

Evaluating Costs and Benefits of the Department of Defense Legacy Resource Management Program



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Abstract

This analysis examined multiple sources of unclassified information to assess the net benefits or return on investment of activities of the Department of Defense (DoD) Legacy Resource Management Program. We concluded that current data were insufficient to conduct either cost-benefit analysis, where benefits would be monetized, or cost-effectiveness analysis, where benefits would be quantified using a non-monetary benefits indicator. We found sufficient information to link Legacy program activities to many types of beneficial military readiness outcomes and used that information to frame an approach to cost-effectiveness analysis using benefit metrics of training days saved and costs avoided. Our recommendation for estimating benefits of the Legacy program with this type of framework would be to engage DoD personnel in a structured decision support process to finalize a practical assessment approach.

List of Acronyms and Abbreviations

AEPI	Army Environmental Policy Institute
AFB	Air Force Base
ATM	Asian Tiger Mosquito
BASH	Bird/Wildlife Aircraft Strike Hazard
BRAC	Base Realignment and Closure Commission
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness Analysis
CRB	Coconut Rhinoceros Beetle
DENIX	DoD Environment, Safety, and Occupational Health Network and Information Exchange
DoD	Department of Defense
IJTS	Initial Joint Training Site
JSF	Joint Strike Fighter
NAVFAC	Naval Facilities Engineering Command
REPI	Readiness and Environmental Protection Integration
RIFA	Red Imported Fire Ants
SAIC	Science Applications International Corporation
T & E	Threatened & Endangered species

Introduction

This study aimed to evaluate the costs and benefits of the Department of Defense Legacy Resource Management Program activities (hereafter referred to as the Legacy program), including the return on investment. The Legacy program was established in 1990 to conserve and protect resources on military installations while preserving DoD's primary mission of military readiness. The Legacy program is guided by the principles of stewardship, leadership, and partnership which refer to safeguarding "irreplaceable resources for future generations", generating a "model for respectful use of natural and cultural resources," and partnering to "access the knowledge and talents of individuals outside of DoD" (DoD, n.d.).

Legacy projects promote resilience of lands to different threats through range management, invasive species and pest control, species migration monitoring, and cultural resource preservation. Substantial public benefits are provided through stewardship of scarce natural resources on installations including support for endangered species, densities of which are highest on military installations among federal lands (DoD Natural Resources Program, 2017). However, this analytic effort used a narrow focus of benefits to encompass only military readiness affected by natural resource condition on US installations. Such a focus omits benefits that accrue to those living on base, neighboring communities, and future beneficiaries. It further omits readiness benefits that may emerge through collaborations across nations. For example, Legacy program efforts enabled a joint training exercise in Australia because inspection and equipment cleaning protocols had previously been established to avoid spreading invasive species.

The economic approach of cost-benefit analysis (CBA) measures benefits in monetary units that reflect changes in public well-being and is used to directly compare benefits and costs. For this study, the goal was to characterize the value of the Legacy program to military mission goals, rather than evaluating public benefits due to environmental changes. In scoping the analysis, we considered that installations are expected to achieve their primary mission goals of ensuring military readiness, while also protecting the on-site natural resources and managing conflicts with neighboring communities.

After reviewing available information, we concluded that data on project costs and outcomes were insufficient to support a robust CBA, which is a data-intensive undertaking. Data on legal costs avoided (e.g., fines associated with violating the Endangered Species Act) would be appropriate to use in a CBA, but did not reflect the benefits associated with military readiness that was the goal of this analysis. A lack of quantitative data on outcomes of environmental restoration programs, such as the Legacy program, is typical since many programs prefer to devote resources to implementation rather than post-implementation observation.

As an alternative to CBA, many government programs use cost-effectiveness analysis (CEA), in which a quantitative metric is used as a leading indicator or proxy for benefits. For example, various federal natural resource programs frequently track acres restored, in order to measure beneficial outcomes. In this case, a CEA analysis would require a metric that connected environmental changes to benefits associated with troop and equipment readiness. Since data were not available to directly make this link, and we were precluded from developing these data through expert panels, we developed an analysis framework that could be implemented by the military in the future. We demonstrate what this analysis could provide using hypothetical data.

The primary use of CEA is to compare alternative approaches to achieving a goal (e.g., Scodari, 2009) in terms of the benefits per dollar spent. CEA has the advantage over CBA in that it generally requires fewer assumptions and less resources to implement than CBA, when benefits have not been measured with dollars. We discuss alternative approaches for developing a CEA, depending on resource availability. Data gaps could be filled with additional monitoring, exploring existing records, or by engaging base managers in ranking the importance and benefits of outcomes.

Methods

We developed a CEA framework to assess Legacy program performance in terms of net changes to military readiness, using a variety of data and information sources. The key element needed to enable a CEA is finding consensus among decision makers on a benefit or performance metric. That metric could either be a single measurable outcome or an index that reflects a weighting of multiple outcomes. Creating an index requires input from those who understand the scope of installation missions and can weigh tradeoffs among outcomes. An example of a single outcome metric for the Legacy program would be *bird strikes avoided*. An index representing multiple types of outcomes would be a combination of quantitative metrics reflecting *mission activities, troop safety, training sufficiency, and equipment condition*.

Benefit Index Creation

We synthesized data to create a system of benefit metrics in terms of military readiness, which were defined as activities that promoted 1) troop health and safety, 2) equipment operation and maintenance, and 3) training quality and sufficiency. We only considered military activities that would be affected by the types of environmental investments that are typically made as part of the Legacy program, such as those that rely on condition of natural areas, field equipment and infrastructure.

To create the benefit metric, we evaluated how Legacy program activities enabled use of areas that might otherwise have been off limits due to invasive species risks, bird strike risks, potential harm to threatened or endangered species, fire risk, or other concerns. After considering many alternative metrics, we selected the benefit metric of training days gained, by type of training. Some examples of training days gained through legacy investments are clear days for practicing shooting due to forest fuel reduction (and fires avoided), or days of paratrooper training enabled by control of thorny invasive plants. Suggestions for measuring this metric is discussed in results.

The metric of *training days gained* has the advantage of providing clear readiness benefits and is a common outcome of the types of projects we evaluated. We add costs avoided to the benefit assessment to ensure thoroughness of benefit accounting for cases when other costs are incurred. Costs may be incurred to mitigate effects of lost training opportunities (e.g., costs of providing alternative training offsite) or to address other harms such as to repair to damaged equipment.

Data development

We evaluated three main approaches to developing data to assess net benefits 1) Literature review and interviews with subject area experts, 2) evaluation of databases of projects funded by the Legacy program; and 3) case study evaluations. This effort involved searching, collating and summarizing publically available documents on installation characteristics, general environmental initiatives, specific legacy projects and project outcomes and costs. We relied heavily on information about funded grants

to evaluate costs and outcomes, because project budgets were separable from other installation activities and expected impacts were reported.

Literature review and interviews

Literature searches were conducted to identify published papers documenting environmental projects that had been linked to military readiness outcomes. We used standard online search engines (e.g., www.google.com) and specialized academic literature search engines (Google Scholar [scholar.google.com], Web of Science [www.webofknowledge.com]) to conduct the search. Searches combined keywords such as *natural resources*, *Department of Defense (DoD)*, *legacy*, *mission readiness*, *environment*, *expenditure* and Boolean operators into search strings such as '*legacy AND dod AND readiness*'. Targeted searches were conducted to document specific case studies at specific installation.

