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Enlisting Ecosystem Services: Quantification and Valuation of Ecosystem Services to Inform Base Management

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14. ABSTRACT
An integrated understanding of the natural and social implications of land-use decisions can lead to more effective land management in the DoD using an ecosystem service approach developed by the Natural Capital Project. The approach provides estimates of the values of natural capital through iterative stakeholder engagement, scenario planning, biophysical and economic/social modeling with free, open-source InVEST (Integrated Valuation of Environmental Services and Tradeoffs) software, and synthesis of multi-service outputs. In coordination with installation personnel, we applied our approach to multiple-use landscape management at three DoD installations by evaluating ecosystem services under future scenarios that reflect alternative military missions and natural resource management strategies. The tested approach and tools are especially helpful in 1) offering a mechanism for incorporating ecosystem services into the existing ecosystem-based management framework employed by the DoD for spatial planning and resource management, 2) providing spatially explicit, quantitative estimates of current and future ecosystem services to complement field observations and qualitative measures common in current environmental impact assessments, and 3) demonstrating a flexible, modular structure to aggregate various types of information (e.g.,training activities, cultural resources) and tools (e.g., SWAT, HexSim)to support a more comprehensive assessment of changes in biodiversity and multiple ecosystem services.

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LIST OF ACRONYMS

ac	Acre
ACUB	Army Compatible Use Buffer
BAU	Business-As Usual
BMP	Best Management Practice
BRAC	Base Realignment and Closure
CEQ	Council on Environmental Quality
CTA	Close-in Training Area
EA	Environmental Assessments
EIS	Environmental Impact Statements
EPA	Environmental Protection Agency
DEM	Digital Elevation Model
DISP	Defense Installation Strategic Plan
DoD	Department of Defense
DoDI	Department of Defense Instruction
EPD	Environmental Protection Division
ESA	Endangered Species Act
GHG	Greenhouse Gas
GHMTA	Good Hope Maneuver Training Area
GIS	Geographic Information System
ha	Hectare
HBDT	High Budget-Decreased Training
HBIT	High Budget-Increased Training
HQDA	Headquarters, Department of the Army
HRA	Habitat Risk Assessment
HRU	Hydrologic Response Unit
HUC	Hydrologic Unit Code
INRMP	Integrated Natural Resource Management Plan
InVEST	Integrated Valuation of Environmental Services and Tradeoffs
IPBC	Infantry Platoon Battle Course
IPCC	Intergovernmental Panel on Climate Change
ITAM	Integrated Training Area Management
JBLM	Joint Base Lewis-McChord
LAI	Leaf Area Index
LBDT	Low Budget-Decreased Training
LBIT	Low Budget-Increased Training
LEF	Long-term Ecological Forestry
LUDP	Land Use Deconfliction Process
LULC	Land Use and Land Cover

MCoE	Maneuver Center of Excellence
MPRC	Multi-Purpose Range Complex
MUSLE	Modified Universal Soil Loss Equation
NASA	National Aeronautics and Space Administration
NatCap	Natural Capital Project
NBCD	National Biomass and Carbon Dataset
NCDC	National Climatic Data Center
NEPA	National Environmental Policy Act
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
PES	Payment for Ecosystem Services
PET	Potential Evapotranspiration
PO	Performance Objective
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RCW	Red-cockaded Woodpecker
REPI	Readiness and Environmental Protection Initiative
RUSLE	Revised Universal Soil Loss Equation
SSC	Suspended Sediment Concentration
SCS	Soil Conservation Service
SCT	Short-term Concentrated Training
SDT	Short-term Diffuse Training
SWAT	Soil Water Assessment Tool
TA	Training Area
T&E	Threatened and Endangered species
TMDL	Total Maximum Daily Loads
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Command
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
WMU	Watershed Management Units

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The full suite of environmental benefits accruing to or affected by federal land management activities typically is not accounted for in decision-making processes, leading to uncertainty in planning and unnecessary costs to the agencies and society at large. Federal agencies are increasingly interested in adopting an ecosystem service approach to address some of their unique resource management challenges. A clear understanding of ecosystem service values and their interconnections could help the Department of Defense balance mandated mission activities with environmental stewardship requirements, sustain multiple uses of lands, evaluate environmental impacts for proposed actions or policies in compliance with the National Environmental Policy Act, resolve land use conflicts within and among agencies, and communicate management objectives with Congress and the public.

