Natural Resource Damages and the Department of Energy: Integrating Ecosystem Recovery into the Remediation Process

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The United States and other developed countries are faced with restoring and managing degraded ecosystems. Degradation can include physical disruption (loss of habitat or changes in patch size), human disturbance, biological disruption (invasive species, diseases), or chemical/radiological exposures. Evaluating the relative effects of these stressors on ecological resources is the responsibility of managers, risk assessors, resource trustees, and ecologists (as well as economists). Evaluations of the degradation of ecological resources can be used for determining ecological risk, making remediation or restoration decisions, aiding stakeholders with future land decisions, and assessing natural resource damages. Department of Energy (DOE) lands provide a useful case study for developing a conceptual model for examining degradation of ecological resources in light of past pr present land uses and natural resource damage assessment (NRDA). We suggest that NRDA considerations should be incorporated into the cleanup and restoration phase to reduce the ultimate NRDA costs, and hasten resource recovery. While the formal NRDA legal determination of injuries is limited to damages for trust resources lost, injured or destroyed by chemical/radiological releases since 1980, the restoration and pre-assessment phase could incorporate ecosystem recovery as well as injuries due to these releases. For most DOE lands there were multiple releases, of multiple radionuclides and chemicals, over a wide geographical area, in contrast to a chemical or oil spill that usually has one release event at one site. The lands that DOE purchased for its mission over 50 years ago ranged from relatively undisturbed to heavily-impacted farmland. Thus the degree of impact (or injury) that occurred once DOE occupied these lands varied markedly from regeneration of natural ecosystems (a positive benefit) to increased exposure to several stressors (negative effects). During the time of the DOE releases, other changes occurred on the lands, including ecosystem recovery because of the removal of farming, grazing, and residential occupation, and the cessation of human disturbance. Thus, the injury to natural resources that occurred as a result of chemical and radiological releases occurred on top of ecosystem recovery. Both spatial (size and dispersion of patch types) and temporal (past/present/future land use and ecological condition) components are critical aspects of resource evaluation, restoration, and NRDA. For many DOE sites, integrating natural resource restoration with remediation to reduce or eliminate the need for NRDA could be a win-win situation for both responsible parties and natural resource trustees by eliminating costly NRDAs by both sides, restoring natural resources to a level that satisfies the trustees, while being cost-effective for the responsible parties. It requires integration of remediation, restoration, and end-state planning to a greater degree than is currently done at most DOE sites.

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# INTRODUCTION

The public, governmental agencies, and the private sector are interested in preserving, restoring, and managing ecosystems and their associated species. One type of land requiring environmental management is that contaminated by toxic chemicals and/or radionuclides. Cleanup and remediation of contaminated sites has been a national priority in the United States and elsewhere, within a framework of protecting humans and the environment, now and in the future (Crowley and Ahearne, 2003). Maintaining healthy ecosystems that can protect the well-being of organisms living within them, including humans, requires environmental planning and management. While there is general agreement that cleanup and remediation of contaminated sites is an important and urgent task (Crowley and Ahearne, 2003), there is less agreement about the strategy for such cleanup with respect to the role of risk to humans and the environment, and the impact of future land use(s) on cleanup decisions and goals (Burger *et al.*, 2004).

In the early 1980s the prevailing view was that contaminated sites should be cleaned up to residential standards and returned to productive uses, very loosely defined. Residential standards are set sufficiently low that there is no risk to adults and children living and working there. The paradigm used for assessing the risk to both human and ecological receptors includes problem formulation, hazard identification, dose-response, exposure assessment, and risk characterization (NRC, 1983, 1993). In the 1990s and early 2000s managers and policy-makers began to acknowledge cost and technological constraints, and that not all land must (or should) be used for residential purposes (Dale and Parr, 1997; Brown, 1998; Nelson 2001, Burger *et al*. 2003). Managers and policy-makers then faced a number of questions, including: 1) Can the Nation afford the complete treatment or removal of all contamination? 2) How much should future land uses influence cleanup standards? 3) What is the role of risk in determining cleanup standards and restoration goals, and in determining future land uses? 4) What are the damages to ecological resources and human health as a result of chemical/radiological contamination?, and 5) What is the role of the citizenry in influencing or making these decisions?

A number of protocols and paradigms have been developed separately or in combination that are useful for ecosystem management of contaminated lands, including 1) natural resource evaluation, 2) stressor (e.g. chemical/radiological) evaluation, 3) exposure assessment, 4) ecological risk assessment (partly a combination of 1 - 3), 5) natural resource damage assessment (NRDA), 6) remediation and restoration, and 6) stakeholder preferences and attitudes. While the similarities and differences in aims and scope of ecological risk assessment and NRDA were recognized early on (Lipton and Galbraith, 1992), the synergisms have not been explored sufficiently.

Natural Resource Damage Assessment (NRDA) is used to determine whether there have been injuries to natural resources and to calculate the costs necessary to restore (or replace) those resources (DOE, 1993a, 1997). Natural resources, under CERCLA (section 101 [16]), are defined as "land, fish, wildlife, biota, air, water, groundwater, drinking water supplies, and other such resources." An injury to a natural resource is a measurable adverse change in the chemical or physical quality or viability of that resource, and damages are assessed on the basis of loss or reduction in quantity and quality of natural resource services (DOE 1993b). Under CERCLA, natural resource damages may be recovered by federal and state trustees, and Tribal governments, for injury to natural resources caused by releases after 1980 (Trimmier and Smith, 1995). Under CERCLA, then, it is only the effects of releases after 1980 that are recoverable.

Trusteeship can be a daunting task, for example, the Secretary for the Department of the Interior acts as trustee for resources managed or protected by the Department, which includes 450 million acres (20 % of the United States, see Executive Order 12580, Deason and Taylor, 1998). Many NRDAs have also been conducted under the Oil Pollution Act (OPA) of 1990 (Austin, 1994; Burlington, 1999; Burlington, 2002), and the Clean Water Act (Sheehy and Vik, 2003). The federal government has uniform rules and procedures for assessing economic losses and injuries, developed by the U.S. Department of the Interior (charged with developing the rules for CERCLA), and the U.S. Department of Commerce for OPA (Deis and French, 1998; Ofiara, 2002).