Searchable literature was quickly reviewed, vetted and either archived for closer reading or discarded. In addition to the general search, a set of 30 recommended reports (McFerren II, 2017) consisting of installation management plans, resource conservation reports, memos about environmental security, and DoD AEPI environmental records. These documents gave insight into the risks and harms that environmental changes cause on military bases, funding plans to manage environmental impacts, and the advantages of implementing natural resource management plans.

Two advisors, Robert (Robbie) Knight and Carl (Dave) McFerren II, who work directly with installations on environmental management, served as advisors on this project. They connected us to others who participate in Legacy projects or observe outcomes on installations. We held four meetings via phone with various combinations of our advisors and Legacy program staff to 1) review program goals, 2) discuss observed benefits, 3) and discuss methods of translating observations of beneficial outcomes into quantifiable metrics. In addition, Mr. Knight gathered insights from military land management groups with which he worked such as Range Sustainability, Conservation Committee, and Partners in Flight. Both advisors were able to draw on their long tenures with the Army and Air Force to provide insights into types of benefits produced by the Legacy program and sources of additional information.

Project data sources

Data on proposed Legacy program projects came from public databases. We identified two resources with information about proposed projects, the Readiness and Environmental Protection Integration (REPI) Program (www.repi.mil/) and the Legacy Resource Management Program project tracker (www.denix.osd.mil/legacy/home/). The publicly accessible, front-end of these online resources provided project reviews in the forms of Fact Sheets and Project Summaries for REPI and Legacy projects.

We requested and were provided with a more detailed summary of a subset of Legacy project proposals from the DENIX database (projects from 1991-2018) (Scanlin, 2018). These project data included many data fields describing the project plans, expected outcomes and costs. A field documenting the proposers' perspectives on expected military readiness outcomes was an input into readiness metric development. The limitation of using proposed projects is that we did not have post-project verification that outcomes were achieved.

Case Studies

Using the literature sources and interviews, we identified a set of potential case studies to test an approach to comparing costs and benefits. We evaluated the state of available information for

supporting quantitative analysis and looked for ‘best case’ scenarios based on available information on activities, outcomes and expenditures. We further sought case studies that would be representative of conditions across installation types.

Results

The results are organized into sections representing the three data sources before showing how those data were integrated into a benefits index suitable for CEA. The data source sections are 1) interviews and literature; 2) project data sources; and 3) case study reviews. We further describe approaches to developing the index, expected results of applying the index, and future steps necessary to enable a CEA or CBA.

Outcomes of interviews & literature review

A review of the literature and synthesis of interviews with project advisors and Legacy personnel provided insight into many beneficial outcomes of Legacy program activities as well as tensions that can arise during implementation. Interviews with subject area experts revealed many anecdotes of harms avoided due to Legacy program activities. Perhaps most important was hearing perspectives from long-term program observers about problems that used to occur prior to natural resource management investments, but are now forgotten since current problems are rare. For example, in the 1980s, before erosion control via vegetation management was common, one interviewee knew of cases where vehicles had overturned due to insufficient erosion control on dirt roads.

A key message from the interviews was that the primary goals of installation managers are to maintain and facilitate military readiness and avoid costs (e.g., cost associated with restoration of training areas after catastrophic changes). Although the program goals are broader than the installation operation perspective, military readiness goals are the most meaningful to installation managers and many DoD decision makers. DoD representatives expressed concerns that Legacy program activities can interfere with training or operations and that disruptions from management activities should be considered when evaluating benefits, to ensure a net gain of training opportunities.

Interviews and literature provided numerous examples of Legacy program projects that contributed to readiness. Some examples are below.

1. Bird Survey at Dugway Proving Ground, UT – Completion of a robust avian survey demonstrated that no migrating species of concern were present, a procedure that enabled a full spectrum of training opportunities and avoided costs associated with the need to reschedule training to conduct ongoing monitoring.
2. Amphibious assault training on beaches – Two solutions were found to avoid cancellation of mission activities when eggs and fledglings of species of concern were present in amphibious training zones. These solutions included creating movement corridors for war-fighters by discouraging nest construction by dragging/disturbing beach areas prior to nesting while building mitigation areas elsewhere, leading to birds preferentially building nests in untouched areas away from operation spaces.
3. Hawaii mud-ops – Tank training and movement operations were identified as a mission-compatible management strategy to maintain the natural foraging habitat of the Endangered Hawaiian stilt. Research showed that tank movements created natural ruts in the grassy

substrate which replicated the muddy flats needed by stilts as feeding habitat. This synergy led to the lifting of restrictions on tank use in the area.

4. Yellow starthistle at Ft Hunter Liggett, CA – Paratrooper training operations were disrupted due to an outbreak of yellow starthistle, an invasive weed possessing thorns capable of damaging parachutes and injuring troops. In this case, mitigation was necessary and troops were forced to travel to a nearby airport to avoid the infested area during training. The mitigation activity prevented the loss of training but resulted in training delays and incurred additional costs associated with vehicle and airfield rentals.
5. Joint training in Australia – Joint training activities were enabled because invasive species protocols had been developed and were implemented, with the net result of enhanced readiness through expanded training opportunities.

A productive set of conversations (led by Robbie Knight) was held among rangeland management experts whose input was used to develop an initial table connecting natural resource management actions to beneficial outcomes (Table 1). Cells with an X indicate that the management action shown in the column is likely to have a beneficial effect on the training activity or readiness factor in the corresponding row.

The information we found in reports, news articles, literature and interviews on projects provided descriptions of ecological threats, environmental hazards, and management activities (See Appendix 1 for additional projects). Biophysical degradation problems of base infrastructure were common themes among the reports, but further information about the degree of disruption to training or the cost of repairs would be needed to quantify and aggregate effects. Due to these data limitations, we were not able to conduct a planned test implementation of a readiness index for a few installations that represented a range of military branches, physical sizes, and biogeographical characteristics (Appendix 2).

Table 1. Expert judgement of effects of rangeland management activities on readiness outcomes

Operations of Troop Readiness, Training, and Procedures	Natural Resource Management Actions										
	Prescribed Burning	Encroachment Minimization	Wetland Construction	Wetland Protection	Integrated Planning	Species & Other Monitoring	Trapping Programs	Habitat Creation	Habitat Replenishment	Habitat Relocation	Invasive Species Control
Explosions	x	x		x	x	x	x		x	x	
Road Construction & Use		x	x	x	x	x	x	x	x	x	x
Recovery Operations											
Off-road Travel	x	x	x	x				x	x	x	x
On-road Travel											
Refuse Disposal		x	x	x				x	x	x	
Aircraft Flights	x	x					x				
Target Flights	x	x					x				
Missile Flights	x	x					x				
Simulated Chemical Attacks	x	x	x	x			x	x		x	x
Sewage Disposal		x	x	x				x	x	x	
Water-well Drilling		x	x	x	x			x	x		
Building Removal		x	x	x	x	x	x	x	x	x	
Building Construction		x	x	x	x	x	x	x	x	x	x
Pyrotechnic Flares	x					x					
Release of Obscurants		x	x	x	x	x	x	x	x	x	
Night Operations	x					x					
Parachute Drops	x										x
Mountaineering											
Small Arms Fire	x	x			x	x	x			x	x

Outcomes of project data queries

Out of the 587 project records that were included in the DENIX database extract that we received, only a fraction provided specific effects on military readiness. More commonly, relevant outcomes were described in terms of effects on habitat or species, with the implication that improvements in the condition of habitat or species populations would improve installation overall function. More recent records had better examples of readiness benefits, relative to older records. The data included project costs, as needed to support a CEA, but did not characterize non-monetary costs in the form of disruptions to operations that might occur as a result of the project.

