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Simplifying Risk Assessment and Management for Communication with Stakeholders: Two Case Studies from the Department of Energy

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ABSTRACT

Understanding and managing ecological resources to protect human health and the environment requires appropriate assessment tools and on-going monitoring and adaptive management. While formal risk assessment protocols for examining human and ecological health are a central part of environmental management, we propose that a simpler four-tiered approach may allow more communication and collaboration among diverse stakeholders. Our protocol suggests that there are four main aspects of environmental evaluations that can increase such collaboration: 1) include all stakeholders throughout the process, 2) consensus among stakeholders on the problem or issue and a path forward, 3) data acquisition and analysis to address data and knowledge gaps, and 4) consensus on a solution based on sound science and stakeholder collaboration at every stage. Environmental indicators form the basis of data acquisition, and we present two case studies to illustrate this process: 1) closing the Department of Energy's (DOE) Amchitka Island where three underground nuclear tests were conducted (1965-1971) and 2) developing an ecosystem indicator that can be used across eco-regions to evaluate ecological resources. In the former case, the process involved extensive stakeholder involvement at all stages, while in the latter case, there was a general need for a screening tool (an indicator) for evaluating ecological resources on diverse DOE sites across the U.S. In both cases the general approach used the four main aspects of environmental evaluation to demonstrate its usefulness as a tool for collaboration among a variety of governmental and non-governmental stakeholders.

1. INTRODUCTION

Increasing human populations worldwide, development, and climate change have placed increasing demands on land for residences, recreation, agriculture, and businesses, as well as the need to preserve some relatively wild ecological lands. The latter is important not only to provide goods and services people require, but the provision of health, social, and cultural benefits [1]. For example, the presence of green spaces has both indirect and direct benefits on human mental health, cardiovascular health, and the reduction of mortality [2]. Ensuring sufficient wild lands can occur by preserving protected land that currently exists, allowing disturbed or contaminated land to revert to the local climax community, or restoring degraded land. A climax community refers to the dominant vegetation type (or ecological land cover) that would exist in a place based on its topography, climate, and geological conditions [3, 4]. For example, the climax vegetation in the northeastern United States is deciduous forest, while that in the southeast is coniferous forest, and in the southwestern U.S., the climax vegetation is desert that has some cactus and other small vegetation [5]. All these methods of ensuring sufficient wild, protected ecological lands require considerable stakeholder involvement throughout the process of determining land use, resolving conflicts over land use, and preserving or protecting the preferred land use [6-8]. By stakeholders we mean everyone who is interested and affected by decisions or actions (or inactions) about an issue or place. This includes US federal and Tribal governmental agencies and personnel, non-governmental agencies, and a full range of individuals or groups including neighboring communities.

Whenever an issue or problem arises, or a solution is determined and implemented, it is customary to formulate or define the problem and determine a path forward. In the U.S., the National Research Council [9-12] and the Environmental Protection Agency [13-16] developed methods and a formal approach to ecological evaluations. These formal approaches, however, are rigorous risk assessments for which data may not be available, funds may not exist to collect or analyze needed data, and the process and outcomes may not be readily available to the public. Further, some aspects may not lend themselves to an understanding of the overall problem and issues leading to a path forward. That is, some stakeholders may want a more consistent, transparent approach to a complex problem in a readily accessible format that allows their collaboration in ecological management or conservation.

In this paper, a simplified method of considering solutions to ecological or environmental management issues is presented that allows both transparency and communication among stakeholders. This method does not replace formal risk assessments but allows a holistic communication process that can be compared among sites. We use two case studies from the U.S. Department of Energy (DOE) to illustrate the commonalities of this approach that include: 1) involving stakeholders at all stages, 2) determining key issues or problems,3) obtaining relevant data and performing necessary analyses, and 4) consensus building and agreeing on actions or data gaps that inform a management path forward.

The DOE case studies examined in this paper are 1) Amchitka Island, Alaska (now a DOE Legacy Management site) and 2) several DOE sites with continuing remediation and cleanup. The cases differ in that the first case involves in-depth solutions at one site that led to closure, while the second involves examining ecological risk across former or current DOE-Environmental Management Sites (DOE-EM). At Amchitka Island, the DOE conducted underground nuclear tests in the 1965-1971 period [17]. Around 2000 DOE-Environmental Management announced its intention to “close” the site and transfer it to Legacy Management. Much of the site is now a U.S. National Wildlife Refuge. The issues included whether there was potential exposure to radiation and whether the foods (both commercial and subsistence) from the area were safe, and whether organisms on the food chain had levels of radionuclides above any adverse effects levels. Aleuts were one of the major concerns because they rely on subsistence foods to eat [17]. There was a lack of data and a need to resolve differences in views of the potential risks from radionuclide contamination in the environment, including both risks to people and to biota. State and Tribal governments and the Fish and Wildlife Service (US F&WS) and the Public had a stake in the outcome. A Science Plan was approved by all stakeholders, and data were obtained, interpreted, and reported to all groups. In this case, resolution was achieved illustrating the ability to derive a holistic path forward agreed upon by federal, Tribal, and state agencies, and the public despite the complexities of the site.

The second case involves considering a method to compare overall ecological health among several DOE-EM sites using climax vegetation; the case allows comparison among such diverse habitats as forest, grasslands, and deserts. In this case, DOE, State agencies, local Tribes, and others were interested in whether DOE had succeeded in protecting human health and the environment through extensive cleanup and containment of radioactive waste. It became apparent that DOE had preserved more of the local climax vegetation than occurs in the surrounding regions; hence some DOE sites had become valuable ecologic resources. While remediation continues, the issue is how to compare vegetation (and thus ecological communities) on sites with habitats in the surrounding region, and how to compare habitats among DOE sites. The project is on-going and iterative [7, 8].

The U.S. Department of Energy continues to make progress toward meeting cleanup goals on their sites, while protecting human health and the environment [18]. DOE has one of the largest cleanup tasks in the world [18, 19]. Some of the cleanup projects will require at least another 50 years to complete [20, 21]. However, decisions on the final land use and disposition for DOE legacy sites may be delayed for decades, and it is important to develop transparent and consistent tools to assess the risks to both humans and the environment [20]. There is a reciprocal relationship between cleanup goals and future land use, as well as the extent of cleanups allowing residential use of some sites, industrial use of others, and perhaps no use at some [22]. On the large DOE sites, such as Oak Ridge Reservation, Los Alamos, and Hanford Site, only about 10% of the land was industrialized, and the rest was left to serve as a security buffer [23, 24] and allowed to undergo natural succession.

The buffer lands around industrial facilities on some DOE sites have rare, threatened, and endangered species and unique ecosystems, as well as cultural resources that should remain undisturbed during remediation, and some should be protected or used for light recreation [25-28]. The U.S. Congress recognized the importance of ecological resources on DOE lands by designating some lands on large DOE sites as National Environmental Research Parks [29, 30]. This ecologically valuable security buffer land escaped development, had little hunting, and was allowed to revert to more natural ecosystems rich in plant and wildlife diversity [23]. This contrasted with rapid development in surrounding areas and communities. Thus, it is important to have tools, and appropriate communication information, to allow the full range of stakeholders to participate in remediation and future land use decisions. This paper provides case studies illustrating a way to simplify the traditional ecological risk assessment paradigm to be useful over the long-term to increase dialogue between governments, other organizations, and a wide range of publics.

