possible. However, that should not discourage stakeholders from pursuing offsets in a similarly integrated fashion.

Restoration approaches that emphasize the benefits of early planning hold the potential for expedited recovery of ecosystem services when harmonized with the contamination assessment process. In addition, integration allows early planning for expanding ecosystem services on contaminated lands that might otherwise have been damaged by the remediation approach. Ecosystem services have market value which, when demonstrated, can leverage funds for long-term monitoring and management. Parties responsible for remediating and restoring contaminated sites have the opportunity to consider themselves as producers of environmental credits provided they are additional to their environmental liabilities. Offsite options for restoration present opportunities for a collaborative, coordinated, regional-level approach to restoration of contaminated environments. Offsite options also can deliver opportunities for climate mitigation and/or resiliency and habitat connectivity. Some regional ecosystem gains can help with liability resolution, generating positive public relations, and leveraging new partners to expand scale. Finally, integration of ecosystem performance measures with contamination monitoring can benefit from considering ecological goals from the outset in addressing contaminated environments. Performance measures can build from existing understanding of how contaminants interact with other environmental factors in affecting ecological structure and function. Decision making is challenging given the possibilities of multiple, sometimes competing objectives, long time horizons and many management alternatives. Adaptive management involving recurrent decision making over time is a useful tool in this context.

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REFERENCES

Allan C, Stankey GH. 2009. Adaptive management: A practitioner’s guide. Dordrecht (NL): Springer Science + Business Media. 351 p.

[BBOP] Business and Biodiversity Offsets Programme. 2012. Standard and guidelines. BBOP standard on biodiversity offsets and associated material. [cited 2014 June 3] Available from: http://bbopt.forest-trends.org/pages/guidelines

Bini C. 2010. From soil contamination to land restoration. New York (NY): Nova Science Publishers. 68 p.

Cairns J. 1995. Rehabilitating damaged ecosystems (2nd ed). Boca Raton (FL): Lewis Publishers. 425 p.

Carlisle DM, Clements WH. 2005. Leaf litter breakdown, microbial respiration and shredder production in metal-polluted streams. Freshwater Biol 50:380–390.

Chapman DJ, Julius BE. 2005. The use of preventative projects as compensatory restoration. J Coastal Res 40:120–131.

Clements WH, Carlisle DM, Courtney LA, Harrahy EA. 2002. Integrating observational and experimental approaches to demonstrate causation in stream biomonitoring studies. Environ Toxicol Chem 21:1138–1146.

Cooley J, Oleander L. 2011. Stacking ecosystem services payments: Risks and solutions. Nicholas Institute for Environmental Policy Solutions. Duke University, Durham, NC. NIEP 11-04 [cited 2014 June 3]. Available from: http://nicholasinstitute.duke.edu/sites/default/files/publications/stacking-ecosystem-services-payments-paper.pdf

Cox GW. 2004. Alien species and evolution: The evolutionary ecology of exotic plants, animals, microbes, and interacting native species. Washington (DC): Island Press. 400 p.

Dennison WC, Lookingbill TR, Carruthers TJB, Hawkey JM, Carter SL. 2007. An eye-opening approach to developing and communicating integrated environmental assessments. Front Ecol Environ 5:307–314.

Duncan JP, Burk KW, Channess MA, Fowler RA, Fritz BG, Hendrickson PL, Kennedy EP, Last GV, Poston TM, Sackschewsky MR. 2007. Hanford Site National Environmental Policy Act (NEPA) Characterization. Richland (WA): Pacific Northwest National Laboratory (PNNL).

Farag AM, Hull RN, Clements WH, Glomb S, Larson DL, Stahl R, Stauber J. 2016. Restoration of impaired ecosystems: An ounce of prevention or a pound of cure? Introduction, overview, and key messages from a SETAC-SER workshop. Integr Environ Assess Manag 12:247–252.

Farag AM, Skaar D, Nimick DA, MacConnell E, Hogstrand C. 2003. Characterizing aquatic health using salmonid mortality, physiology, and biomass estimates in streams with elevated concentrations of arsenic, cadmium, copper, lead, and zinc in the Boulder River watershed, Montana. Trans Am Fish Soc 132:450–467.

Gianti S, Dailey R, Hull K, Smyth J. 1993. The streamlined approach for environmental restoration. In Proceedings of Waste Management; 1993 February 28–March 4; Tucson, AZ. p 585–587.
Harris JA, Birch P, Palmer J. 1996. Land restoration and reclamations: Principles and practice. London, UK: Addison Wesley Longman. 230 p.

Harris JA, Hobbs RJ, Heggs P, Aronson E. 2006. Ecological restoration and global climate change. Restor Ecol 14:170–176.

Hartman DH, Goltz MN. 2001. Application of the analytic hierarchy process to select characterization and risk-based decision-making and management methods for hazardous waste sites. Environ Eng Policy 3:1–7.

Hooper MJ, Glomb SI, Harper DD, Hoelze TB, McIntosh LM, Mulligan DR. 2016. Integrated risk and recovery monitoring of ecosystem restorations on contaminated sites. Integr Environ Assess Manag 12:284–295.

Hornberger MI, Luoma SN, Johnson HI, Holyoak M. 2009. The influence of remediation in a mine-impacted river: Do improvements upstream impact metal trends over large spatial and temporal scales? Ecol Appl 19:1522–1535.

Hornberger MI, Luoma SN, Cain DJ, Parchaso F, Brown CL, Bouse RM, Wellise C, Thompson J. 2000. Linkage of bioaccumulation and biological effects to changes in pollutant loads in South San Francisco Bay. Environ Sci Technol 34:2401–2409.