However, evaluating ecosystem services at scales and in currencies that are relevant to everyday decision-making processes is an important gap in natural resource management, and few tools exist that can be applied in a systematic, repeatable, and transparent manner across sites at the spatial scales and time frames relevant to major decisions.

This project aims to demonstrate that an integrated understanding of the natural and social implications of land-use decisions can lead to more effective land management in the DoD. We demonstrate an integrated ecosystem service methodology for incorporating the provision and value of ecosystem services and biodiversity into management decisions of DoD installations using a novel, open-source software package to estimate the relative benefits of alternative land uses, military activities, and protection or restoration of habitats for species at risk on installations. Additionally, we provide the DoD with support to enable technology integration into overall installation management. This project is the first application of our approach in the regime of federal land management, aiming to reconcile potentially competing objectives of maintaining military mission and sustaining ecosystem services under regulatory constraints.

TECHNOLOGY DESCRIPTION

The ecosystem services approach developed by NatCap provides estimates of the values of natural capital in clear, credible, and practical ways through iterative stakeholder engagement, scenario planning, biophysical and economic/social modeling with InVEST, and multi-service synthesis of outputs. InVEST (Integrated Valuation of Environmental Services and Tradeoffs) is a free and open-source software tool that can be used with a number of Geographic Information System software packages to integrate ecosystem service values into decision-making. InVEST is best used as part of a decision process, and entails linking credible models based on ecological production functions and diverse valuation methods.

The InVEST toolset currently includes seventeen distinct InVEST models suited to terrestrial, freshwater, and marine ecosystems, and additional supporting tools for scenario development and post-processing of results. InVEST has been developed since 2006 by NatCap, a partnership among Stanford University, The Nature Conservancy, World Wildlife Fund, and the University of Minnesota. This tool has been applied and tested in over 20 demonstrations around the world with rapidly growing user base.

DEMONSTRATION RESULTS

We demonstrate the ecosystem services approach and InVEST tools at three DoD installations, i.e., Joint Base Lewis-McChord, WA, Fort Pickett, VA, and Fort Benning, GA, which vary in their size, location, environmental conditions, and management priorities. We have successfully attained a majority of our quantitative and qualitative performance objectives across the three sites. The objectives include developing management scenarios jointly with installation personnel; applying InVEST and ancillary models to quantify, value, and map ecosystem services; examining the tradeoffs and synergies among multiple services based on absolute and relative estimates; conducting uncertainty analysis and model validation; identifying decision-informing opportunities; and evaluating ease of use and user acceptance of our results.

For the **Joint Base Lewis-McChord** case, we examined tradeoffs and synergies among five ecosystem services (i.e., prairie habitat provision, infantry and vehicle training capacities, timber production and carbon sequestration) under a business-as-usual scenario and four alternative scenarios of varied training intensities and budgets for resource management. Aggregate tradeoff and synergy analysis reveals the budget for resource management is a dominant factor in sustaining realistic training environments – a DoD-specific ecosystem service – and a rare prairie ecosystem with species at risk. Timber production and carbon sequestration are predicted to degrade with increased training intensity, which is linked to the dispersal of a pervasive root disease. Understanding the spatial distribution of ecosystem services also can be used to identify priority areas for sustaining current levels of ecosystem services and areas that might be targeted to improve service provision by shifting management funds or training activities. Our qualitative analysis suggests several opportunities for InVEST models to inform and improve natural resource decisions at JBLM, and identifies where Army protocol already incorporates ecosystem service information into their environmental management. Due to lack of technical capacity, installation staff were unable to use InVEST independently, but they provided positive feedback on the value of our analytical approach and the scenario generation process.

For the **Fort Pickett** case**,** we evaluated the ecological suitability of alternative siting choices for a hypothetical training range as an abbreviated demonstration of our ecosystem service approach. We identified nine reasonable siting locations and assessed the ecosystem impacts on carbon storage, biodiversity, and sediment export from creating the new firing range on each location.

We provided recommendations of suitable siting choices based on aggregated ecosystem impacts. Locations most suitable for siting appear to cluster in areas where the baseline landscape has relatively large patches of grasslands and minimal interaction with the water network. This hypothetical application demonstrates how the ecosystem service approach might inform future environmental impact assessments with its spatially explicit, quantitative measures and modular framework. Although installation personnel were not able to adopt InVEST as it requires security certification and additional technical capacity, they were very interested in applying the general ecosystem service framework for selecting sites for new training and energy facilities.