A representative cross section of the records (Table 2) provide examples of the types of useful information provided (middle column) and the types of quantitative information that would be needed to support a CEA (right column). The descriptions suggest that installation records might be used to quantify outcomes prior to interventions such as area unavailable for training, injury count, training days lost, flight time lost, equipment compromised, and costs avoided.

If harms prior to management intervention can be documented, then the information provided in the database suggests three alternatives for quantifying effects of natural resource management activities. The most resource-intensive approach would be to track changes in quantitative outcomes once projects are implemented by mining existing records or developing new record-keeping techniques. A second and simpler approach would be to use expert judgement as input to simple models that would project how conditions are expected to change with the natural resource intervention. The third, and simplest approach, would be to survey installation managers and have them rate the success of the project in terms of readiness outcomes.

Table 2. Examples from DENIX database of readiness outcome information and suggestions for changes to enable quantitative assessment

Project Title	Impact on Military Readiness Reported by Project Investigators (quotes from DENIX)	Additional Desirable Information or Data
Establishment of BIRD RAD Network at Military Air Bases	High-resolution radar to reduce bird strikes, and recognize habitats on base that are important stopover areas for migratory birds.	Improvements in operations (e.g., more flights, more flight time, reduced accidents)
Regional Ecosystem Management in the North Carolina Sandhills	Reduce training restrictions on Fort Bragg to enhance readiness. Provide additional training areas (3-5,000 acres) & buffers between military training area and private land.	Effect of added acres on training outcomes (e.g., number of troops trained, training days by activity type)
Tickville Springs Watershed Rehabilitation and Enhancement	Runoff and erosion will be controlled. The roads will be more stable.	Number of days/year that roads were usable before and after management, change in equipment repair costs, or change in troop delays or injuries.
Pitch Pine Barren Rehabilitation & Management Strategy	Reduced risk of wildfire in fire-prone habitat, increased on-foot mobility by personnel.	Training days lost due to fires before, during and after management.
Maximizing the efficacy of intra-installation translocations to mitigate human-rattlesnake conflicts	Ensuring safe, continuous access to training areas.	Training days lost due to area restricted due to rattlesnakes, rattlesnake injuries
Southeastern US Surveillance Overflights of Northern Right Whale (<i>Eubalaena glacialis</i>)	Acquiring information on the presence and movements of the Right Whale, which will reduce accidental takings through ship collisions.	Training days lost due to mammal ship collisions, troops injured, equipment compromised (with and without information).
Invasive Wild Pigs – Best Practices and Decision Support Tools	Disruptions in training lands will be reduced, enhancing military readiness and effectiveness. In addition, the reduction of feral swine population will reduce the damage to infrastructure, which has mission and economic benefits.	Training days lost due to feral swine, costs to repair any compromised equipment and infrastructure.
Developing Coastal Wetland Restoration Techniques to Enhance Coastal Habitats at Ahua Reef, Hickam Air Force Base, Hawaii.	Restoration of Ahua Reef is expected to increase Hickam AFB security by improving their line-of-sight visibility.	Costs avoided from ameliorating line-of-sight security concerns
Using Acoustic Surveys to Monitor Population Trends in Bats	This project would encourage development of bat monitoring program. The presence of bats reduces the area of an installation where training or stewardship activities occur or could alter the allowable timing of said activities (seasonal restrictions or area closures). By identifying bat population information, actions can be undertaken to minimize impacts to the Mission.	Training days (or area) lost due to restricted training area due to the presence of bats

Outcomes of case studies

The case studies identified as likely to have large amounts of data and information were still insufficient for quantifying military readiness outcomes of management activities. The case studies with the most complete data included large installations with extensive environmental reporting documentation. Qualitative information on project goals or outcomes were the most commonly available source of data and occasionally quantitative data on project scope such as years, area treated, or costs were available. However, the quantitative information needed to calculate changes to military readiness were absent.

We identified two installations, Marine Corps Base Camp Pendleton, CA (approximately 125,000 acres) and Eglin Air Force Base, FL (464,000 acres) as being the most data-rich examples. Details of findings are described below to highlight data gaps even among these ‘best case scenarios’ (summary in Table 3).

Marine Corps Base Camp Pendleton – At Marine Corps Base Camp Pendleton, programs exist to counter the spread of invasive species, monitor and protect threatened and endangered (T&E) species, and control interference of birds with flight operations (e.g., BASH). Cost and effort data associated with these projects are incomplete but available for some activities. For example, \$1.2 M was reported spent in eradication efforts to control the spread of invasive fauna over a period of 5 years (Dalsimer, Burkett, and Golla 2017). Up to 30% of the flora is also nonnative on Camp Pendleton and many of these species are considered invasive (Naval Facilities Engineering Command [NAVFAC], Southwest Division, 2017). The installation maintains a riparian invasive plant program that focuses on controlling invasive riparian plant spread and propagation (NAVFAC 2017). A total of about \$10 M has been allocated to this program since 1995 and has involved control actions over 1,300 acres. Biennial monitoring of T&E species at the installation is conducted to maintain regulatory compliance and support adaptive decision-making to avoid negatively impacting listed species (NAVFAC 2017). Data on specific costs associated with monitoring activities and restrictions on training arising from avoidance of T&E species conflicts are not available. While these reports, particularly the NAVFAC (2017) Integrated Natural Resources Management Plan, provide details on programs and effort, the lack of consistent data availability of quantitative data on how these programs affect military readiness make it impossible to integrate these semi-quantitative data into a robust modeling framework.

Eglin Air Force Base (AFB) – Elgin AFB has numerous programs in place to mitigate conflicts between the natural environment and base operations. Information on specific Legacy programs is available, as are programmatic costs in some instances. However, data on how and to what extent these activities advance mission readiness are lacking. Elgin AFB maintains the prescribed burning of approximately 90,000 acres per year, a dedicated wildfire (primarily caused by mission activities) suppression program, forest management of native longleaf pine and opportunistic sand pine, habitat restoration programs that include erosion control along river corridors, nuisance and non-native animal management, BASH, ecological monitoring to support adaptive management and protected T&E species, and develops sustainable recreational opportunities compatible with maintaining the military mission (Science Applications International Corporation [SAIC], 2013). Information on costs avoided due to management activities are available for Eglin AFB. For example, the installation has avoided \$9 M in solid waste disposal costs, some of which has involved repurposing materials such as concrete range targets for artificial reef construction to support local marine faunal communities and provide recreational SCUBA diving opportunities (DoD, 2018). To support a 2005 recommendation from the Base Realignment and

Closure (BRAC) Commission (BRAC, 2005) that Eglin AFB serve as the F-35 Joint Strike Fighter Initial Joint Training Site (JSF IJTS), large tracts of land under and leading up to the Eglin AFB airspace are being preserved to ensure mission-suitable land use compatible with low-level flight paths (Readiness and Environmental Protection Integration [REPI], 2019). A total of \$24.3 M had expended and approximately 24,000 acres preserved through 2017, with ecological benefits including the preservation of movement corridors and habitat for wildlife in the region in addition to supporting US military mission capacity. Tracing the effectiveness of these activities back to military readiness is not feasible with available information. Even with perfect information, quantifying the impact of a project on military readiness may not be feasible due to changes in training plans that occur for other reasons.