2. GENERAL METHODS

Two different approaches were used in developing this paper: 1) extensive meetings with a full range of stakeholders leading to a plan and a solution (Amchitka), and 2) extensive analysis of DOE and contractor reports, and the published literature, with information from different federal and state agencies and the public to ascertain the need for an overall indicator of ecological resources that could be used to compare different DOE sites. For the Amchitka study in the Bering Sea (**Figure 1**), we used several meetings with DOE, U.S. Fish & Wildlife Service (USFWS), National Oceanographic and Atmospheric Administration (NOAA), State of Alaska Department of Environmental Conservation (DEC), the Aleut/Pribilof Island Association (APIA), and other stakeholders to develop and approve a comprehensive Science Plan. This plan included details of the expeditions needed for geologic assessment of the test sites as well as collection of foods consumed by Alaskan natives who might exploit waters around Amchitka. The plan was presented to four indigenous communities and modified by their recommendations. A novel component of the plan was to include Aleuts on the expedition to enhance the collection of foods. Subsequently, the information on radiological levels and risks was reported to all the above groups, including personnel returning to Aleut villages to report findings. Detailed methods for stakeholder involvement and management can be found in Burger [31, 32] and Burger *et al.* [33-37] and for radionuclide data collection and analysis in Burger and Gochfeld [38] and Burger *et al.* [39-41].

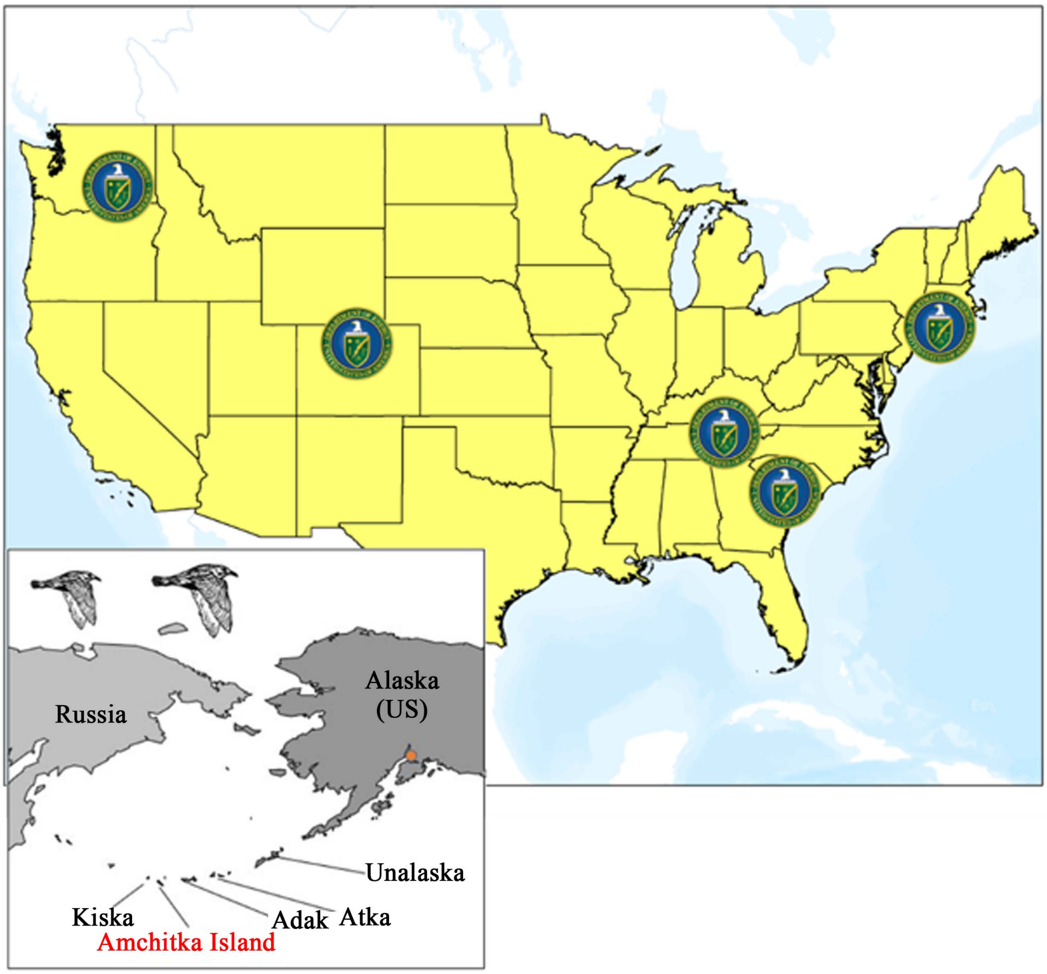

Figure 1. Location of the sites examined in this paper. Amchitka Island (case 1) is in the Bering Sea off the coast of Alaska, and the climax vegetation study was conducted at five DOE sites in the continental United States (case 2).

The second case study involved initial meetings with DOE and contractors, as well as review of published information to consider what was needed to allow stakeholders to evaluate the ecological resources on each of five major DOE sites. The sites for this study included Hanford Site (HS) in Washington, Savannah River Site (SRS) in South Carolina, Oak Ridge Reservation (ORR) in Tennessee, Rocky Flats (RF) in Colorado, and Brookhaven National Laboratory (BNL) in New York (See **Figure 1**; for individual sites [24]). Hanford Site's only mission is cleanup and continued protection from contamination on site. SRS, ORR, and BNL have continuing missions involving research and stewardship. Rocky Flats are closed. Our analysis of these sites indicated that each site had bioindicators of both health of individual species and contaminant levels in biota. Thus, we wanted to develop an indicator that could be used to compare ecotypes among DOE sites.

The National Land Cover Database [42, 43] was selected to examine and compare the climax vegetation on-site, off-site, and among sites. We determined the percentage of each land use/land cover on each site and on the surrounding regions (10 km, 30 km areas around each site). The NLCD is useful because it has data on land use for all regions of the continental U.S., and the data are gathered every few years, making it possible to use the data in the future to examine trends. The data are publicly available, so all stakeholders can address whatever question they wish. Additional information on these methods can be found in Burger *et al.* [44-48].

The approaches described in this paper were derived from the authors' work at several DOE-EM sites over the course of up to 30 years each. While we have participated in very detailed human and ecological health evaluations and assessments and are committed to these formal procedures, our condensation here allows the public and other stakeholders to have a common understanding of issues, data, outcomes, and solutions.

3. OVERALL APPROACH FOR CASE STUDIES

The approach we recommend includes: 1) stakeholder involvement, 2) issue or problem definition, 3) data collection and analysis, and 4) consensus building on future actions. From our perspective, identification of environmental issues or problems can be identified from governmental officials, Tribes, or members of the public. It is essential to involve all stakeholders at every stage in the development; trust is key to future acceptance [49, 50]. This involvement is particularly necessary in the identification of the issue phase – clear definitions will help. Definition of the problem should inform the development of a plan to collect (or collate) the necessary data. Collection of data and analysis often form the bulk of the inquiry and may take the most time; this phase may or may not include the full range of stakeholders. However, once data are assembled and agreed upon by stakeholders, a solution should be devised. In most cases, adaptive management (an iterative process) is required to monitor, maintain, and respond to new information. The following examples illustrate these steps.