For the **Fort Benning case,** we applied our ecosystem services approach to the installation and adjacent lands purchased, or soon to be acquired, as part of the Army Compatible Use Buffer program. We examined tradeoffs and synergies among three ecosystem services, i.e., provision of low-risk habitat for federally endangered red-cockaded woodpecker (RCW), sediment retention, and carbon sequestration. Through interactive discussion with installation personnel, we developed two 20-year scenarios that differ in the spatial distribution of mechanized training activities, and a 100-year ecological forestry scenario featuring adaptive longleaf pine restoration. Results suggest the more diffuse distribution of mechanized training had relatively small, but positive effects on all three ecosystem services modeled. The long-term ecological forestry scenario shows a large, positive impact on carbon sequestration and greater availability of low-risk RCW habitat. We also compared the InVEST sediment model and habitat risk assessment model with more complex alternatives (i.e., the SWAT and HexSim models, respectively), and found close agreement between the sediment assessment results but significant divergence between RCW population predictions using a habitat risk approach and alternative habitat quality estimates as inputs. Lastly, we evaluated performance objectives related to scenario development, uncertainty analysis, model validation, decision-support opportunities, and ease of use with a post-demonstration survey of installation personnel. The response score ranged from 3.9 to 4.6 on a 5-point Likert scale, indicating general acceptance of our ecosystem service approach and assessment results.

Application of our ecosystem service approach across three installations demonstrates its flexibility to a variety of management priorities, types of land use and cover, data availability, and changes in model parameters. We found the tested approach and tools are especially helpful in: 1) offering a mechanism for incorporating ecosystem services into the existing ecosystem-based management framework employed by the DoD for spatial planning and resource management, 2) providing spatially explicit, quantitative estimates of current and future ecosystem services to complement field observations and qualitative measures common in current environmental impact assessments, and 3) demonstrating a flexible, modular structure to aggregate various types of information (e.g., training activities, cultural resources) and tools to support a more comprehensive assessment of changes in biodiversity and multiple ecosystem services.

IMPLEMENTATION ISSUES

We learned five key lessons throughout our demonstration of an ecosystem service approach to multiple-use landscape management on DoD installations. First, we found an iterative and interactive approach to define when, and what kind of ecosystem service (ES) information is needed was critical to create credible science that could be used in decision processes. Our second conclusion is that it is important to take the time to clearly articulate the appropriate use of InVEST to support novel outcomes in DoD management. The InVEST tools are designed to require relatively few data to broaden the range of applicable locations and decision contexts. As for any simple models, simplifying assumptions are inherent, and thus InVEST is typically most useful for comparing tradeoffs and relative magnitudes of ecosystem services among multiple alternatives of land use planning and natural resource management scenarios. In contrast, InVEST is not as reliable for predicting precise estimates of the absolute magnitudes of ecosystem services at a particular place or time. The tradeoff between ease and relative speed of simple models and greater comprehensiveness of more detailed models will help dictate an appropriate modeling approach to match regulatory or policy needs. Third, we found ecosystem value metrics are most relevant when they are conveyed in measures related to the organization's decision context. Although monetary economic values of ecosystem services are commonly understandable and can be convenient in supporting decisions, non-monetary measures of ecosystem services (e.g., water quality threshold values, habitat area to support species) often play a more vital role in government decision-making. Fourth, we found that successful adoption of InVEST requires technical capacity within organizations. Although some technical support is available through NatCap and on-line user forums, often technical needs exceed these resources. For example, technical capacity/expertise is needed to parameterize, troubleshoot and run InVEST, make scientific judgments about how to fill knowledge gaps (e.g., installation-level input data), and understanding methods for analyzing and visualizing results. Lastly, we suggest that adoption of ecosystem service approaches and tools such as InVEST could be made easier through aligning policy incentives (e.g., linking ecosystem-based management approaches already in place with ecosystem-service approaches), and centralized data support. Based on our discussions with installation personnel and observations, such measures could help reduce current barriers to uptake, such as limited technical capacity and staff time at the installations.

We developed two new resources to further facilitate adoption of our ecosystem service approach and InVEST tools across the DoD. First, we developed novel pre- and post-processing capabilities to standardize some labor-intensive work necessary for applying InVEST models typically used on DoD installations. Second, we developed an online training curriculum, which will serve as a primer on the ecosystem service approach and InVEST tools through the Stanford Online training platform. This course includes specific examples from DoD demonstration sites to illustrate how the approach has worked in each case, and highlights key methods and tools available for future implementation by DoD and other land and resource management entities. The course will be open to all DoD personnel and other interested parties in 2015.