This paper examines briefly the relationship between natural resource evaluation and NRDA, and then develops conceptual models for understanding ecological risk and recovery within a framework of pre-NRDA considerations for contaminated lands, using Department of Energy (DOE) sites as a case study. It takes a proactive approach of suggesting that restoration to reduce total NRDA liability should occur during the remediation phase, and should include considerations of both injury and benefits that accrued from DOE releases and activities, not solely with environmental degradation. At the very least, natural resources trustees should consider the positive benefits (i.e. ecosystem recovery) that occurred on several DOE sites during their tenure, as well as the injury from releases. Since in many cases the cost of conducting research to demonstrate injuries may exceed the expected value of the damages (Unsworth and Bishop, 1994), it may be prudent for responsible parties and natural resource trustees to work amicably to restore the resources during remediation with the endstate in mind, without resorting to damage claims in court. This may lead to restoration to more natural ecosystems than existed at the time of DOE land acquisition.

With the ending of the Cold War, the DOE and Department of Defense (DOD) redefined their mission to include environmental remediation and restoration, such as the protection of environmental resources and biodiversity (DOD, 2001; DOE, 1994a, 1994b; Lubbert and Chu, 2001). This mandate requires that they understand the current risk to ecosystems (and their component parts), the past damages their activities caused, and potential future damages that result from either remediation itself or DOEs continued activities and contamination. Efforts within DOE to incorporate NRDA liability with remediation and restoration under CERCLA began early, but were largely limited to thinking about specific releases (Sharples *et al.*, 1993; DOE, 1993, 1997).

## NATURAL RESOURCES ON DEPARTMENT OF ENERGY LANDS

During World War II and immediately thereafter, the U.S. Department of Energy and its antecedents obtained many tracts of land for the purpose of developing, producing, and testing nuclear weapons. The initial state of these lands varied from relatively undisturbed to extensive farming and grazing, with some residential and small towns. In some places small towns were moved or displaced. The haste and secrecy of establishing the DOE complex distracted public and regulatory attention from pollution and environmental quality, resulting in extensive releases and contamination, environmental degradation (including habitat loss and fragmentation), and storage of chemical and radioactive wastes. Beginning in the early 1980's, the DOE entered into a series of 'Tri-Party' compliance agreements with the U.S. Environmental Protection Agency and State agencies to cleanup contamination, in the absence of adequate data on the magnitude of contamination or the costs of cleanup.

Nuclear weapons production ended abruptly in 1989, and the DOE established an Office of Environmental Management (EM) to deal with the remediation tasks on their facilities (Sink and Frank, 1996; Daisey, 1998). DOE's EM mandates were largely driven by compliance with the Comprehensive Environmental Response and Liability Act (CERCLA), the Resource Conservation and Recovery Act (RCRA), and the triparty compliance agreements, which dictated the most extensive cleanup possible. The regulatory authority for the sites varies across the complex; some sites are under RCRA or CERCLA, others are under the AEA, and all are subject to regulations of federal Environmental Protection Agency, NRC, appropriate state agencies, and in some cases, tribal Nations.

Protecting ecological resources or ecosystem health was not initially part of the process, even though DOE lands were extensive and ecologically valuable (Dale and Parr, 1997; Brown, 1998; Burger *et al.* 2003). Initial cost estimates for cleanup were astronomical (DOE, 1995; Frisch *et al.*, 1998), worker health and safety risks were great, and suitable technologies for safe, permanent, and cost-effective remediation were not available. This led DOE to develop a risk-based approach to cleanup and future land use (DOE, 1996; Geiser, 2003). Nelson (2001) and Burger *et al.* (2003) suggested that the need to assure long-term protection of human health, cultural values, and high levels of biodiversity and ecological integrity that currently exist at many DOE sites may lead to their protection as ecological reserves.

Because of DOE activities over a half-century period, their lands have experienced a range of stressors, including physical disruption, human disturbance, and chemical/radiological exposure. While the nature of physical disruption and human disturbance on DOE sites is not fundamentally different from other degraded ecosystems, the degree and type of chemical/radiological contamination on DOE sites is distinctive. DOE sites have highly toxic, and long-lived radiological wastes, both in storage facilities and as surface and groundwater contamination. This results in limitations on the types of remediation that are possible, high remediation costs, and long-term care of wastes where remediation costs are prohibitive, transportation is difficult, or technology does not currently exist to remediate. Further, DOE is different from most contaminated sites in that large sites have multiple ecosystem or habitat types, and have experienced multiple stressors (radionuclides, chemicals, physical disruption, human disturbance, habitat loss).

DOE's stewardship program was announced in 1994 (DOE Order 430.1), with the goal of achieving sustainable development through ecosystem management, including management of its lands as valuable national resources (Malone, 1998). The order included integrating economic, ecological, social and cultural factors into land use (and facility) decisions. Many of the most contaminated sites have already taken steps to implement the DOE's policy on long-term stewardship, sustaining both DOE missions and natural resource protection through comprehensive resource management (Malone, 1998). The ecological importance of seven of the largest DOE sites has been recognized through their designation as National

Environmental Research Parks (NERPs, DOE, 1994a, 1994b).

Thorny issues resulting from the DOE Cold War legacy include determining levels, methods, and time frames for remediation and restoration, assessing natural resource damages from DOE's activities, and determining future land use(s) within the framework of what is legally, logistically, and economically feasible. Additionally the preferences of stakeholders is a critical factor (Shaw 1997).