4. RESULTS: AMCHITKA ISLAND

4.1. Stakeholders, Problem and Issues

The DOE has not monitored radioactivity on Amchitka Island or in biota around the site since the underground nuclear tests in 1965-1971, but they wished to close the site, turning it over to DOE's long-term Legacy Management (for periodic monitoring of radionuclides) and ultimately transferring ownership to the State of Alaska or USFWS. However, the State of Alaska, led by the Alaska Department of Environmental Conservation (ADEC) did not want to assume responsibility for Amchitka, fearing possible monumental cleanup costs. Transfer would have to wait until they were sure the environment around Amchitka was not contaminated with radionuclides, and food was safe both for the Aleuts living on nearby islands and for commercial fishery. The US F&WS was also concerned about contamination in the food web overall. These groups were not convinced by DOE's geophysical and human health risk models, nor were the other stakeholders, particularly the Aleuts who would gather sea food from the shore and offshore water [33, 47]. It was an issue of trust and needing to have current data on radionuclide levels in different nodes on the food chain. The dispute was resolved by the Governor of Alaska asking the Secretary of the DOE to have the Consortium for Risk Evaluation with Stakeholder Participation (CRESP) develop and implement a program to examine radionuclide levels and risks in the Amchitka Ecosystem [51]. CRESP is a multidisciplinary, multi-university group of scientists that has worked with DOE-EM on a variety of scientific and technical issues related to the legacy waste cleanup.

The CRESP approach was to write a Science Plan for Amchitka that included not only biological sampling and radionuclide analysis, but also geophysical characterization of the test sites. The biological Science Plan was aimed at providing the data needed to understand the risk from the viewpoint of consumers of marine organisms (Aleuts, other Alaskan citizens, commercial fisheries), and biota living in the environment on Amchitka Island and surrounding waters [34, 35]. From the beginning to the end of the Amchitka project, a broad range of stakeholders were involved (**Figure 2**). CRESP sought input from different agencies, as well as from Aleuts. Specifically, the Aleuts suggested adding some species to the protocol to reflect their interests and needs. Before the expedition (2004), we visited the Aleut villages to exchange ideas about the expedition with Tribal Aleut Elders and other Aleuts in their communities, as well as holding meetings with all the major stakeholder federal and state agencies [52]. Monitoring and long-term stewardship will continue on the island for the foreseeable future [53].

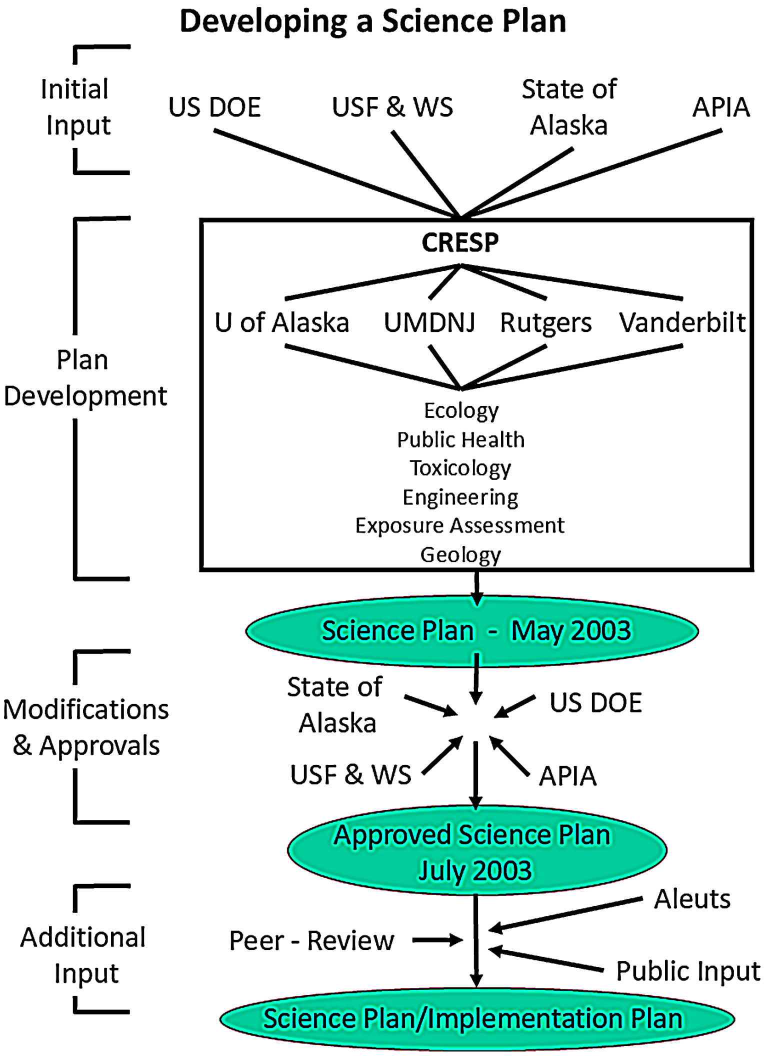

Figure 2. The initial Amchitka Science Plan developed and implemented to address both human health and ecological health issues and concerns (after Burger *et al.* [32, 33]). APIA = the Aleutian/Pribilof Islands Association; US F&WS—the United States Fish and Wildlife Service.

4.2. Data to Address Human Health and Ecological Concerns

The CRESP Science Plan laid out a marine and land-based plan to collect samples for radionuclide analysis from invertebrates, fish, and birds that represented different nodes on the food web, species of ecological concern, and species specifically requested by Aleuts, NOAA, and US F&WS [31]. We rented a 55-m fishing ship and retrofitted it for the month-long expedition; we had only limited (once/day or less) contact with anyone on shore. Without shore contact, we had limited options for rescue or evacuations if something happened to the land-based or diving crews. Because DOE detonated three underground nuclear test shots in different parts of Amchitka Island, samples were taken around each of these sites, and on Kiska Island (**Figure 1**) as a control. The sampling plan was designed and modified to include commercial species (algae, fish, and crabs), Aleut subsistence species (e.g., many species not commercially taken), and key species on the biota food web. At each sampling site, the land-based biological and diving teams collected samples along transects, while the Aleuts collected subsistence foods they normally eat and foods they would eat when stranded. Personnel included a team of four biologists from Rutgers University (New Jersey), four Aleuts from local villages (present on the vessel), and four divers from the University of Alaska.

Species collected were processed in the on-board laboratory at night to reduce the volume of material. All appropriate sampling procedures and chain of custody were followed and samples were placed in freezers. Large enough samples were taken to allow for radionuclide analyses and later mercury analyses, as well as for archiving [54, 55]. In the end, we collected samples from 4 algae species, 12 invertebrate species, 17 fish species, and 5 bird species (including eggs from two of these species). Composites consisted of samples from many different individuals of the same species. That is, for algae, fish, and birds, sample material from five individuals was combined to form one composite sample for analysis. For small invertebrates, material from many more individuals was required to make a composite sample. Samples were further processed at Rutgers University, and radionuclide analyses were completed at Vanderbilt University and Idaho National Laboratory.