1.0 INTRODUCTION

Land management decisions can have significant societal impacts that are presently difficult to include in accounting approaches. It is challenging to forecast the impacts of land management and land use change in a systematic way because the provision of such ecosystem benefits as flood control, water quality, climate stability, and wildlife habitat depends on the cumulative effects of biophysical processes occurring at different scales. Yet ignoring the value of these ecosystem services can result in costly outcomes, as has been revealed by Mississippi River flooding, coastal damages leading to loss of life and infrastructure from Hurricane Katrina, and the Dead Zone affecting fisheries and livelihoods in the Gulf of Mexico. The Department of Defense (DoD), as a manager of expansive tracts of land and waters, both depends upon and impacts these ecosystem services. Typically, the full suite of environmental benefits enjoyed or impacted by the DoD is not accounted for in decision-making practices, leading to uncertainty in planning and unnecessary costs to the DoD and society at large. For example, the use of heavy machinery during training exercises at Fort Benning results in soil compaction, which in turn leads to excess storm-peak and nutrient runoff (Maloney et al. 2005). The goal of demonstrating an integrated ecosystem services approach using our software, Integrated Valuation of Environmental Services and Tradeoffs (InVEST), at three DoD installations is to identify the benefits of making resource- and land-use decisions with information about the tradeoffs and synergies between intensive land use and ecosystem service provision.

1.1 BACKGROUND

Scientific understanding of the critical connections between people and nature has only slowly moved into the decision-making arena. Economists have explored the value of natural assets (Krutilla and Fisher 1975) and how best to manage them for decades, focusing on agricultural production (Beattie and Taylor 1985), renewable resources (Gordon 1954, Krutilla 1967, Clark 1990), non-renewable resources (Dasgupta and Heal 1979), and environmental amenities (Freeman 1993). However, this appreciation has only recently begun to influence resource-use policy. After decades spent struggling to fence nature off from people, natural resource managers and developers are moving toward a middle ground where conservation and development goals are integrated (Ninan 2009). This shift is evidenced by novel policy mechanisms introduced around the world in the last decade, including the establishment of water funds and other Payments for Ecosystem Services (PES) programs, market-based land-use regulation such as conservation and wetland mitigation banking, and international carbon markets (Ecosystem Marketplace 2013).

Federal agencies increasingly are interested in integrated approaches to address some of their unique resource management challenges: balancing mandated mission activities with environmental stewardship requirements, sustaining multiple uses of lands (e.g., resource conservation, wildlife protection, recreation, and energy development), evaluating environmental

impacts for proposed actions or policies in compliance with the National Environmental Policy Act (NEPA), resolving land use conflicts within and among agencies, and communicating management objectives with Congress and the public. The concept of ecosystem services has been gradually incorporated into some U.S. federal policies and guidance. For example, the President's Council of Advisors on Science and Technology advised federal agencies to improve their capabilities on ecosystem service valuations and integrate the assessment results into their major planning and management decisions (PCAST 2011). The White House Council on Environmental Quality provided guidance on using an ecosystem services evaluation framework for federal water resource investment projects (CEQ 2013). The Forest Service requires incorporating ecosystem services in national forest management plans (USDA Forest Service 2012). Aligned with many other federal agencies, the DoD has started exploring ways to better assesse and communicate the value of the environmental services provided by their natural assets upon which their enterprises depend.

However, evaluating ecosystem services at scales and in currencies that are relevant to everyday decision-making processes is still an important gap in natural resource management. Although ecosystem service assessments have been conducted (see Imperial 1999 for a review, UK NEA 2001, the Millennium Ecosystem Assessment 2005, CONABIO 2006, IPBES Catalogue of Assessments for sub-global assessments, Daily et al. 2013) and ecosystem services analytical tools are being developed (Waage and Kester 2013), few tools can be applied in a systematic, consistent manner across sites at the spatial scales and time frames relevant to major decisions. Without these tools, natural capital is invariably undervalued, or not valued at all, by governments, businesses, and the public (Daily et al. 2000, Balmford et al. 2002, National Resource Council 2005). A major challenge in creating such tools is sufficient information to develop simple ecological production functions that define how changes in the structure and function of ecosystems impact the delivery of ecosystem services. InVEST is designed to address these issues and to improve land- and water-use decisions by quantifying and mapping changes to a suite of ecosystem services and their values across multiple scales (Kareiva et al. 2011).