## MELDING REMEDIATION, NATURAL RESOURCE EVALUATION AND NATURAL RESOURCE DAMAGE ASSESSMENT

NRDA is the process whereby natural resource trustees can assess damages for injuries to natural resources, recover costs of these damages, and restore, replace or acquire the equivalent of the damaged resources (or compensate for lost services, Helvey, 1991; Sheehy and Vik, 2003). Assessing resource damage must involve resource evaluation, which is a complex task that includes examining ecological resources with respect to species, habitats and ecosystem functioning (Table 1), and at several levels of biological complexity (see Table 2). Investigations to document injury usually involve field observations and data collection, although laboratory-generated models to predict injury to biological systems have been developed (Grigalunas *et al.*, 1988). For ecological resource metrics, response time is critical (Barnthouse and Stahl, 2002). That is, molecular and cellular responses occur within minutes or days, while ecosystem changes occur over time spans of years and decades. The flip-side of this is that ecosystem recovery also can take years and decades. For example, following vessel groundings in seagrass beds in the Florida Keys recovery may take up to 60 years (Fonseca *et al.*, 2004). These temporal responses must be accounted for in NRDA. For example, death of individuals may take only days to weeks, while changes in productivity and food web relationships may be apparent only years or decades after the release.

To some extent the parameters examined in Table 1, especially those dealing with species and habitats, are mandated by laws and regulations, and are a necessary first step for NRDA. For example, both state and federal law (Endangered Species Act) requires protection of threatened and endangered species, and identifying the species and populations of such species is essential to their protection. Table 2 indicates some of the metrics that can be used to assess ecological resources at different levels of biological organization, and how they might be used for management or NRDA. While such a complete evaluation of ecological resources is usually not feasible for any given site, managers and resource trustees can select a suite of metrics appropriate for local resources, including endangered and threatened species, species or species groups of special concern, and endangered or rare habitats (see Burger, 2005a). In many cases, sufficient time may not be available for primary research on ecological resources (Unsworth and Bishop, 1994).

Cataloguing and evaluating ecological resources currently on site is integral to ecological risk (determining the potential risk to the resources from proposed management, such as remediation and restoration) and to NRDA (evaluating the effects of chemical/radiological releases). Although both risk assessment and NRDA focus on negative impacts (injury, Trimmier and Smith, 1995), we suggest that a shift in our thinking is necessary to include assessment of both the positive and negative aspects of any management practice or stressor. This is particularly true when the stressor (or releases) occurred over a long period of time (as at DOE and DOD sites).

While assessing and evaluating ecological resources provides a baseline for future risk assessments and future natural resource damage assessments, the importance of having biological information prior to a release (such as an oil spill, chemical spill, or remediation) cannot be overestimated (Menell and Stewart, 1994; Burlington, 2002). Although pre-release information for a given locale may not be available, there are other ways to assess both ecological risk and resource damages. Finding massive dieoffs of birds or mammals following an oil spill, for example, provides one measure of resource damages (see Anderson, 1982; Burger, 1994, 1997; McCayl, 2003). Further, it is sometimes possible to conduct studies immediately following a release (before the chemical or oil has spread to the area ultimately affected), and compare these findings with those a few months later when the entire ecosystem has been affected (see Shaw and Bader, 1996). There are two other recognized methods of evaluating natural resource damages and for ecological risk assessment: 1) comparing the resources (or attributes of the resources) in the affected area with similar, adjacent areas, and 2) selecting a similar habitat (with similar species composition) as a reference site. For example, metrics such as numbers of individuals, numbers of ill or deformed individuals, maturation rates, and growth rates in the affected area can be compared with these characteristics of species in adjacent areas or reference sites. Leaving aside the question of valuation of the lost or damaged resources, ecologists can describe and quantify the level of degradation. That is, the first step for both ecological risk assessment and NRDA is a comparison of current ecological resources (qualitative and quantitative) with a baseline for the same region, with similar adjacent habitats, or with a reference site. The second step for natural resource damage assessment is quantifying temporal changes in the resource (or the individuals or populations within that habitat) following the release or other stressor (or management action).

In the last two decades NRDA has usually involved evaluating damages following a catastrophic or acute event, such as an oil or chemical spill (Miller, 1994; Burger 1994, 1997; Wooley 2002; McCayl 2003;). In these cases, the resource assessment is primarily examining negative effects. However, evaluating resource responses to other stressors, such as physical disruptions and habitat changes is more difficult, and has not been a focus for resource managers. DOE, DOD, and some large Superfund sites, however, provide examples where disruptions can have both positive and negative effects, and the magnitude of these effects often depends upon the date selected for a baseline. We argue that the presumption of injury following a release (or other stressor) is narrow, and NRDA considerations should be broadened to include positive as well as negative effects. The argument revolves around the temporal placement of the baseline, and the inclusion of positive benefits that derive from the activities of the party responsible for the releases.

Finally, it should be mentioned that the assumption that releases or injuries are occurring on pristine environments or wilderness areas bears examination, even for the most remote areas. For example, Wooley (2002) recently suggested that even the Valdez oil spill in Prince William Sound did not occur in a pristine wilderness, but one impacted by fur traders, commercial whalers, commercial fishermen, miners, loggers, fox farmers, and military construction crews. The same can be said for many of the DOE sites considered "pristine."

In this section the evaluation of damages to natural resources was discussed from the standpoint of ecosystem structure and function. However, NRDA are often calculated in human terms as the loss of specific services, such as decreased catch rates of fish following releases of wastes (Iadanza *et al.*, 1999; Morey *et al.*, 2002), loss of drinking water because of oil spills (Clark *et al.*, 1990), and loss of groundwater for residential, industrial or commercial use (Dunford 2000). These ecological services are often valued in terms of replacement costs, willingness to pay, willingness to accept compensation (Brown and Gregory, 1999; Dunford *et al.*, 2003), demand functions (Dunford, 2000), contingency valuation (Montesinos, 1999; Dunford, 2000), and existence values (McConnell, 1997). Recoverable sums often equal restoration costs, plus compensable values and reasonable assessment costs (Ofiara, 2002).