4.3. Radionuclide Data and Analysis

The amount of sample material in composites was an important aspect of analysis for ^{137}Cs and actinides. Rather than present the values for each species, we grouped the species into different tropic levels: 1) primary producers (plants), 2) low tropic level grazers and filter feeders, 3) lower-level predators, 4) medium level predators, and 5) top trophic level predators. Because the radionuclide levels were so low or non-detectable, we present two types of data: percent of composites above the MDA (minimum detectable activity), and levels of radionuclides in samples that were above the MDA. Data on percentage above the MDA were provided. The percentage that was below the MDA indicates that for those species, there was likely no or little risk.

Table 1 provides the number of composites that were above the MDA, listing the number of composites analyzed and the number of species in each trophic level. That is, there were a total of 84 composites analyzed for primary producers for each radionuclide; primary producers included five algae species (Table 1). Some trophic levels had no samples above the MDA for a particular radionuclide, and others were 100% above the MDA. This information accomplishes two things: it shows which groups were not accumulating radionuclides and identifies species to use for biomonitoring. Several conclusions can be drawn from this

Table 1. Percentage of composites from Amchitka that were above the MDA as a function of species and isotopes examined in the Amchitka Study (1000 gr samples for ^{137}Cs, 100 gr samples for actinides, after Burger *et al.* [34, 38, 41]). Given is the mean percentage for each group, as well as the number of analyses and species in each group.

Trophic Level	No. Analysis/ Species	Species	^{137}Cs	^{241}Am	$^{239\text{-}249}$Pu	^{234}U	^{235}U	^{236}U	^{238}U
Primary producers	84/5	Algae	0	10	20	100	25	13	100
Grazers Filter feeders	38/6	Urchins, chitons, mussels	0	24	21	100	2	3	100
Lower predators	5/7	Fish, Eiders, and eggs	26	0	0	100	20	0	100
Medium predators	17/5	Some fish, Gulls and eggs, Puffins	38	12	12	18	12	0	24
Top trophic level predators	28/2	Halibut, Pacific Cod	62	<1	4	82	<1	0	86

Note: There were no composite samples with values above the MDA for any species for ^{129}I, ^{60}Co, ^{152}Eu, ^{90}Sr, and ^{90}Tc.

table regarding detection: 1) ^{137}Cs composites were below MDA for organisms low on the food web and were above MDA for organisms that were high on the food chain, 2) ^{234}U and ^{238}U were mainly above the MDA for organisms low on the food chain (*i.e.*, 100%) and low for medium and top-level predators, 3) ^{236}U had a low percent above the MDA for species low on the food chain (and none for top level predators), and 4) a low percentage of organisms had values above the MDAs for ^{241}Am and $^{239\text{-}249}$Pu (Table 1).

Examining both the percentage of samples above the MDA (shown in Table 1) and the mean values is useful in determining potential bioindicators for future monitoring. Algae (primary producers) and filter feeders had some actinide (U, Pu, Am) levels above the MDA, and the mean values for three of the species with the highest levels are shown in Table 2. Table 2 indicates that *Fucus* generally had the highest levels of actinides, meaning it would be a good bioindicator for future monitoring.

For high trophic level fish and birds, all the composites with values above the MDA for ^{137}Cs levels are shown in Table 3. The species shown in Table 3 are those within each trophic level that had the highest

Table 2. Comparison of mean actinide specific activity levels (Bq/kg) among lower trophic level organisms collected on the Amchitka Expedition. Values in parentheses mean that only one or two of the composites were above the MDAs. Values were significantly different (P > 0.01) for all but ^{241}Am [34, 40]. Such information is essential to assess human health risk but also to design a future biomonitoring program. The highest value for each actinide is highlighted.

Isotope	Algae *Fucus*	Algae (*Alaria fistulosa*)	Horse Mussel (*Modiolus madiolus*)
^{241}Am	0.01 ± 0.008	0.013 ± 0.006	0.016 ± 0.004
^{239,249}Pu	0.31 ± 0.017	0.051 ± 0.05	0.022 ± 0.011
^{234}U	3.124 ± 1.09	1.005 ± 0.557	0.844 ± 0.804
^{235}U	0.147 ± 0.052	0.052 ± 0.042	0.030 ± 0.048
^{236}U	(0.044)	(0.022, 0.016)	None
^{238}U	2.74 ± 0.953	0.906 ± 0.848	0.730 ± 0.646

Table 3. Levels of ^{137}Cs in fish and birds from the Amchitka Expedition that were above the MDA [41]. All the other fish that were analyzed did not have any composites above the MDA.

Species	Scientific name	No. composites below MDA	Values of composites above MDA (each value = 1 composite)[a]
Dolly Varden	*Salvelinus malma*	0	0.70, 0.78, 0.10
Yellow Irish Lord	*Hemilepidotus jordani*	2	0.13
Pacific Ocean Perch	*Sebastes alutus*	2	0.11
Black Rockfish	*Sebastes melanops*	0	0.19, 0.13, 0.11
Walleye Pollock	*Theragra chalcogramma*	1	0.46
Glaucous-winged Gull	*Larus glaucescens*	1	0.094
Pacific Halibut	*Hippoglossus stenolepis*	1	0.190, 0.315, 0.446
Pacific Cod	*Gadus macrocephalus*	7	0.176, 0.200, 0.209, 0.315, 0.323, 0.399, 0.602

[a] These values are what one might get if they ate a fish or bird above the MDA.

detectable values. The three high values for dolly varden were from composites collected from Lake Cannikin on Amchitka Island that formed right above the underground test blast. Pacific Cod is high because they are top level predators. **Figure 3** is a summary figure illustrating the percentage of composites above the MDA, the mean values for ^{137}Cs, the number of composites and number of individuals, and the maximum age of each species. In general, the higher the trophic level, the higher the specific activity of ^{137}CS (in Bq/kg). The values in **Table 3** are those a consumer might expect to get if they consumed that species at the higher range. For fish, larger fish generally have higher specific activities.