Kapustka LA, Bowers K, Isanhart J, Martinez-Garza C, Finger S, Stahl R, Stauber J. 2016. Coordinating ecological restoration options analysis and risk assessment to improve environmental outcomes. Integr Environ Assess Manag 12:252–263.

Linkov I, Moberg E. 2011. Multi-criteria decision analysis: Environmental applications and case studies. Boca Raton (FL): CRC Press. 204 p.

Linkov I, Varghese A, Jamil S, Seager T, Kiker G, Bridges T. 2005. Multi-criteria decision analysis: A framework for structuring remedial decisions at contaminated sites. In: Comparative risk assessment and environmental decision making. New York (NY): Springer. p 15–54.

[LRRP] Louisiana Regional Restoration Planning Program. 2007. Final Regional Restoration Plan Region 2. [cited 2014 June 4]. Available from: http://www.darrp.noaa.gov/pdf/Final_Regional_Restoration_Plan_for_Region_2.pdf

Luoma SN, Cain DJ, Rainbow PS. 2010. Calibrating biomonitor: A new technique for explaining metal effects in natural waters. Integr Environ Assess Manag 6:199–209.

[NOAA] National Oceanic and Atmospheric Administration. 1996. Restoration planning. Guidance document for natural resource damage assessment under the Oil Pollution Act of 1990. NOAA Damage Assessment and Restoration Program, Silver Spring, MD. [cited 2014 June 4]. Available from: http://www.darrp.noaa.gov/library/pdf/ppd.pdf

[NOAA] National Oceanic and Atmospheric Administration. 2002. Commencement Bay NRDA Site—Natural resource damage assessment background and process overview. [cited 2014 June 4]. Available from: http://www.cbrestitution.noaa.gov/overview.html

[NOAA] National Oceanic and Atmospheric Administration. 2011a. Commencement Bay NRDA Site—Natural resource damage assessment background and process overview, [cited 2014 June 4]. Available from: http://www.cbrestitution.noaa.gov/overview.html

[NOAA] National Oceanic and Atmospheric Administration. 2011b. Memorandum of agreement between the Natural Resource Trustees and Chevron concerning potential early restoration activities associated with the Star Lake Canal Superfund Site, Jefferson County, Texas. 1–11. [cited 2014 June 4]. Available from: http://ssempub.epa.gov/arcollction/DB/AR6318

[NOAA] National Oceanic and Atmospheric Administration. 2013. Commencement Bay NRDA Site—Natural resource damage assessment background and process overview. [cited 2014 June 4]. Available from: http://www.cbrestitution.noaa.gov/overview.html

[NRC] National Research Council. 1992. Restoration of aquatic ecosystems. Science, technology, and public policy. Washington (DC): National Academies Press. 576 p.

[NRC] National Research Council. 2005. Superfund and mining megasites—Lessons from the Coeur d’Alene River Basin. Washington (DC): National Academies Press. 504 p.

Palmer MA, Filoso S. 2009. Restoration of ecosystem services for environmental markets. Science 325:575–576.

Parnell GS, Frimpon M, Barnes J, Klueber JM Jr, Deckro RE, Jackson JA. 2001. Safety risk analysis of an innovative environmental technology. Risk Anal 21:143–155.

Rapp J. 2009. Overview of NOAA's restoration up-front of Assessment/Restoration Credit Trading (RUFA/RCT) policy and case experiences. US Department of the Interior 2009 Restoration Program National Workshop, Phoenix, AZ. [cited 2014 June 4]. Available from: http://www.doi.gov/restoration/upload/Rapp.pdf

Rohr JR, Johnson P, Hickey GW, Helm RC, Fritz A, Brasfield S. 2013. Implications of global climate change for natural resource damage assessment, restoration, and rehabilitation. Environ Toxicol Chem 32:93–101.

Rohr JR, Farag AM, Cadotte MW, Clements WH, Smith JR, Ulrich CP, Woods R. 2016. Transforming ecosystems: When, where, and how to restore contaminated sites. Integr Environ Assess Manag 12:273–283.

Stahl RG, Guouguet R, DeSantis A, Liu J, Ammann M. 2008. Prospective environmental restoration/restoration up front: A concept for an incentive-based program to increase restoration planning and implementation in the United States. Integr Environ Assess Manag 4:6–14.

[USDOE and USEPA] US Department of Energy and US Environmental Protection Agency. 1996. Streamlined Approach for Environmental Restoration (SAFER) Pilot Project Final Report. [cited 2014 June 4]. Available from: http://home.ornl.gov/sesa/environment/guidance/cercla/safer.pdf

[USEPA] US Environmental Protection Agency. 2014. Wetland mitigation banking fact sheet. [cited 2014 June 4]. Available from: http://water.epa.gov/lawsregs/guidance/wetlands/mitbanking.cfm

Wagner AM, Larson DL, DalSoglio JA, Harris JA, Labus P, Rosi-Marshall EJ, Skrabis KE. 2016. A framework for establishing restoration goals for contaminated ecosystems. Integr Environ Assess Manag 12:264–272.

Whisenant SG. 1999. Repairing damaged wildlands: A process-oriented, landscape-scale approach. Cambridge (UK): Cambridge University Press. 328 p.

Wildlands. 2009. Hylebos Creek Estuarine Restoration Project case study. [cited 2014 June 4]. Available from: http://www.wildlandsinc.com/case_studies/hylebos-creek-estuarine-restoration-project/

Williams BK, Szaro RC, Shapiro CD. 2007. Adaptive management: The US Department of the Interior technical guide. Washington (DC): Adaptive Management Working Group, US Department of the Interior, Washington.

Wu L. 2004. Review of 15 years of research on ecotoxicology and remediation of land contaminated by agricultural drainage sediment rich in selenium. Ecotoxicol Environ Safe 57:257–269.