## DOE AND LAND TRANSFER WITHOUT FORMAL NRDA

When the DOE (and its antecedents) obtained land in the 1940's and 1950's to develop the United States' secret nuclear mission, it took large tracts of lands both to maintain secrecy and security, and to preclude having to worry about contaminants going 'offsite'. Very large buffer zones were preserved around some of the largest industrial facilities. At some of the large DOE sites, 80-90 % of the land is largely uncontaminated (Burger *et al.* 2003), even though it is adjacent to highly contaminated land. The buffers created around DOE and DOD sites have provided long-term habitat protection for many rare plants and animals, as well as preserving large, intact ecosystems (Mann *et al.*, 1996; Dale and Parr, 1997; Brown, 1998; Burger *et al.,* 2003a, b). Thus, an unexpected benefit of the secrecy and restricted access the DOE maintained for over 50 years has been the protection of a wide range of ecological and cultural resources in these buffer areas around the industrial sites devoted to nuclear weapons production (DOE, 1994a). As human populations have increased around the DOE sites, and agricultural use intensified, some of these DOE buffer zones have the highest biodiversity remaining in their regions. Should these sites be fragmented, potential losses in valuable ecosystems will be borne by the entire Nation as well as local residents and Tribal Nations (Dale and Parr, 1997; Brown, 1998; Burger, 2002; Burger *et al.*, 2003).

Over the last decade Natural Resource Damage Assessment (NRDA) has risen to the fore at the DOE (DOE, 1993a, 1997) as lands on some sites have been turned over to other natural resource agencies. For example, Rocky Flats is in transition to the U.S. Fish & Wildlife Service. There are other DOE examples that can serve as models where ecological resources on site were recognized, although formal NRDA were not conducted. These include the transfer of the Crackerneck portion of the Savannah River Site to management by South Carolina, and the transfer of some lands at Oak Ridge (Tennessee) to local ownership and management. Fernald, a site close to closure, is largely being converted to a undeveloped park or wildlife refuge.

Other DOE sites have lands that are already recognized as ecologically valuable. At Brookhaven National Laboratory (Long Island, New York) there are rare pine barrens ecosystems that could be transferred to adjacent pine barrens preserves; an ecological preserve has already been established on part of the site. Some of the land at the Idaho National Engineering and Environmental Laboratory represents the only pristine shrub-steppe land in the region, and could be converted to a shrub-steppe ecological preserve (DOE, 1996b). Uncontaminated buffer lands not necessary for the future mission of DOE's Los Alamos National Laboratory (New Mexico) could be transferred to the National Park Service that operates Bandolier National Monument which abuts much of the DOE site.

These examples illustrate the ecological importance of DOE lands, and to some extent, are defacto acknowledgment of the positive aspects of DOE ownership. These positive benefits could offset the usual negative aspects or injuries considered under NRDA, or at least during the pre-assessment phase of establishing restoration goals and endstates for the land. That is, although there are injuries on DOE lands that resulted from their chemical/radiological releases, the positive benefits of environmental protection (including the exclusion of the public from some of these lands for over 50 years) bears consideration in DOEs discussions with their natural resource trustees concerning remediation and end state planning. There is precedent for reducing the NRDA liability of the responsible party that include "actions taken by the responsible party that reduce environmental injury," (Geselbracht and Logan, 1992, p. 167); surely habitat recovery as a result of DOE activities might be considered in this vein.

## INCORPORATING NRDA IN DOE REMEDIATION/RESTORATION

NRDA at DOE sites normally includes injuries to natural resources that occurred as a result of their activities (DOE, 1993a). One key element, however, is a definition of the baseline, and the date of that baseline (Fig. 1). While in CERCLA it is legally mandated as 1980 for formal NRDA, we suggest a consideration of a range of baselines for the purposes of integrating NRDA with remediation. For example, at SRS, much of the land pre-DOE was farmed, and was of relatively low ecological value. However, when DOE purchased the land, a large percentage was left as a buffer and ecosystem recovery occurred. Although one could argue that complete recovery did not occur because of contamination on some parts of the forest ecosystem (dotted line on Fig. 2), this injury is relatively small compared to the degree of recovery from its previous state of farmland. Remediation, if it involves physical disruption or soil removal, involves additional natural resource injury, and would require additional time for ecosystem recovery (if the land were designated for wilderness or forests).

There are a wide range of possibilities for resource damages following disruption due to occupation by DOE, DOD, and other facilities with chemical and radiological wastes. If the site had been forests, then the degradations would be largely negative. However, if the ecosystem had been farmland, then the ecosystem following, for example, DOE occupation might have been improved because of the cessation of human activities and disturbances. Thus, we argue that the resource damages due to chemical/radiological releases occurred on top of ecosystem enhancement.

The approach we advocate is a landscape approach: integrating natural resource restoration during the remediation/restoration phase, taking into account both the positive and negative effects of DOE activities in light of pre- and post-DOE occupation. There are landscape metrics for examining some of these larger aspects of ecosystem damage and recovery. Bartell et al. (2002) used aerial photography and maps to examine land use on one part of SRS pre-DOE (1943) and in 1994 (when aerial photography was available). They found that the amount of forest rose significantly even on some of the SRS units with buildings, and the amount of cleared land (farming in 1943) declined from nearly 80 % to zero (Fig. 3). When the whole SRS site is considered, nearly 90 % of the site is currently forested or has other functioning ecosystems (Burger *et al.* 2003). Since this site was largely farmed prior to DOE occupation, there were few remaining undisturbed ecosystems on site. However, once DOE arrived and developed security and buffer zones, these degraded ecosystems underwent natural succession to forest ecosystems. Thus, there are landscape metrics for examining these large-scale, landscape effects of DOE occupation.