Installation managers at the DoD are keenly aware that maintaining the environmental resources on each installation can help the DoD successfully meet its mission. For example, the DoD invests in maintaining buffer areas and in restoration activities on installations for several reasons: to meet regulatory requirements, to minimize friction with neighboring communities, to improve species persistence, to establish and maintain suitable and/or realistic landscapes (compared to overseas conflict areas) for testing and training, and to act as a responsible land steward.

One challenge for installations is to meet regulatory requirements related to such attributes as water body sediment concentrations, and habitat conservation for federally listed species and wetland areas. In addition, active management of greenhouse gas emissions may be necessary when land management practices result in an installation being either a source or a sink,

depending on the amount of carbon sequestered in vegetation, soil, and sediments (Executive Order 13514, Obama 2009). At the same time, carrying out DoD's military mission requires that testing and training opportunities are not significantly diminished due to existing regulation, potential future requirements, or encroachment from expanding civilian population centers. Quantitative assessments of how management activities affect different ecosystem services, in addition to habitat for listed species, would help the DoD manage these multiple objectives by identifying methods to minimize the cost of regulatory compliance and maximize the social benefits from management investments.

The DoD also makes decisions about the types of testing and training activities that are allowed (or prohibited) in different regions of its lands. InVEST models are spatially explicit and enable examination of the consequences of different zoning rules for testing and training and the siting of associated infrastructure. Using ecosystem service assessments, the DoD can manage its landscapes to balance necessary testing and training exercises with natural resource stewardship, thereby minimizing impacts that result in costly treatment, regulatory burden, or strained relations with the public. Moreover, by accounting for ecosystem services in land-use decisions, those mission activities that are themselves dependent on continued provisioning of particular ecosystem services are likely more sustainable.

The Defense Installation Strategic Plan (DISP) aims to ensure that installations have the necessary assets and services to support military forces in a cost-effective, safe, sustainable, and environmentally sound manner. Programs such as the Readiness and Environmental Protection Initiative (REPI) are designed to aid in off-installation conservation to provide relief for mission activities on installations. InVEST could be an effective complement to these existing efforts. The InVEST tool will support these programs by broadening the costs and benefits considered by installation managers when they scope management improvements and alternatives.

1.2 OBJECTIVE OF THE DEMONSTRATION

This project aims to demonstrate that an integrated understanding of the natural and social implications of land-use decisions can lead to more effective land management. Our approach to ecosystem service assessment can support sustained testing and training realism, sound infrastructure development, and the maintenance of ecosystem integrity. With maps of ecosystem service provision and value, installation managers will be able to identify the specific tradeoffs or synergies that exist when siting testing and training activities, complying with environmental regulations, and achieving other goals or requirements associated with their natural resources. Such maps could also be useful in identifying ways to maximize the environmental returns of off-installation conservation or restoration efforts. Furthermore, we hope that this pilot effort will provide the DoD with a clear means of integrating this transferable and transparent approach into its overall management efforts across all of its installations.

The main objectives for the project are to:

● Demonstrate an integrated ecosystem service methodology for incorporating the provision and value of ecosystem services and biodiversity into management decisions of the installations;

● Use a novel, open-source software package to estimate the relative benefits of alternative land uses, military activities, and protection or restoration of habitats for species at risk on installations; and

● Provide the DoD with sufficient support to enable technology integration into overall installation management.

1.3 REGULATORY DRIVERS

Federal and state environmental regulations, as well as DoD directives and agency-wide management practices, reveal a need to measure and track impacts to multiple aspects of the ecosystems on DoD lands. Here, we present regulations and policies that govern the natural resource management decisions of installations and that motivate our exploration of InVEST and an integrated ecosystem services approach as potential ways to further compliance efficiency.

Pursuant to a 1997 amendment to the Sikes Act, DoD installations must regularly prepare Integrated Natural Resource Management Plans (INRMPs) to ensure the integrity of natural resources in a way that both sustains military operations and is consistent with federal and state stewardship and legal requirements. INRMPs include provisions to maintain several distinct aspects of the natural environment at the landscape level, including the management or enhancement of fish and wildlife, wetlands protection, the maintenance of land and forests, recreation areas, and the sustainable use of natural resources by the public (DoD 2012).
Under the federal Endangered Species Act (ESA), DoD installation managers are required to ensure their actions do not adversely impact or modify critical habitat of threatened and endangered (T&E) species. In rare cases, ESA compliance can result in restrictions or modifications to training activities if they intrude on critical habitat. The management of listed species and other species at risk represents a significant issue for the DoD, as its lands are home to the highest density of T&E species of any federal land management agency (Boice 2013) and plans for species' protection must be outlined in installation INRMPs.