Data on how project completion or initiation influences readiness is critical to understanding how Legacy actions serve to support environmental and mission goals. In the case of Camp Pendleton, there is evidence that quantitative metrics of mission-readiness benefits could be created from data and information available to the DoD. For example, a summary on the status of Endangered Species on Air Force lands by Boice (2010) from the Legacy DENIX portal states, “As a result of the consultation and Camp Pendleton's proposed management practices, military training can now occur in riparian areas previously off limits due to the presence of endangered species”. Information on how the riparian invasive plant program translated to the maintenance of mission-critical activities, such as provision of suitable vegetation cover for ground troop training days or avoidance of training days lost due to incompatible docking interfaces, would allow military readiness to be quantified.

Similarly, investing in JSF training and support at the Elgin AFB JSF IJTS is a high priority for the DoD (DoD, 2005), but the details necessary to translate expenditures or area preserved to quantifiable mission benefits were not available. For example, natural resource management was undertaken to ensure the availability of low-altitude flight corridors for training F-35 JSF pilots. Therefore, an accounting of the enhanced training capabilities (in flight hours) resulting from the land preservation/acquisition program would support a CEA. To standardize scoring would require additional reporting and interaction between installation military and Legacy personnel in order to effectively interpret outcomes relative to goals.

Table 3. Summary of data availability for case study analysis for two bases

Available Quantitative Data in Public Case Studies	Base	
	Camp Pendleton	Eglin AFB
Invasive species	X	X
T & E species	X	X
Costs (partial)*	X	X
Years Treated (partial)*	X	X
Acres/Units Treated (partial)*	X	X
Size of Base (Acres)	X	X
Military Readiness Score	Missing information	Missing information
Environmental Benefit Score	“	“
Costs by activity	“	“

* A note of “partial” indicates that data availability is constrained to only one or more activities and is not available for the full suite of Legacy projects for a given installation.

Performance metrics

The information collected was used to create a set of performance metrics to reflect different types of military readiness outcomes affected by natural resource management projects. We used the common metric of training days lost for all outcomes and direct military costs avoided to manage harms (e.g., treating injuries) or mitigate harms (e.g., using off-base training areas). Clearly, the military readiness benefits of harms avoided (e.g., fires, aircraft-bird collisions) extend beyond lost training activities. In particular, protecting troop health is a concern for a variety of reasons beyond lost training time. However, using a common metric across types of impacts simplifies the aggregation of effects across different activities. We omit components related to broader social costs (e.g., social impacts of habitat loss), to be consistent with our narrow framing of the CEA as effects on military readiness.

The military readiness metrics that we developed (Table 4) are intended to describe needs across services and reflect diverse needs for proficiency training for troops. The metrics only include training that requires activities in the field. The metrics are not comprehensive, but rather are intended to reflect major activities potentially affected by the Legacy program.

To use Table 4 to summarize net program benefits, an analyst would need 1) projections of training days lost in the absence of Legacy program efforts or the *without program baseline*; 2) projections of costs incurred in responding to or mitigating harms in the without program baseline; 3) net change in training days available and costs avoided due to program efforts that included days gained from improved conditions and days lost from the management activity.

Performance outcomes would not be simultaneously recorded in all three readiness categories (Table 4, column 1), to avoid double counting benefits. The choice of category (or categories) depends on how managers are likely to handle the risk. If, under baseline conditions, managers are likely to cancel training to manage the risk, the training days gained would be recorded in the appropriate row under *training sufficiency*. If risk was avoided in this without program baseline, there should be no entry under troop health or safety, or equipment protection. Consider a case where paratrooper training would be cancelled or moved if training grounds were rendered unusable due to invasive vegetation. In this case, the analyst would omit equipment damage from the assessment and the program benefit would be costs avoided from any lost training days and costs of moving troops to an alternative training location under the training sufficiency category. Alternatively, if the problem, under baseline conditions, is likely to result in unanticipated accidents to troops or equipment, then benefits would be recorded using the categories of *health and safety* and *equipment condition*. Lost training days due to accidental injuries would be recorded under the morbidity and mortality section, and training days lost due to ongoing equipment repair would be recorded under equipment condition section.

Projections of changes due to Legacy projects are likely to rely on expert judgement. Some simple decision rules or models could be developed to standardize the process, to minimize bias in estimates. For example, past evidence could be used to assess the percent of time that Legacy projects (grouped by type) were successful in restoring full to partial use of an area and the number of days that troops used the area before and after the intervention. That understanding could be used to estimate the baseline conditions and create an expected outcome as a function of probability of success, also referred to as a risk-weighted outcome (further information in Keeney and Raiffa, 1993).

Table 4. Proposed performance metrics to assess net harms avoided from natural resource management

Readiness Category	Training Activity	Troop & Training Risks	Beneficial Outcome	Metric of avoided harms due to natural resource management Training day losses avoided/year	Costs Avoided
Troop Health & Safety	Ground Based Training	Morbidity & Mortality	Harmful vegetation control	Training days lost due to vegetation contact injuries	Medical costs, compensation
			Disease free area	Training days lost due to disease	"
			Dust storm-free days	Training days lost due to eye or lung injuries	"
			Fire-free days	Training days lost due to burns or smoke inhalation	"
			Vehicle travel stabilization	Training days lost due to injuries sustained in ground vehicles	"
	Ground Based Artillery		Bullet ricochet control	Training days lost due to artillery injuries	"
Flight Training	Bird-free area (strikes avoided)	Training days lost due to injuries sustained in aircraft bird strikes	"		
Equipment Condition	Ground Based Training	Ground Vehicle Repair/Replacement	Compatible roads for equipment transport	Training days lost due to ground equipment failures from inadequate roads	Equipment repair costs
	Flight Training	Plane Repair/Replacement	Bird-free area	Training days lost due to aircraft failures from bird strikes	"
	Marine Training	Ship Repair/Replacement	Water area with low risk for mammal conflicts	Training days lost due to ship failures from sea mammal strikes	"
Training Sufficiency	Ground Based Training	Sufficient (Allowable) Area per Troop	T&E species constraints avoided	Training days lost (temporary) due to incompatible species activities (nesting)	Alternative training costs
				Training days lost (permanent) due to activity constraints (T&E species)	"
	Ground Based Artillery		Clear sky days (ground visibility)	Training days lost due to restricted munitions use (troop visibility)	"
				Training days lost due to restricted munitions use (fire risk)	"
	Flight Training	Available Air Space for Training	Clear sky days (air visibility)	Training days lost due to flight restrictions due to visibility concerns	"
			Dust storm-free days	Training days lost to dust storm occurrences	"
			Suitable flight corridors	Training days lost due to flight area restrictions from T&E species	"
			Bird-free area (strikes avoided)	Training days lost due to area restricted due to bird presence	"
	Marine Training	Compatible Ground Areas	Compatible runways and helipads	Training days lost due to incompatible vegetation on landings	"
			Compatible Landing Areas	Compatible docking area (vegetation-free)	Training days lost due to incompatible docking conditions
	Sonar capabilities	Useable sonar area	Training days lost due to restricted use of sonar / sound-emitting equipment	"	

Expected results from using metrics, indices and decision support tools

The results of conducting the proposed analysis would be to provide quantitative and/or monetary estimates of Legacy program benefits that could be compared to costs. To summarize total program benefits, an analyst would complete the table and sum training days gained, sum costs avoided, and aggregate both into a common metric, if desired. This metric would be divided by costs for a CEA analysis or costs would be subtracted from monetized benefits for a partial CBA.