Another example will illustrate the use of this methodology. The relative amount of forest on some of the Oak Ridge units remained the same during DOE's occupation (Fig. 3, Bartell *et al.*, 2002). That is, the continued activities during this time did not result in a decrease in the amount of functioning ecosystems. These two examples illustrate that landscape methods can be used to examine overall land use within a context of NRDA to examine the following questions: Has the amount of specific natural ecosystems (such as forest, shrub-steppe) changed with the arrival of DOE? Have the activities of DOE during its tenure increased or decreased the amount of natural ecosystems? Has there been a change in the relative percent of particular ecosystem types (forest vs gassland vs wetlands)? and finally, What is the effect of remediation (and different types and degrees of remediation) on ecosystem types?

## DISCUSSION

NRDA under existing law (OPA, CERCLA, CWA) provides for the recovery of damages to natural resources, due to injury from releases since 1980. It has generally been applied to the acute release of chemicals and oil (Anderson, 1982; Burger, 1994, 1997; Austin, 1994; Burlington, 1999; Burlington, 2002; Penn and Tomasi, 2002, McCayl, 2003; Sheehy and Vik, 2003, among others), although it has been used for chronic exposure from chemical releases (see Sharples *et al.*, 1993; Brosnan *et al.*, 2002). It has proven easier to develop natural resource damage assessment restoration plans for ecosystems with multiple chemicals, multiple release sites, and multiple receptors (Lantor and Qlark, 1999) than to assign damages to the responsible parties. An apparent presumption of NRDA is that the release (or other stressor) caused injury, which requires compensation to restore, replace, or acquire the equivalent resource (Helvey, 1991; Sheehy and Vik, 2003).

NRDA thus requires evaluation of ecological resources, which can be completed either with field work aimed at collecting injury data using a variety of metrics (refer back to tables 1 and 2) or by using computer models (Grigalunas *et al.*, 1988). To some extent, the same types of data can be used for ecological risk assessment (assessing potential future damage, or retrospectively), restoring natural resources while doing remediation, and for NRDA. However, the processes are not the same since risk assessments can be used for a variety of purposes (deciding whether to develop or otherwise change land use, to determine possible future land use, to predict the effect of a particular activity or release), while NRDAs aim is to determine compensation for the purposes of restoring, replacing, or acquiring equivalent resources.

This paper suggests that NRDA considerations should inform remediation/restoration, and be integrated into the process, rather than applied following the ceasation of all remediation. That is, instead of focusing attention on formal NRDA after the completion of remediation, both the trustees and DOE (not to mention the resources themselves) would benefit from incorporating the restoration of damaged resources to the satisfaction of natural resource trustees at the time of remedation. This could then focus the collection of ecological data in the pre-remediation and restoration phase to those aspects of natural resource damages that are deemed important by the resource trustees. Further, attention could focus on those resources that might be amenable to restoration, and are of interest to the public.

We suggest that the pre-NRDA phase for DOE, including decisions about remediation/restoration, should include the positive benefits of their activities, along with injuries. Natural resource injury on DOE lands, and other entities with large and complex ecosystems, differs fundamentally from many CERCLA and OPA situations where there is a single release of one contaminant (or in rare cases, mixtures). For most DOE lands there were multiple releases, of multiple radionuclides and chemicals, over years or decades. In some cases, multiple agencies were responsible for releases and subsequent damages, making the assignment of monetary damages difficult. Further, most DOE sites have multiple release sites over a wide geographical area, in contrast to a chemical spill or oil spill that usually has one release site.

During the time of the DOE releases, other changes occurred on the lands, including natural ecosystem recovery because of the removal of farming, grazing, and residential occupation, and the cessation of human disturbance. Thus, the injury to natural resources that occurred as a result of chemical and radiological releases occurred on top of ecosystem recovery. In the example given above, the roughly 80% of the Savannah River Site that had been in farms prior to DOE occupation, reverted to nearly 90 % forest ecosystem during DOE operations (and remains so today). Without DOE there would have been few species (and species assemblages) of concern to be impacted by chemical/radiological releases. That is, without DOE the conditions would not have existed to have the magnitude of natural resource injury to ecological receptors that exists today (except on a limited basis).

In essence, DOE allowed succession to occur naturally on its buffer lands, thereby creating conditions whereby species and their associated ecosystem were exposed to radionuclides and contaminants, accruing injury. While DOE should clearly be held liable for these latter injuries, we suggest this liability should be placed within a framework of the value of ecosystem recovery. This applies, however, only to the sites (or parts of sites) where the natural ecosystems were degraded by prior land use (farming, grazing, residential, industrial), and where DOE allowed the land to revert to natural ecosystems. At the other end of the continuum, DOE bought land that was relatively undisturbed, and then their activities reduced suitable habitat as well as exposing organisms to radionuclides and other contaminants.

Finally, allowing DOE, DOD, and other large and ecologically complex Superfund sites to expand the pre-NRDA phase to include both the positive and negative effects of their activities in the injury determinations would allow the Nation to move forward with an effective, cost-effective remediation and restoration strategy for contaminated lands. In many cases, sites could then be restored to functioning ecosystems (forests, grasslands, scrublands), rather than to pre-DOE conditions (farmland, residential). In this scenario, degraded lands that have reverted to functioning and ecologically valuable ecosystems could be protected by DOE (or other federal entities) while reducing the overall costs to the Nations NRDA budget of costly remediation to standards for agriculture or farmland (Burger *et al.*, 2003). It is a win-win situation since valuable ecological resources would be preserved, and remediation/restoration costs would be reduced.


## ACKNOWLEDGMENTS

Over the years our thinking about the characterization of contaminated sites, ecological risk, and natural resource damage assessment has been influenced by S. Bartell, K. Campbell, M. Carletta, M. Greenberg, B. D. Goldstein, J. Clark, S. Handel, D. Kosson, H. Mayer, L. Niles, and A. Upton. We thank S. Shukla for help with the graphics. This research was funded by the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) through the Department of Energy (AI # DE-FC01-95EW55084, DE-FG 26-00NT 40938), by NIEHS ESO 5022, EPA, and New Jersey Endangered and NonGame Species Program. The results, conclusions and interpretations reported herein are the sole responsibility of the author, and should not in any way be interpreted as representing the views of the funding agencies.