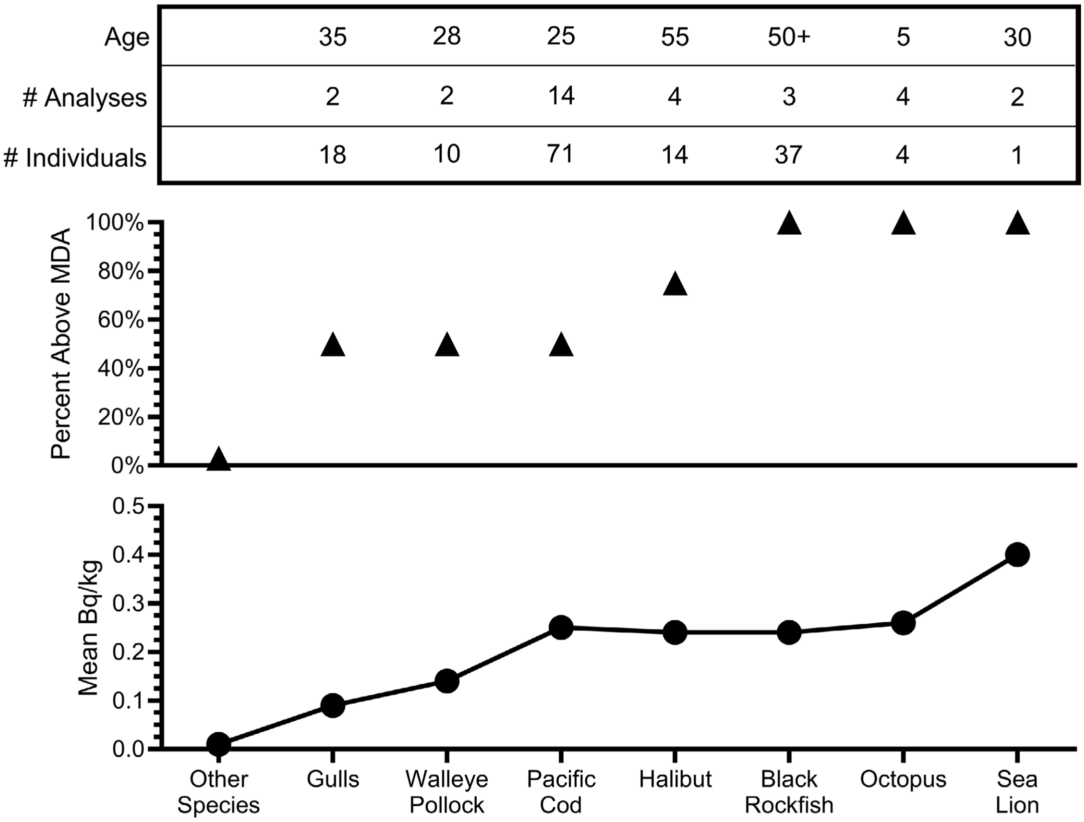

Figure 3. Percentage of samples above the MDA and the mean specific activity (Bq/kg) for key species collected at Amchitka Island. Also provided are the maximum age and number of composites analyzed (and individuals that made up those composites).

For most of the organisms sampled, the levels of radionuclides were below the MDA's, the levels were lower than established health standards, and they were lower than recorded in other oceanic locations in the northern hemisphere [38, 40, 41]. Some of the high trophic level fish had levels of mercury that are of concern, especially for pregnant women [54-58]. The information we provided allowed individual Aleuts to determine which invertebrates or fish to eat or to avoid eating because of contamination. Further, the source of mercury was atmospheric deposition, and not from DOE activities. The Aleuts, however, appreciated the information on both radionuclides and mercury [38, 54, 56, 58].

4.4. Solutions and the Future

Results for the analyses were presented to all the stakeholder groups in open, public meetings, including DOE, NOAA, US F&WS, ADEC, APIA, and the public. In addition, we re-visited Aleut villages. Communication and collaboration at every phase in the Amchitka Project led to openness, transparency, and acceptance of the data [34, 35, 37]. Two additions to the original Science Plan were very important to success:

1) including four Aleut hunters and fishers on the expedition itself and 2) the addition of a fisheries biologist on the NOAA research trawler. These two additions ensured that appropriate commercial and subsistence species were collected, as well as engendering trust in the data. Attitudes and perceptions related to the health risk from radionuclides among Aleuts, for example, indicated a significant decline in concern about radionuclide exposure [37].

Data from the expedition were used to propose a biomonitoring plan that included representative species at all levels on the food web and included key commercial and subsistence species [34]. The plan was to be implemented every 5 years, but an earthquake in the region should trigger an immediate census of a small set of biomonitoring species. If any radionuclides were detected, an immediate assessment of the species originally examined would be triggered. An examination of the radionuclide tables by DOE, Tribes, regulators, and different stakeholders in public meetings suggested that top-trophic level organisms were better indicators of ^{137}Cs exposure, while primary producers were generally the best for actinides overall. The results suggest that the primary producers should be examined with respect to the algae species of most concern for subsistence people, and fish and birds should be examined for ^{137}Cs. Once Amchitka Island was transferred from DOE-EM to long-term stewardship, our biomonitoring plan was implemented on a 5-year review cycle [53].

When we discussed the Science Plan with Aleuts on different Aleutian Islands, they were also quite concerned about mercury exposure, and we later analyzed mercury levels using non-DOE funds [54-57]. These results were reported back to the Aleuts when we returned to report on radionuclide exposure. Subsequently, Hardell *et al.* [58] examined polychlorinated biphenyls (PCBs) and three organochlorine pesticides in some of the fish from the Amchitka Study. These three studies (radionuclides, mercury, PCBs) provided the Aleuts and other consumers of fish and crabs from the Bering Sea data on potential risk from consumption of foods from these waters. These contaminant studies were important for the Aleuts in making informed decisions about eating fish and crabs gathered from around their islands.

In this study there were two major points at which trust and consensus were needed to move forward toward the solution: 1) agreement on the Science Plan, and 2) agreement that radionuclides did not pose a human or ecological health problem allowing DOE to turn over the land to the State of Alaska and U.S. Fish and Wildlife Service (US F&WS). The original agreement between the parties (DOE, State of Alaska, EPA, and APIA) required an approved Science Plan before implementation that would answer the main questions of all parties regarding radionuclide exposure. This was accomplished through in-person meeting and approval of all signatories. The second point involved meeting with all parties to present results, and their final agreement that DOE could proceed with closure of the Island. APIA and the Aleut community were the most concerned about radionuclides because most of their diet came from subsistence foods gathered in the region. While APIA itself agreed with the findings, we demonstrated trust in the data and consensus on moving forward by collecting data on Aleut concerns prior to the expedition, and following the expedition as expressed in public meetings conducted in their Aleutian villages. There were significantly fewer concerns about radionuclides and the safety of their food following the expedition [37].

5. RESULTS: VEGETATION CLIMAX COMMUNITY AS AN INDICATOR OF ENVIRONMENTAL HEALTH

5.1. Stakeholders, Problems, and Issues

DOE has sites still requiring remediation in many states and it is important to be able to identify which sites have unique and rare ecosystems that are likely to include threatened and endangered species [23-26]. One of the goals of DOE-EM is to conduct remediation, restoration, and long-term protection of stored nuclear and other wastes while maintaining protection of human health and the environment [59]. Some DOE sites have uncontaminated buffer areas as well as cleaned-up areas suitable for a variety of recreational or cultural activities. These areas are important to a range of stakeholders from Tribal, cultural, and subsistence users to commercial and recreational hunters and fishers, as well as for neighbors and others worried about human health and safety. DOE-EM sites have some level of human health and environmental monitoring, although in some cases it is only soil and water. For many sites the protection and conservation of ecological resources is part of future land use plans, even at the beginning of DOE-EM program [60]. Thus, sites usually have on-site ecological monitoring for species' health (*i.e.*, changes in population sizes) and for contaminant levels. In the latter case, assessing contaminant levels and trends provides not only information to determine the potential risk to the plants or animals themselves, but as surrogates for exposure to people and as direct indicators of exposure to people consuming them (e.g., deer, fish) or using them for medicinal or cultural purposes. DOE-EM has many sites and limited resources. DOE, other federal and state agencies, Tribal agencies, and community members have expressed interest in protection of ecological lands on DOE-EM sites, particularly in relation to regional resources. There are three metrics that will be evaluated here: 1) ecological resources on a DOE site, 2) DOE site ecological resources compared to regional resources, and 3) ecological resources on one DOE site compared to another. The results for these three metrics can also inform DOE and state agencies about the allocation of funds to site-specific protection of funds.