Although training days gained from Legacy program activities can be easily summed, they may not be simply additive, if some activities have greater effect than others on troop training sufficiency. For example, a day of lost artillery training may be half as important to troop readiness as a day of paratrooper training, given the frequency of training opportunities. Therefore, a weighting scheme could be used to weight training days by their importance. This weight could be a non-monetary multiplier (e.g., a 0-1 scale), where the high value is used to represent the most irreplaceable type of training activity and low values represent training activities that are less critical or more easily substituted. Alternatively, training days could be valued in monetary terms by activity type, to represent the relative concern about losing a specific type of training experience.

Both types of weights on training days (scalar or value) can be used in CEA, however, a monetary value would enable effects on training days to be directly summed with costs avoided. Thus, the benefits of the Legacy program in terms of readiness would be the sum of net training days gained (weighted by importance to readiness) and costs avoided (Equation 1). Costs avoided are readily summed, since monetary values already reflect relative importance and potential tradeoffs.

$$\text{Readiness benefits} = \sum bd_i + \sum c_i \quad (\text{Eqn 1})$$

where d is net training days gained due to Legacy investments per activity i ; b is a scalar used to value a training day of type i ; and c is costs avoided from mitigating for lost use.

A valuation or weighting scheme on training days would need to be developed using expertise from within DoD and could be facilitated using economic or decision science techniques. Although we show a simple approach to metric aggregation, indices or multi-attribute measures of performance can easily become distorted if they are not developed carefully. Decision science techniques have been developed to promote an accurate representation of the desirability of outcomes when created an index. Similarly, economic techniques have been developed to promote unbiased assessments of value of a change. A monetary value could be based on the willingness to pay by military managers to add a training day and could be estimated through a survey. Existing guidance on troop training goals might also be usefully applied to understand effects on training sufficiency since they already embed information on what types of training are most critical to achieving service member readiness. Methods will need to be tailored to different types of installations, given that each has a specific set of constraints under which it must operate, such as available area, climate conditions, and potential for conflicts (e.g., due to noise, vibration, electromagnetic spectrum).

If readiness benefits were monetized (if b is used converts days to dollars), they could be compared to program costs to conduct a CBA. However, this result would be misleading since readiness benefits are not a comprehensive view of program benefits. A more appropriate approach would be to add in benefits associated with maintaining the base in good condition and the public's willingness to pay to

maintain species and habitats (Eqn 2). This more comprehensive estimate of benefits could be compared to costs to estimate net benefits (Eqn 3).

$$\text{Legacy benefits} = \text{Readiness benefits} + \text{Other base management benefits} + \text{Social (non-military) benefits} \quad (\text{Eqn 2})$$

$$\text{Net benefits} = \text{Legacy benefits} - \text{program costs} \quad (\text{Eqn 3})$$

Barring the ability to conduct a full CBA, a CEA could be conducted using training days gained per dollar spent to compare program effects over time. As an example of a CEA result, if we said the program expenditures were \$300 million and used equal weights to sum training days gained, then the cost-effectiveness result would be 10,360 training days / \$300 M costs = 35 training days saved per \$1 M spent (Table 5). To provide a more complete picture of benefits by incorporating the costs avoided in addition to training days gained, we would have to create an index that weighted and summed the training days and costs avoided. The result would be in the form of 30,000 (unitless) benefits per \$1M spent. Alternatively, if training days were valued at \$20,000 per day, total readiness benefits could be summed, and were about \$700 million in this example. This monetary total is not appropriate for a CBA, since it did not comprehensively assess benefits to people on and off installations.

Table 5. Hypothetical example of aggregating proposed benefit metrics for cost-effectiveness analysis

Readiness Category	Training Type	Training days gained / year	Costs Avoided (\$millions/yr)	Training day value equivalents (\$millions/yr)	Total cost savings (\$millions/yr)
Troop Health and Safety	Ground	480	\$10	\$9.6	\$20
	Air	250	\$20	\$5.0	\$25
	Water	150	\$15	\$3.0	\$18
Equipment Operation & Maintenance	Ground	100	\$100	\$2.0	\$102
	Air	50	\$200	\$1.0	\$201
	Water	30	\$100	\$.6	\$101
Training Sufficiency	Ground	5800	\$20	\$116.0	\$136
	Air	2000	\$15	\$40.0	\$55
	Water	1500	\$10	\$30.0	\$40
Total		10,360	\$490	\$207	\$697

Data needs to quantitatively assess program outcomes

This analysis described several types of data that would be needed to conduct a CEA or CBA in terms of military readiness. Those needs included 1) an evaluation of baseline outcomes and risk mitigation strategies if natural resource management were not undertaken, 2) the success of those projects in terms of adding net training days or preventing costs, and 3) judgment as to the relative importance of different beneficial outcomes including the degree of harm to training sufficiency per type of training day lost. These data needs could be filled in one of three ways that differ in resources required:

1. *Low cost* – Best professional judgment and simple models used to project expected results
2. *Intermediate cost* – Data collection from base records (e.g., vehicle repair records, troop training outcomes, including causes of accidents or days lost) combined with best professional judgement of project success
3. *High cost* – New field data collection of project sites before and after projects; changes in installation cost accounting to track costs specific to natural resource management program

In all cases, the best results could be expected from engaging installation managers in designing the benefits assessment. Economists and decision scientists have developed methods to elicit expert judgment in ways that promote objective and unbiased assessments and an expert judgement approach is likely to be the simplest and least costly way to assess impacts. It can be done with approaches that range from simple to complex, where the more complex approaches offer greater accuracy. For example, the Readiness and Environmental Protection Integration (REPI) program uses a simple weighting scheme to select projects for funding based on an index of 1) encroachment threat (reduction of), 2) environmental protection, and 3) viability of agreement (Messer et al., 2016).

A typical approach to developing a benefits index for decision support would be to form a committee that represents the spectrum of interests across services and installation types. The committee would meet several times with a decision support scientist to establish goals, select metrics and verify that outcomes of the process were useful for decision support (details in Gregory and Keeney, 2017; Marttunen et al., 2017). The benefit and cost data needed to compare performance to costs would require changes in information gathering. Accounting methods, such as those used by some parts of the United States Army Corps of Engineers, can be designed to account for costs on a project-by-project basis to assess staff time and overhead that are being applied to specific projects. Accuracy of benefit measures can be promoted by using data mining and field monitoring to quantify results.

Conclusions

In this report, we suggested multiple potential benefit or performance metrics to use to evaluate Legacy program performance. We proposed an approach that would allow benefits to be aggregated as training days gained and costs avoided. We further suggested that the simplest way to aggregate these two beneficial outcomes would be to sum them after monetizing the training days gained. The value of training days gained should represent their importance to training effective warfighters. Our recommendation would be to use a structured elicitation process (e.g., workshops, focus groups, and a survey) with DoD personnel to create a method of monetizing training days.

Use of this analysis would provide a means to score the military readiness benefits by project or for the program as a whole. Such an approach would be useful for a post-hoc analysis of projects but would not necessarily serve as a guide to future investments. Since we only included readiness benefits, this

analysis omits many types of benefits provided through the program and, importantly, does not represent any social tradeoffs that might be present between benefits of protecting irreplaceable natural resources and benefits derived from military readiness.

To fully implement benefits accounting for the Legacy program would require changing information available. The best source of information that we found was the DENIX database of projects. As a minimum step to improving information, grantees could be incentivized to improve their evaluations of military readiness in their project reporting. Some simple quantitative performance metrics could also be required to improve accounting. For example, grantees could be asked to estimate the number of acres improved and to fill in a checklist of the types of training activities likely to benefit from the project. Table 4 provides some example terms that might be used in such a checklist under the column “beneficial outcomes.” Alternatively, Table 1 provides the type of detailed outcomes that installation partners may be able to easily supply. A narrative description of how training activities will be supported should be used to document the checked box choices.