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Table 1. Key ecological information needed for initial evaluation of resources. This is not meant as an exhaustive list, but as a starting point for sites. Within each category, the first one or two are the most important (after Burger, 2005a).

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Species
- Names of threatened/endangered species (both state/federal)
- Names of unique assemblages (i.e. neotropical bird migrants)
- Period of vulnerability (i.e. neotropical migrants, fall)
- Names of species of special concern (federal/state)
- Numbers of species groups (i.e., 65 resident birds)
- Lists of species groups of interest (i.e., list each species)
- Changes in population sizes of threatened/endangered species

Habitats
- Habitat diversity (number of different habitats, by acreage)
- Unique habitats (i.e. pine barrens)
- Habitats for endangered/threatened species
- Relationship of on- to off-site unique or rare habitats
- Preserves on- and off-site

Functioning
- Measures of productivity (i.e. biomass, or lumber logged)
- Number and extent of invasive species
- Changes in numbers or distribution of endangered species
- Temporal patterns of use of the site (by migrants)
- Information on aquifers and watersheds
- Predator/prey imbalances
- Competitor relationships and implications
- Delineation of types of functional ecoreceptors

Risk
- Availability of risk assessments (with citations)
- Results of risk assessments
- Results of Environmental Impact Statements
- Results of comparisons with Hazard Quotients[a]
- Toxicity factors (by species, age class or other host factors)
- Qualitative statements (i.e. woodpeckers declined by 80 %)

Intersection of Human/ecological
- Common pathways and routes of exposure
- Key recreational/cultural/religious/medicinal resources that are ecological in nature
- Degree of human disturbance by habitat type
- Interactions between threatened/endangered species and species of special concern with people

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a. Hazard Quotient is a comparison of an estimated chemical intact (dose) with a reference dose level below which adverse health effects are unlikely. Expressed as the ratio of the estimated intake to the reference dose (EPA 2004).

Table 2. Possible metrics of biological/ecological degradation at different biological levels of organization to ecological health (modified after Burger and Gochfeld 2004b, Burger 2005b, and unpublished). These metrics can be used for ecological risk assessment (current or future risk), natural resource damage assessment (past damage), and as a measure of the efficacy of remediation/restoration. Although designed for ecoreceptors, some of the individual and population metrics can be applied to humans.

| Ecological Level | Type of Metric | Ecological Health |
|---|---|---|
| Individual | Contaminant levels of concern<br>Lesions<br>Disease<br>Tumors<br>Infertility<br>Size<br>Growth<br>Longevity<br>Reproduction<br>Age of reproduction<br>Health of endangered species | Used to evaluate health of individuals;<br><br>For evaluation of risk to higher-level consumers;<br><br>As an indicator of health of its foods, including prey. |
| Population | Population levels, especially of endangered or threatened species<br>Reproductive rates<br>Growth rates<br>Survival rates<br>Infertility rates<br>Average longevity<br>Movements<br>Biomass<br>Energy flow<br>Percent males vs females<br>Relationship among age and size classes | Used to evaluate health of populations of species, particularly endangered or threatened species;<br><br>For comparison among populations;<br><br>For temporal comparisons. |

| | | |
|---|---|---|
| Community | Species present<br>Foraging guilds<br>Breeding guilds (groups of related species)<br>Nesting guilds<br>Migratory guilds<br><br>Predator-prey interactions<br>Competitive interactions<br>Commensal interactions<br>Cascading effects | Measures health of species using the same niche, such as colonial birds nesting in a colony, or foraging animals such as dolphins and tuna;<br><br>Indicates relationship among different species within guilds or assemblages;<br><br>For spatial and temporal comparisons;<br><br>For evaluating efficacy of management, remediation and restoration options. |
| Ecosystem | Species diversity<br>Species richness<br>Species present<br>Decomposition rates<br>Erosion rates<br>Primary productivity<br>Energy transfer<br>Physiognomy (structure of the system)<br>Nutrient flow<br>Contaminant flow and movement<br>Relationship among different trophic levels | Measures changes in relative presence of species, how fast nutrients and energy will become available, how fast nutrients in soil will no longer be available, how much photosynthesis is occurring;<br><br>Examines overall structure of the ecosystem in terms of the relationships among trophic levels;<br><br>For evaluating efficacy of management options. |