One of CRESP's on-going projects is to examine and develop indicators that can be used across DOE sites. After discussions with DOE, relevant DOE National Laboratories, DOE contractors, state regulators, resource trustees, and the public over many years, it was obvious a screening indicator was needed that could quickly identify whether there were potential high quality ecological communities on-site, off-site, and in regions surrounding a given site. No individual indicator (e.g., a species) could be used at all sites because the DOE sites are in many different eco-regions across the U.S. from forests to deserts [5]. For any non-urban area, there is a characteristic vegetation type influenced by water, temperature, and soil conditions. Even a denuded area would be predicted to undergo gradual changes in vegetation, until it becomes the characteristic vegetation. This succession may take a century or more. It is called the "climax" vegetation because once reached, it is stable and characteristic of an area (at least until climate change alters conditions).

5.1.1. Example: Idaho National Laboratory (INL)

INL is located in shrub-steppe and grassland eco-region in the western United States (**Figure 1**). Cleanup involved dealing with special nuclear materials, spent nuclear fuel, transuranic waste, tanks waste, and soil and ground water contamination [59]. In such a large site (231,105 ha), the NLCD [42, 43] land cover maps can capture and portray the overall land types (**Figure 4**). **Figure 4** illustrates that there is little development in the region; shrub/scrub dominates the habitats in the region. There is no agricultural cultivation on site while agriculture (for example, potatoes, barley) is important in the regions surrounding the site. Grassland on site extends out into the surrounding region. Livestock grazing occurs on- and off-site but the NLCD does not identify grazed versus ungrazed grassland. However, although the maps visually display these differences, the actual data illustrate the relative proportion of habitats on- and off-INL (**Table 4**). Several observations can be made from this table: 1) shrub-scrub (also called shrub-steppe) dominated the site and the region, 2) INL has significantly more grassland that the surrounding region, and 3) the surrounding region has significantly more agriculture cultivation. The actual area is important for DOE, regulators, and the public for the purpose of future land use planning and understanding whether key habitats on site are being protected. This understanding is particularly important at INL because some of the surrounding regions may be vulnerable to future agriculture development, making on-site habitats even more rare and valuable.

5.1.2. Example: Rocky Flats (RF)

In contrast to INL, Rocky Flats (RF) is a small site of 21 km^2 that is located 26 km northwest of Denver [60]. From 1952 to 1989, its mission was to fabricate plutonium pits, the trigger initiating the fission of an atomic bomb explosion [61, 62]. For security, the industrial facilities were in the center of the site. RF is an example of a DOE-EM site that was remediated as of 2005, leaving some residual hazardous material contained in a central exclusion area. RF is now in long-term stewardship whereby the DOE retains responsibility for the developed/nuclear area in the center, but the surrounding land has reverted to ecological lands as a national wildlife refuge under the auspices of the U.S. Fish & Wildlife Service. Recreational

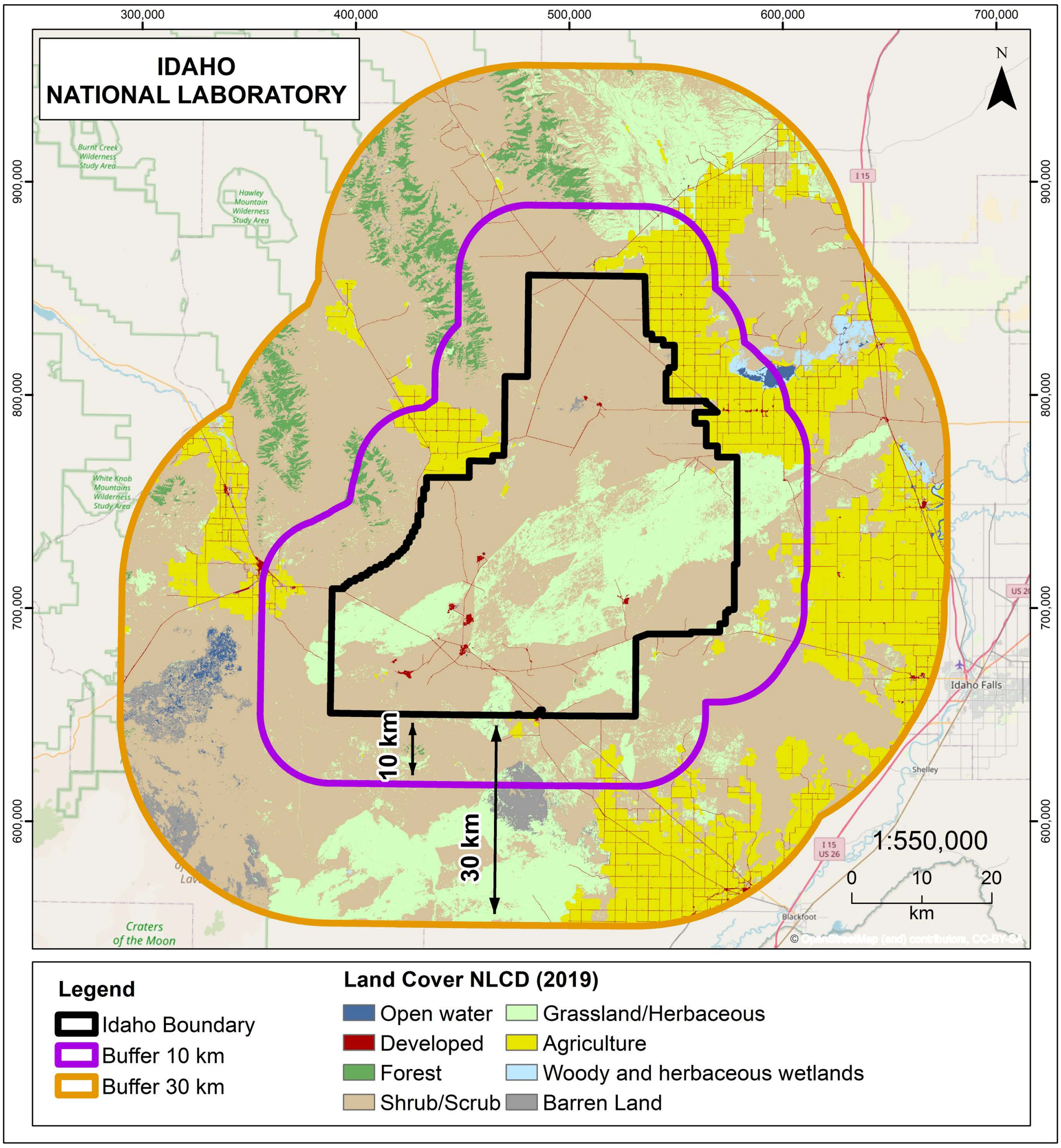

Figure 4. Map of Idaho National Laboratory (INL) illustrating different land use types on site and in the 10-km and 30-km band around INL (after Burger *et al.* [46]). Note that while the map illustrates different types of habitat, it does not indicate the amount of each.

Table 4. Comparison of land use cover (and habitats) on the Idaho National Laboratory with the surrounding 10-km and 30-km bands [43, 46]. Area given is ha and (percent). 100 ha = 1 km^2. (significant difference between INL and region of $P < 0.05$, Tukey's Test).