Cost data are also needed to assess CEA or CBA and the more detailed the cost data, the greater potential to make representative comparisons across projects. For example, if two projects restore the same number of acres but have vastly different total costs, it will be useful to understand the sources of variability. Unless costs are broken down into specific categories, managers will have no way to understand that costs may be higher due to different scopes, such as cases when planning funds were supplied separately from implementation or when specialized approaches were needed. We recommend that project costs be separated, at a minimum, into planning & design, implementation, maintenance, and monitoring. It would be even more useful if implementation costs were broken down into equipment, labor, supplies, and other relevant categories and cost categories would be associated with area restored (e.g., chemical X, cost of \$Y, applied to 20 acres). Volunteer labor hours, volunteer support costs, and in-kind support by installation personnel and/or equipment would complete the cost information.

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Appendix 1. Summary of Legacy Projects or Programs from Literature Review

Table A1.1 Summary of Legacy projects or programs associated grouped by species being managed.

Table is organized by fauna or flora type (Category) with additional information on taxonomic groups, where available. Information on the nature of the interaction between the biota and base personnel, management actions pursued, benefits to the base or troops, and a description of the cost to military readiness is provided. The military base is given (in some instances several installations are aggregated), costs in millions of USD for individual projects or programs are noted, as are years or area treated under the management action. Blank cells indicate no data.

Category	Taxon or Taxa	Interaction with military personnel	Management Action (Treatment)	Benefit to Base/Troops	Cost to Troop Readiness	Military Base/Fort, State	Cost (millions of \$)	Years treated	Acres treated
Insects	Red Imported Fire Ants (RIFA)	RIFA cause injury via mass bites/stings, and impact sensitive wildlife due to their aggressive predatory behavior.	Removal of ants by insecticides if size of colony is manageable.	Able to carry on with operations without physical harm to troops.	Training areas were off-limits that had ants, therefore decreasing troop readiness. RIFA hinder personnel and equipment movement.	Camp Bullis, TX			
	Monarch butterfly, Pollinating Birds and Insects, Amphibian, and Reptiles	Certain species are of concern of endangerment.	Monitor wildlife species of concern by conducting inventory surveys and studies to comply with military order to participate in & contribute to conservation efforts.	Military personnel can carry on with training and are not endangering any insects under the compliance of the ESA.	Lost training days scouting species of concern and performing surveys. Training operations needing to be relocated or altered depending on what species of concern are nearby.	Camp Pendleton, CA		Every 2 years.	
	Coconut Rhinoceros Beetle (CRB)	They bore holes into Hawaiian coconut and other palm trees, leading to widespread tree mortality which creates a safety hazard for troops.	Monitoring populations, eliminating breeding sites, managing plant debris, and conducting public outreach and education.	Plant debris will not be a hazard to training. Falling trees will not be a hazard to troop safety.	Training days were lost, safety was in danger from falling trees.	Joint Base Pearl Harbor-Hickam (JBPHH), HI			
	Asian Tiger Mosquito (ATM)	Mosquitoes stowed away in airplanes and transported to bases carrying the Zika virus.	Obtained an emergency Section 18 registration to allow use of insecticidal treatments in cabin areas of military aircraft due to mosquitoes being stowed away and transmitting the Zika virus.	Troop health increased after treatment.	Due to insecticidal treatments, flight days were reduced. Some mosquitoes may have not died, health danger to future troops/surrounding base area.	Several Installations			

Category	Taxon or Taxa	Interaction with military personnel	Management Action (Treatment)	Benefit to Base/Troops	Cost to Troop Readiness	Military Base/Fort, State	Cost (millions of \$)	Years treated	Acres treated
Plants	Giant Hogweed	Giant hogweed causes skin burns and temporary blindness to soldiers when contact is made.	Removal of giant hogweed.	Able to carry on with operations without physical harm to troops.	Halted training due to danger to troops.	Several Installations			
	Non-Native Mangrove	They obstruct line-of-sight near borders, create thickets that distort military exercise and endanger native species, and increase flooding risks.	Removal of mangroves.	Line-of-sight was restored, and military exercise returned at a normal schedule.	Training days were lost, safety was in danger, and military exercises were postponed until treated.	Marine Corps Base Kaneohe, HI			
	Common Reed	Common Reed (an aggressive 8'-16' wetland species) prevents clear line-of-sight around installation perimeter which threatens base security and sensitive species.	Controlling Phragmites using satellite mapping to identify problem areas, conduct targeted herbicide spraying, and then reseeding those areas with native plants.	Able to carry on with training when clear line of sight was restored.	Lost training area due to native planting exercises.	Norfolk Naval Air Station, VA			
						Langley Air Force Base, VA			
						Fort Eustis, VA			
	Invasive Fauna	Invasive fauna was present that would have damaged the base as well as decreased the availability of native plants.	Controlled invasive fauna through pesticides.	Avoided severe infrastructure damage, and devastation to native ecosystems.	Potentially halted or moved training exercises.	Camp Pendleton, CA	\$1.2	5	
	Non-Native Pickleweed and Mangroves	Pickleweed and Mangroves (non-native) were destroying the mating grounds of the endangered Hawaiian silt population.	Drove Amphibious Assault Vehicles through a large area of mud flats to break up the pickleweed and destroy the mangrove roots.	Complied with the ESA. This activity increased the Hawaiian stilt population on base from 60 birds in 1982 to 150 birds in 2017 (10% of the bird population in Hawaii).	Used training vehicles for activities other than training. Amphibious Assault Vehicle training days were reduced.	Marine Corps Base Kaneohe, HI			200
Invasive Grasses	Invasive grasses are growing at a rapid speed and taking over field space, and runway area, endangering the equipment and flights taken by troops.	Resources were expended to remove invasive grasses from the airfield to protect aircrews and prevent damages to equipment used to operational activities.	Field space is opened and runway area is cleared, ensuring the safety of military training flights.	During removal, military flights were cancelled, due to runways being closed.	Holloman Air Force Base, NM				

Category	Taxon or Taxa	Interaction with military personnel	Management Action (Treatment)	Benefit to Base/Troops	Cost to Troop Readiness	Military Base/Fort, State	Cost (millions of \$)	Years treated	Acres treated
	Yellow Star Thistle	Yellow star thistle is flammable, and has large thorns that can injure soldiers/equipment.	Used an Integrated Pest Management Plans, which focused on identifying pests, setting action thresholds, and preventing/controlling pests with insecticides.	Soldiers and civilians living on the base became safer with lower fire risk, and less thorns to tangle equipment in.	Costly work around were implemented to insure adequate training. Training days were lost due to battling the invasive plants.	Fort Hunter Liggett, CA			
	Fountain Grass	Increases frequency and size of wildfires in realistic training area.	Prescribed burns to clear out invasive grasses.	Able to continue training on realistic terrain with a lower risk of fire occurrence.	Lost troop training days due to smoke inhalation hazards and impediments to line of sight from smoke.	Pohakuloa Training Area, HI			
	Excess Vegetation & Invasive Grasses	Increases wildfire risk for training areas overrun by invasive vegetation.	Wildland fire programs reduce and clear excess vegetation, protect sensitive resources, and support recovery efforts for fire-tolerant native species.	Wildfire risk will decrease in training areas.	Lost troop training days due to smoke inhalation hazards and impediments to line of sight from smoke.	Shaw Air Force Base, SC			
	Tall Fescue, and Japanese Stilt-Grass	Loss of biodiversity and displacement of species of interest. Invasive plants are spreading to adjacent lands such as recreational civilian parks.	Removal of invasive vegetation through herbicides and biological control if funding is available.	Spreading to adjacent lands will cease.	Spreading of invasive grasses into civilian areas or training areas. Herbicide spraying may cause a loss of training days.	Fort Lee, VA			
	Narrow-Leaved Cattail	Reduction of flood storage capacity in wetlands.	Removal of invasive vegetation through herbicides and biological control if funding is available.	Removing plants that increase flooding will allow for troop activities to carry on without structural damages.	Structural damages may occur due to an increase in flooding around wetland areas on bases.	NA			
Animals	Various Threatened and Endangered Species ²	A lack of species monitoring. Troops are endangering habitats/organisms. A need for database creation of species/monitoring through GIS.	Maintain a comprehensive record of data for all listed wildlife species on-Base to support effective adaptive management decisions and program funding requirements.	Comprehensive records, integrated database, annual/periodic monitoring of nesting and occupied areas; and habitat studies allow troops to train in designated areas.	Training area was lost due to practices being limited to certain designated areas.	Camp Pendleton, CA			