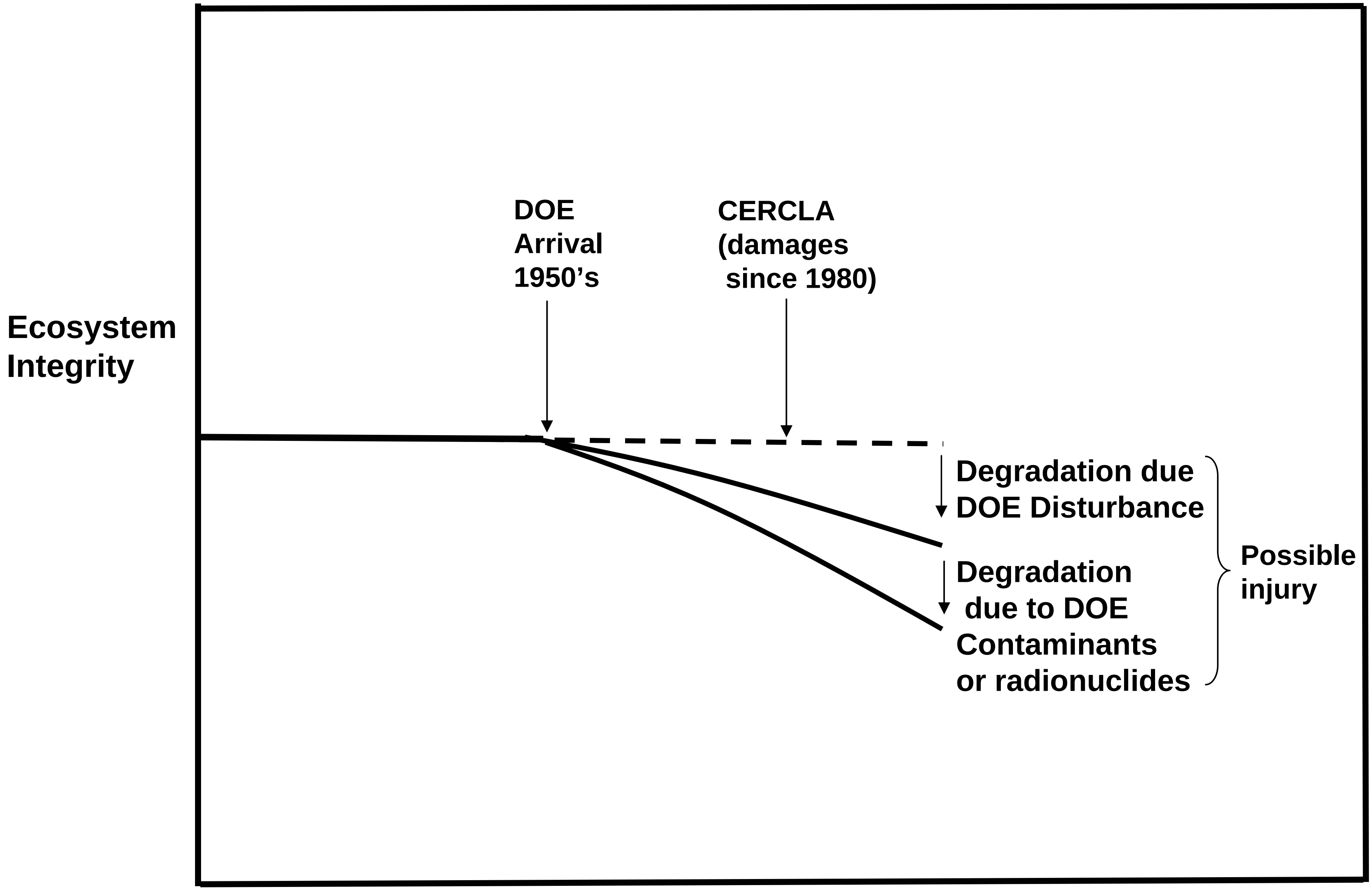
| | | |
|---|---|---|
| Landscape | Total amounts of different habitat types<br>Relative amounts of different habitats<br>Patch size and configuration<br>Patch dispersion<br>Corridors between habitat types or different ecosystems | Measures dispersion of different habitat types, indicates relative species diversity values;<br><br>Measures the among different habitats;<br><br>Measures distribution of corridors and refugias within the landscape;<br><br>Also can measure the relationship between development and natural areas;<br><br>For evaluating the importance of specific ecosystems within the landscape. |

Figure Legends

1. Schemmatic of the degradation on DOE lands and other contaminated sites. The degradation due to physical disturbances is allowable under NRDA because it was a permitted activity.

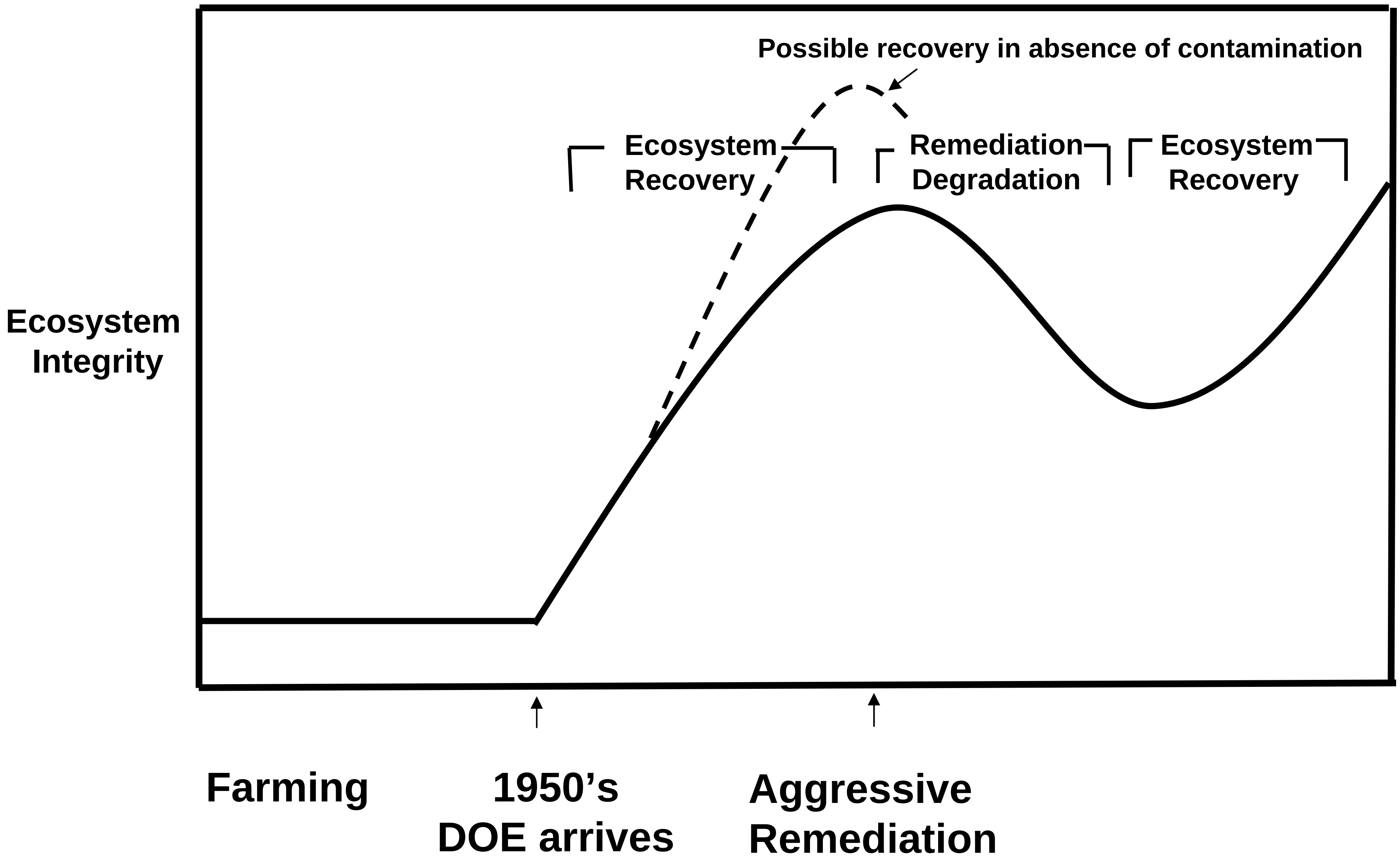
2. Possible changes in ecosystem integrity from farming through DOE occupation to remediation/restoration.