Land Use	Idaho National Laboratory	10-km Band	30-km Band
Total Area (ha)	231,105	252,379	967,328
Developed	1988 (1%)	3040 (1%)	11,476 (>1%)
Shrub/scrub steppe	163,975 (71%)	162,489 (64%)	528,630 (55%)

Continued

Grassland	63,850 (28%)	26,809 (11%)	193,635 (20%)
Agriculture	796 (>0.01%)	51,662 (21%)	192,245 (20%)
Barren land	418 (>0.01%)	1443 (<1%)	20,594 (2%)
Other habitats	78 (>0.01%)	6935 (3%)	21,748 (2%)

visitation on the refuge is confined to the surrounding buffer area which is primarily dry grassland similar to what once covered thousands of hectares in the U.S. plains [63]. The NLCD [42, 43] can also capture the land use currently on the site. Because of the smaller size of RF, a better communication tool is to show the site itself and the surrounding regions in separate maps; otherwise, the land cover on RF is not visible (**Figure 5**). Several conclusions are obvious from **Figure 5**: the DOE facilities on RF are in the center, surrounded by shrub/grassland, technically a xeric tall grass prairie. The development in the surrounding region is to the west of RF; there is a band of shrub/grassland that runs north and south through RF and the 10-km buffer, and forests run north and south to the west of the site.

Figure 5, however, does not provide data that can be used to directly compare the amount of each habitat type on- and off-site, nor does it allow for a discussion of the importance of RF relative to the surrounding landscape. This evaluation requires a comparison of the data. Using the NLCD we computed the amount and percentage of each land use type (**Table 5**).

Table 5. Comparison of land use on Rocky Flats (RF) compared to the 10-km and 30-km buffer zones around RF (after Burger *et al.* [48] and unpub. data). Area given is ha and (percent) (Significant difference between INL and region of P < 0.01, Tukey's Test).

Land Use	Rocky Flats	10-km Band	30-km Band
Total area (ha)	2674	52,655	346,047
Developed	192 (8%)	18,525 (35%)	118,582 (35%)
Evergreen forest	8 (0%)	9655 (18%)	99,166 (29%)
Shrub/scrub	288 (11%)	7240 (14%)	26,814 (8%)
Grassland/herbaceous[a]	2110 (79%)	12,392 (23%)	36,184 (10%)
Pasture/crops[a]	0 (0)	1370 (3%)	36,842 (11%)
Woody wetlands	16 (0.5%)	660 (1%)	3813 (1%)
Emergent wetlands	22 (0.8%)	1111 (2%)	5245 (1.4%)
Open water	22 (0.08%)	1225 (2%)	5884 (2%)
Other	38 (<1%)	1390 (2%)	10,381 (3%)

[a] Where two types are present, the percentage does not distinguish how much is of each type (e.g. what percent is crops versus pasture).

Rocky Flats have significantly more grassland/herbaceous vegetation and less development than the surrounding region (**Table 5**). **Figure 5** shows that the development on Rocky Flats was concentrated in the middle of the site surrounded by grasslands that are continuous with those in the 10-km band around the site. This xeric tall grass prairie is a rare habitat. The data in the NLCD, however, do not describe the kind of grassland, although the NLCD [42, 43] does describe different types of development. The grassland/herbaceous

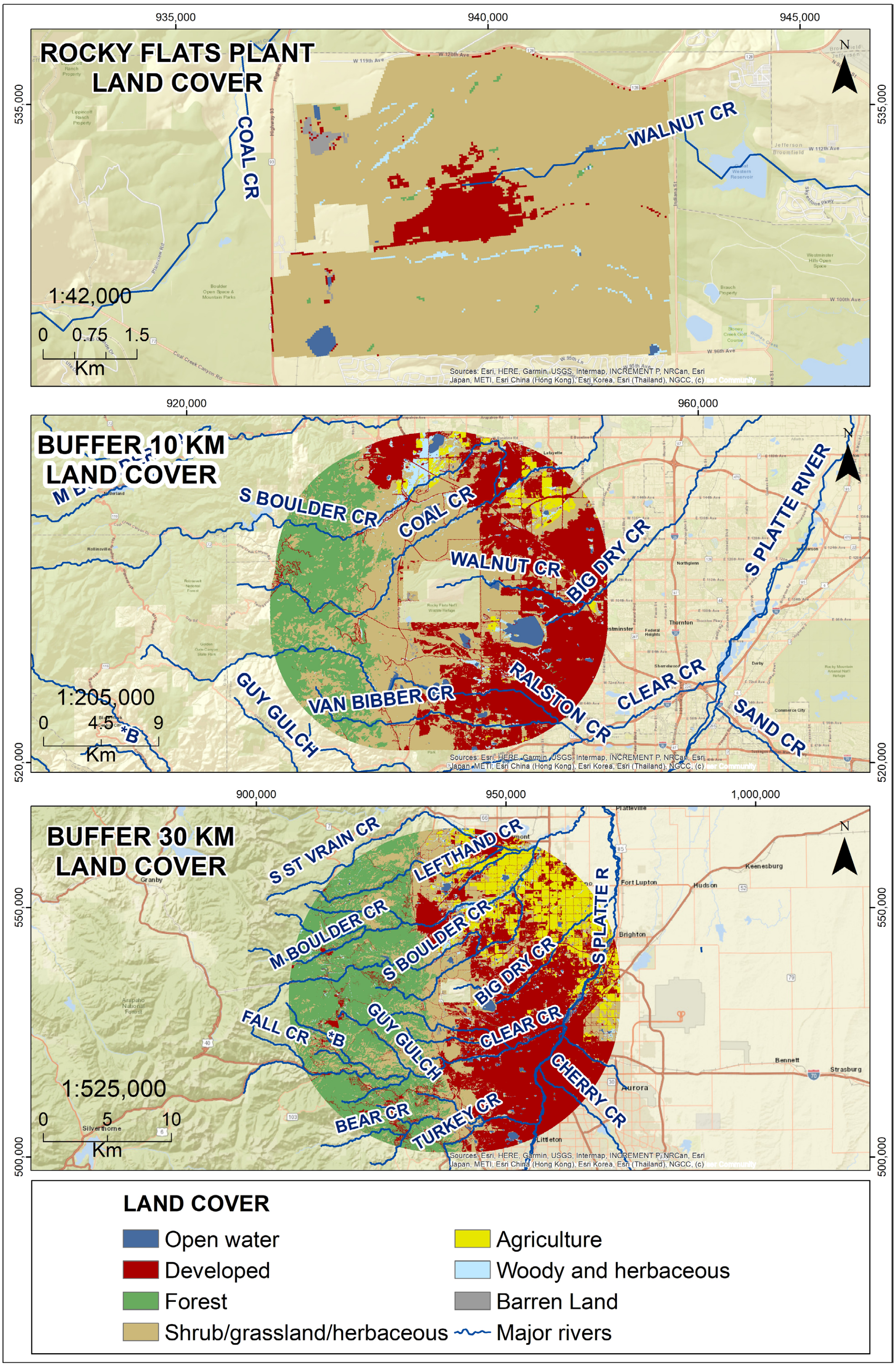

Figure 5. Comparison of land cover on Rocky Flats with the surrounding 10-km and 30-km buffer bands based on the National Land Cover Database [42, 43, 48].

habitat on site is important because it is continuous with the adjacent land and has been relatively undisturbed for decades. Because the land was allowed to undergo succession to the climax vegetation, it is in better condition than habitat in the surrounding area. Moreover, some of this habitat on site is tall grass prairie, one of the most threatened vegetation types in the United States [63]. Rocky Flats is unique because it has tall grass prairie, and it is protected; the undeveloped land is now a U.S. Fish and Wildlife Refuge, with tourists and recreationists coming from Dever and other regions [64]. Considerable radionuclides and other hazardous materials continue to reside on site [62]. The developed, core area will remain under DOE-Legacy Management in perpetuity [60].