Category	Taxon or Taxa	Interaction with military personnel	Management Action (Treatment)	Benefit to Base/Troops	Cost to Troop Readiness	Military Base/Fort, State	Cost (millions of \$)	Years treated	Acres treated
	Feral Swine	Feral swine destroy nesting habitats, eat or uproot endangered plants, disrupt food webs, and prey on endemic fauna, including eggs of T&E species, such as sea turtles. Also known to attack military and civilian personnel and dogs.	DoD manages invasive feral swine by educating and communicating with stakeholders, as well as by hunting, trapping, and monitoring the species.	With the irradiation of feral swine, native plants can continue to grow, and native animals will flourish. Increase in troop health (less swine attacks).	Training areas were limited due to feral swine being present. Troops were in danger health and safety-wise.	South eastern and increasingly northern military installations.			
Birds	Red-Cockaded Woodpecker	Endangered species threatened by military encroachment & training exercises in habitat.	REPI buffering projects to protect habitat off-base. Limited on-base activities: operating vehicles off roads; damaging pine trees; disturbing soil; tree topping; and firing artillery close to trees.	Protects the military mission (to implement measure to recover threatened or endangered species).	Training area was limited in order to create buffer areas, and training exercises were altered to cater to the woodpeckers' sensitivities.	Camp Lejeune, NC	\$12.8		1885
	Red-Cockaded Woodpecker	Endangered species threatened by military encroachment to habitat.	Used a buffer program to protect the sandhills ecosystem that the woodpecker lives in.	Protects the military mission (to implement measure to recover threatened or endangered species).	Training area was limited in order to create buffer areas.	Fort Bragg, NC	Funding History Total (99-05): \$15.6	1999-2005	Parcel History Total (99-05): 19,586
	Brown-Headed Cowbird, Exotic Aquatic Species	Exotic species are causing parasitism in listed riparian bird species.	Removal of target exotic species.	Removing exotic species will allow for the military to obtain reasonable control (distribution and abundance) of exotic wildlife species which will benefit listed and nonlisted species. This will reduce or eliminate parasitism of listed riparian bird species and also remove exotic aquatic species like nonnative fish, bullfrogs, and crawfish. Increase in training days.	Training area and training time was limited due to the removal of exotic species.	Camp Pendleton, CA			

Category	Taxon or Taxa	Interaction with military personnel	Management Action (Treatment)	Benefit to Base/Troops	Cost to Troop Readiness	Military Base/Fort, State	Cost (millions of \$)	Years treated	Acres treated
	Birds	Birds are a flight hazard and fly into training aircraft.	Controllers divert, cancel, or delay flight operations. Implement measures as needed to exclude nesting, roosting, and perching within the Air Station's area of operation, conduct daily inspections to monitor avian use of hangars, maintain vegetation to be at or below 3 inches around the air strip, and conduct BASH (Bird Aircraft Strike Hazard) surveys when needed.	Military safety will increase when conducting flights.	Lost training time trying to divert birds.	Camp Pendleton, CA			
	Aleutain Cackling Goose	The incidence of bird-aircraft strikes.	To reduce BASH, they reduced the attractiveness of environments by implemented activities such as planting beach wildrye, a plant that the goose avoids, and using firecrackers to keep birds away from the runway.	Proved successful, allowing personnel to continue safe flight training while helping maintain bird populations.	Lost training time trying to divert birds.	Eareckson Air Station, AK			
	Western Burrowing Owl	BASH concern (danger to military flights), dwindling population.	Installed artificial nests that helped increase the burrowing owl population and collected information on the movements of the owl, allowing personnel to develop management plans regarding nesting locations.	Burrowing owls will not be a BASH concern and increase in population.	Lost training time diverting owls, and collecting information on the burrowing owl.	39 Arizona military installations: Fort Irwin Kirtland Air Force Base Marine Corps Air Station Yuma		4	
	Invasive Species and Ground-Nesting Birds	Troop training areas were decreasing in quality due to invasive species. Ground-nesting bird habitats were being displaced due to invasive species.	Conducted an invasive species removal project to open habitat for ground-nesting birds.	This project benefited the military personnel at Fort Lee and bird species by supporting range operations and improving available training areas.	Lost training area due to habitat establishment exercises and removal of invasive species.	Fort Lee, VA			

Category	Taxon or Taxa	Interaction with military personnel	Management Action (Treatment)	Benefit to Base/Troops	Cost to Troop Readiness	Military Base/Fort, State	Cost (millions of \$)	Years treated	Acres treated
	Mexican Spotted Owl	Military actions are stressing the spotted owl population. Excess of brush is at the base of mountains.	Created an INRMP to recover the spotted owl. They used prescribed burns to not only prevent accidental fires, but also to designate habitats to the spotted owl.	Prescribed burning lead to safety of military personnel, and fire-free land for training exercises.	Reduced training area due to prescribed burning. Lost training days due to burn days. Low visibility during burn days.	Fort Huachuca, AZ			
	California Least Tern and Western Snowy Plover	Endangered species recovery efforts of the California lest tern and the Western snowy plover.	Managed federally through the Memorandum of Understanding (MOU) with FWS. Staff closed several training lanes during nesting season, created buffers for nesting, and coordinated with FWS to establish a cap on the total number of nests that could restrict training at any given time to ensure plover population recovery would not endlessly impede beach training.	Preserves important buffer areas around installations to ensure habitat for threatened and endangered species while maintaining critical testing and training capabilities. The base was able to resume use of three training lanes that were previously restricted during nesting season.	Lost training area (lanes were restricted) and training days.	Naval Base Coronado, CA			
	Golden-Cheeked Warblers, Black-Capped Vireos, and Brown-Headed Cowbirds	Restricted training on 72,000 acres of land that was deemed important for the recovery of the federally listed birds: the golden-cheeked warblers, and the black-capped vireos.	Created a trapping program to manage the brown-headed cowbird, who preys on the endangered birds, in order to allow more training on areas previously deemed as important habitat for the endangered birds. A 10 year analysis was completed that found the trapping program helped to increase the warbler and vireo population.	Because of the Army's trapping programs, FWS permitted continued live weapons training, and reduced training restrictions to 51,500 acres of land in 2000, and to just 9,500 acres (available for most of the year) in 2005.	Training areas were lost due to the 10 year trapping program, and training exercises were limited during that time.	Fort Hood, TX		10	66000