3. Broad ecosystem changes at facility C on the Savannah River Site in 1943 and 1994, and lack of ecosystem changes at the Y-2 plant of Oak Ridge during its occupation showing lack of change (after Bartell et al. 2002).



Ecosystem
Integrity
DOE
Arrival
1950’s
CERCLA
(damages
since 1980)
Degradation due
DOE Disturbance
Degradation
due to DOE
Contaminants
or radionuclides
Possible
injury


Fig 1



Possible recovery in absence of contamination
Ecosystem Recovery
Remediation Degradation
Ecosystem Recovery
Ecosystem Integrity
Farming
1950's DOE arrives
Aggressive Remediation


Fig 2

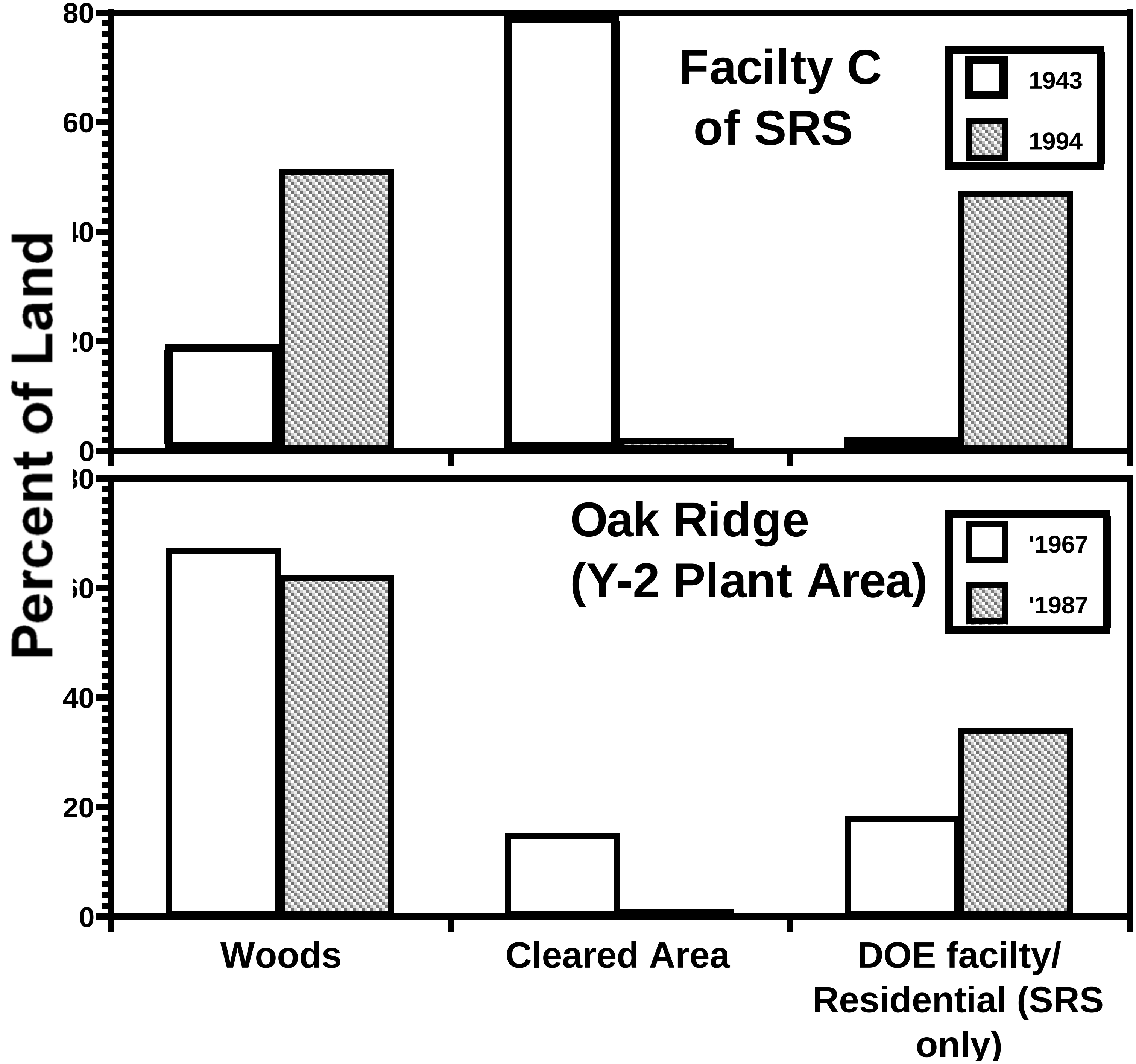

Facilty C
of SRS
1943
1994
Oak Ridge
(Y-2 Plant Area)
'1967
'1987
Percent of Land
80
60
40
20
0
Woods
Cleared Area
DOE facilty/
Residential (SRS
only)

Fig 3