5.2. Solutions and the Future

The screening bioindicator of climax vegetation developed by CRESP has been tested at other DOE sites [44-48] but requires more in-depth analysis to determine its usefulness by DOE, regulators, and the public. This analysis will involve further discussions and refinements after public input.

6. INITIAL PILOT TESTING USING DOE SITES

One potential use of the climax vegetation indicator (CVI) is to compare habitats among DOE sites. As an initial step, we compared the climax vegetation on five DOE sites: two with on-going remediation and an on-going mission (Savannah River Site, Idaho National Laboratory); one with continued remediation but only waste management surveillance (Hanford Site), and two that are completed (Rocky Flats, Brookhaven). **Table 6** indicates the percentage of climax vegetation on each site versus the surrounding 10-km and 30-km buffer zones.

Table 6. Preliminary results comparing the percentage of climax vegetation on DOE sites with the surrounding 10-km and 30-km buffers. Data from Burger *et al.* [44-48] and this paper.

DOE Site	Climax vegetation	Percentage on site	Percentage on 10-km buffer	Percentage on 30-km buffer
Idaho National Laboratory	Grassland/shrub-steppe	99	75	75
Savannah River Site	Pine forest	50	27	28
Hanford Site	Shrub-steppe	50	19	21
Rocky Flats	Grassland/herbaceous	79	23	10
Brookhaven National Laboratory	Pine forest (pine barrens)	61	39	24

Several preliminary observations can be made from this table: 1) all the sites had a higher percentage of climax vegetation than the surrounding region, 2) the immediate area around the sites (e.g., 10-km buffer) has a lower percentage of climax vegetation but not as low as the 30-km buffer (except Hanford), and 3) The difference between the percentage of on-site vegetation and the off-site 30-km vegetation buffer differed among sites. That is, the percentage of climax vegetation on site compared to off-site for RF as greater than for INL. Development, that is non-native habitat, might be greater immediately around the site due to residences and businesses serving the DOE site. The difference between the percentage on-site and in the 30-km buffer is largest for Rocky Flats and Brookhaven National Laboratory—the sites where remediation is completed. They are also sites that have very critical ecological resources on site. Rocky Flats has one of the only native Tall Grass Prairies in the western U.S., and Brookhaven has some of the endangered pine barrens habitat that connects with pine barrens in the 10-km buffer area [65]. These data provide information that governmental agencies and the public should consider when there is proposed development or other management actions on DOE sites. Additionally, the actual amount of each climax vegetation on site must be considered within the framework of the amount available regionally. That is, both Rocky Flats and Brookhaven are smaller sites and thus provide less of the habitat area than the other sites.

Using the NLCD for determination of climax vegetation has some disadvantages. The spatial resolution is not great enough for some analyses, habitats may be misclassified or not sufficiently distinguished, and some management practices are not noted. For example, the spatial resolution may not be sufficient to identify nesting habitat of a species with very specific requirements (e.g., one requiring dense forest with nearby ephemeral ponds). Habitats may be either classified incorrectly or not in enough detail. For example, at Brookhaven the coniferous forest is mainly pine barrens, a specific kind of forest with few and sparce pines, low nutrient, and coastal sandy soils. Further, management practices, such as allowing grazing or logging, are not identified and may lead to believing the grassland or forest is pristine or undisturbed. These disadvantages only point out the importance of ground-truthing some areas, using local ecologists to corroborate findings, or using the literature specific to a site in question. Stakeholders appreciated the importance of adding local and indigenous knowledge to the analysis. In general, however, the advantage of having a uniform evaluation of land cover types across the continental U.S. and having the information renewed periodically provides a useful tool for managers and the public.

7. DISCUSSION AND CONCLUSIONS

There are many ecological indicators that have been used, and they usually involve examining one or many species, or examining one type of habitat (desert, tundra, forest [65]). Yet there are few in-depth analyses of indicators that cover a wide range of eco-cultural and biotic indicators for one site and fewer screening indicators that can be used across multiple ecoregions. We provide two examples of indicator development: one that goes from a seemingly intractable public problem (*i.e.*, how to build enough trust to close a site that had underground nuclear tests; Amchitka Island) and another that addresses the global need to have a screening indicator that can be used rapidly in multiple sites with very different habitats and ecoregions (Climax Vegetation). The first case derived from decades-long concern about the health of commercial and subsistence foods and the biotic food chain. The Amchitka case involved numerous governmental, public organizations, and individuals to agree on the problem and solution, and ultimately a path forward. The second case derived from a general agency and public interest in being able to quickly examine ecological resources on site and in the region and to be able to compare among geographically distant sites. This paper describes a simplified design for moving forward with complicated problems, although each phase requires multiple steps and assessments. The major commonalities of the cases are: 1) identification of the problems or issues, 2) identification and communication with stakeholders, 3) data acquisition and analysis, and 4) charting a path forward. These are the same steps discussed for Amchitka—indicating the applicability of the approach.

The initial phase requires that a problem or issue be identified that presents a problem to individuals, groups, or society overall to the structure and functioning of ecosystems. This is one of the most critical phases, because without involvement of many different stakeholders, any data collected might not address the real and underlying concerns. Often this becomes clear only with multiple in-person meetings with a full range of different stakeholders in a forum where views can be expressed openly [49, 50]. A top-down approach whereby the "government" defines the problem and provides the answers may not be sufficient for stakeholders that have a different world view of the problem and thus the appropriate data needed to address the problem. The first example (Amchitka) provided a situation where without meetings and forums for many different points of view to be expressed and considered, progress would have been impeded; no solution was originally forthcoming. That is, although DOE had initially provided complex computer models, many other agencies, organizations, and people were not convinced [33]. Although involving stakeholders often takes more time, the solution in the end results in successfully moving forward [32, 66].

Communities usually know what they are exposed to, what they are concerned about, and whether they have been exposed for years (cumulative risk) [67]. Further, they can conceptualize problems, analyze data, interpret data, and make risk-based decisions. In this paper, we propose that the formal risk assessment paradigm can be reduced to the four phases described above that allow a commonality among problems and issues for public discourse. The data were presented in different ways to serve as tools to encourage collaboration among different stakeholders.

The U.S. and other industrialized nations are facing remediation and restoration tasks that are multifaceted and may require decades to complete. Protecting human health and the environment requires not only setting cleanup standards but recognition of the needs of different stakeholder groups as well as for ecosystem integrity [60, 67-71]. While the best available science should be used in environmental decision-making [72], including social and cultural values is also critical [60]. Further, few studies have used the NLCD for comparing geographically distant sites for management purposes. The NLCD and other methods of comparing ecoregions are gaining importance, particularly because of global changes in populations and climate [73, 74]. The examples provided in this paper included stakeholder involvement and collaboration throughout the project; having an agreed-upon path forward is an essential part of environmental management.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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