Category	Taxon or Taxa	Interaction with military personnel	Management Action (Treatment)	Benefit to Base/Troops	Cost to Troop Readiness	Military Base/Fort, State	Cost (millions of \$)	Years treated	Acres treated
	Piping Plovers and Red Knots	Endangered species recovery efforts of the piping plovers and red knots. Eroding beach areas and lack of protection against powerful coastal storms.	Constructing sand dunes on the beach to provide food and habitat for endangered birds. Also, provides safety for military personnel/safety from storms.	The reconstruction of the dunes are ideal for special operations training, and serve as a barrier that protects military personnel, training facilities, wildlife, and inland habitats from wind, waves, hurricanes, northeastern and other destructive forces.	Troops lost traveling grounds and training areas along beaches (if eroded) before replenishment project.	Naval Air Station Oceana Dam Neck Annex, VA		8	1100

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2. Various T&E species includes: *Riverside fairy shrimp, San Diego fairy shrimp, Quino checkerspot butterfly, tidewater goby, arroyo toads, Southwestern willow flycatcher, least tern, snowy plover, Ridgway's rail, California gnatcatcher, Stephens' kangaroo rat, and Pacific pocket mouse*

Appendix 2. Case Study Screening Analysis

Table A2.1. Summary of physical, climatological, and mission-relevant information for military installations referenced in Appendix 1.

Table is organized by installation with additional information on the geographical footprint of the installation (acres), climate, description of local terrain, primary troop training facilities, and the branch(es) housed on the installation.

Military Base/Fort, State	Size (acres)	Climate Zone	Terrain	Training Exercises/Facilities	Military Branch
Camp Bullis, Texas	28,000	Hot-Humid	Rugged hill and prairie country terrain with forested areas.	Realistic urban training areas (Combined Arms Collective Training Facility, Military Operations on Urban Terrain compound). 20 live firing ranges, simulation facilities, an armory, a medical clinic, a training complex, and airfield, 4 drop zones, and maneuvering lands to support Joint Base San Antonio and others.	Army, Air Force, and Marines
Camp Pendleton, California	125,000	Hot-Dry	Coastal and mountain terrain. Specifically beaches, bluffs, mesas, canyons, and rivers.	Basic training, Assault Amphibian training, infantry training, and field medical training.	Marines, Army, and Navy
Joint Base Pearl Harbor-Hickam (JBPHH), Hawaii	28,000	Marine	Lush landscape with coastal and rocky terrain.	Provides berthing and shore side support to surface ships and submarines, as well as maintenance and training.	Air Force, Navy
Marine Corps Base Kaneohe, Hawaii	2,951	Marine	Coastal and rocky terrains.	Littoral maneuver training, energy generation and storage, artificial intelligence experimentation, and expeditionary logistics.	Marines
Norfolk Naval Air Station, Virginia	3,400	Mixed-Humid	Coastal terrain, situated near waterways.	Home port to 4 carrier strike groups and their assigned ships. Norfolk also hosts the submarines of the Atlantic Fleet. Shore activities provide administrative and specialty support to regional operational assets, and in some cases the entire Navy.	Navy
Langley Air Force Base, Virginia	3,152	Mixed-Humid	Coastal terrain, situated near waterways.	First Fighter Wing personnel have often led the way in global action and have flown lighter-than-air aircraft, Spads, Jennys, F-86 Sabre Jets, F-4 Phantom IIs, F-15 Eagle, and the F-22A Raptor. Home to the Air Combat Command, the largest major command in the USAF, possess two airfields. Became Joint Base Langley-Eustis in 2010.	Air Force
Fort Eustis, Virginia	8,300	Mixed-Humid	Coastal terrain, situated on low-lying land along the James River.	Army transportation training, research and development, engineering, and operations, including aviation and marine shipping activities, as well as cargo loading. Became Joint Base Langley-Eustis in 2010.	Army

Military Base/Fort, State	Size (acres)	Climate Zone	Terrain	Training Exercises/Facilities	Military Branch
Holloman Air Force Base, New Mexico	59,639	Hot-Dry	Dry and mountainous terrain (located in between two mountains).	Home to the world's longest and fastest rocket sled test track, and has been testing missiles since 1948. Has wing, test, and fighter aircraft divisions.	Air Force
Fort Hunter Liggett, California	167,000	Marine/Mediterranean	Unencroached terrain encompassing mountains, valleys, rivers, plains, and forests.	Provides 47 ranges, 35 training areas and a variety of facilities to support year-round joint, multi-component and interagency training. Available facilities include 4 Tactical Training Bases, Convoy Live-Fire Course, Weapon Qualification Ranges, Urban Assault Course, dirt airstrip, dozens of Drop Zones, and helipads.	Army
Pohakuloa Training Area, Hawaii	108,863	Marine	Lies in a high plateau between slopes of mountains. Rocky and forested terrain.	Has an impact area used for bombing and gunnery practice, as well as helicopter training. Large maneuver fields allows for a wide range of weapons to be used.	Army
Shaw Air Force Base, South Carolina	3,429	Mixed-Humid	Flat, urbanized terrain.	Has an air base with an active railroad line. Fighter wing squadrons and air combat command units are present at this base.	Air Force
Fort Lee, Virginia	6,000	Mixed-Humid	Forested, and urbanized terrain.	Home of "Army Sustainment" and to the Combined Arms Support Command/Sustainment Center of Excellence, Ordnance School, Quartermaster School, and the Transportation School.	Army, Marines
Camp Lejeune, North Carolina	156,000	Mixed-Humid	NA	To help prepare warfighters for combat and humanitarian missions abroad, Camp Lejeune offers 156,000 acres, 11 miles of beach capable of supporting amphibious operations, 34 gun positions, 50 tactical landing zones, three urban terrain training facilities, and 80 live fire ranges. The property is used by more than 170,000 people including more than 63,000 active duty military and 11,000 civilians.	Marines
Eareckson Air Station, Alaska	10,000 ft airfield	Sub-Arctic	Rolling hills of tundra/sandstone terrain, dotted with small lakes, and low-lying marshy areas.	Its location in the middle of the northern Pacific Ocean makes it an ideal refueling stop for military aircraft flying between North America and Far East Asia. Eareckson also serves as a divert field for in-flight emergencies, and a base for search and rescue efforts in the Northern Pacific. Converted to contractor operations and maintenance in 1995.	Air Force
39 Arizona military installations: e.g., Fort Irwin Kirtland Air Force Base Marine Corps Air Station Yuma	NA	Cold, Mixed-Dry, Hot-Dry	NA	NA	NA

Military Base/Fort, State	Size (acres)	Climate Zone	Terrain	Training Exercises/Facilities	Military Branch
Fort Huachuca, Arizona	73,142	Hot-Dry	Desert, dry terrain surrounded by mountains.	Specialize in technological command and military intelligence.	Army
Naval Base Coronado, California	1,204	Hot-Dry	Coastal terrain.	Specialize in amphibious training, home to various aircraft carriers and airfields.	Navy
Fort Hood, Texas	214,000	Hot-Humid	Open space with rolling hills and lakes.	Home to it's own airfields, training areas, and civilian use reservations.	Army
Naval Air Station Oceana Dam Neck Annex, Virginia	6,820	Mixed-Humid	Rests on highlands, marshes, coastal beaches and sand dunes.	Is a US Navy Master Jet Base, home to 17 fighter squadrons, and training is also conducted here in various aircraft.	Navy