The Clean Water Act is the primary regulation that directs the restoration and protection of water resources on DoD Installations through requirements on National Pollutant Discharge Elimination System (NPDES) for permitting discharges, Total Maximum Daily Loads (TMDLs), non-point source runoff, and natural resource protection, etc. (CWASSC 2004). Additionally, watershed management on installations is also encouraged by a Unified Federal Policy that was adopted by the DoD in 2000 (Federal Register 2000).

The DoD has long pursued an integrated, ecosystem-based approach to management, and has recently incorporated ecosystem services in agency-wide policy. Department of Defense

Instruction (DoDI) 4715.3 of 1996 first called for the integrated management of natural and cultural resources on DoD lands (DoD 1996). In 2011, an update to this instruction, DoDI 4715.03, explicitly states it is DoD policy to “sustain the long-term ecological integrity of the resource base and the ecosystem services they provide” (DoD 2011).

The DoD-wide commitment to ecological forestry management is demonstrative of this multi-service, ecosystem-based approach. Rather than mere yield-optimization of forest products, ecological forestry emphasizes the maintenance of multiple ecosystem services in forests, such as habitat for realistic training settings, carbon sequestration, and native biological diversity (DoD 2011, SERDP 2011).

The possibility of new regulation in the future also provides motivation for a broader consideration of the impacts of DoD activities on its lands and the environment. One potential example is the management of greenhouse gas (GHG) emissions. As Executive Order 13514 calls for agencies to set a 2020 greenhouse gas emission reduction target (Obama 2009), DoD installations may need to act proactively by mitigating GHG emissions from energy use, and also by offsetting such emissions via sustainable land management that maintains installation lands and coastal environments as carbon sinks.

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

This section presents the ecosystem services approach developed by the Natural Capital Project and the InVEST tool for quantifying, mapping, and valuing ecosystem services. It also provides a brief comparison between InVEST and other tools that evaluate ecosystem services.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The ecosystem services approach developed by NatCap provides estimates of the values of natural capital in clear, credible, and practical ways through iterative stakeholder engagement, scenario planning, biophysical and economic/social modeling with InVEST, and multi-service synthesis. InVEST (Integrated Valuation of Environmental Services and Tradeoffs) is a free and open-source software tool that enables users to quantify natural capital in biophysical, economic, or social terms. InVEST is designed to integrate ecosystem service values into decision-making by linking scientific models based on ecological production functions and various valuation methods. It enables decision makers to assess the tradeoffs associated with alternative policy options, and to identify areas where investment in ecosystem services can enhance human development and conservation of terrestrial, freshwater, and marine ecosystems. InVEST has been developed since 2006 by NatCap, a partnership among Stanford University, The Nature Conservancy, World Wildlife Fund, and the University of Minnesota. This tool has been applied and tested in over 20 demonstrations around the world (Ruckelshaus et al. 2013) with a rapidly growing user base.

InVEST is most effectively used within a decision-making process that starts with stakeholder consultations. InVEST users can identify questions of interest, management choices, and/or policy options through discussion with stakeholders. Spatial scenarios can then be jointly developed to show, for example, several alternative locations where a new training facility might be built, where forest might be converted to open area for vehicle maneuver, or where best management practices (e.g., riparian buffer, longleaf pine restoration, prescribed fire) are expected to affect soil erosion or habitat for species at risk. Scenarios typically include maps of potential future land use/land cover, which are critical inputs in all InVEST models. Potential changes in vegetation driven by climate change can also be incorporated into the scenario maps if defined by users. Following stakeholder consultations and scenario development, InVEST can estimate how the current location, amount, delivery, and value of relevant services are likely to change in the future. InVEST models are spatially-explicit, using maps as information sources and producing maps as outputs. InVEST returns results in either biophysical terms (e.g., tons of carbon sequestered) or economic terms (e.g., net present value of that sequestered carbon). InVEST results can be synthesized across multiple ecosystem services, which are interconnected through their dependence on land use/land cover, to reveal the impacts of management choices or policy options represented and to inform decisions for stakeholders. The spatial resolution of

analyses is also flexible, allowing users to address questions at the local, regional, or global scales. InVEST is built on an open-source platform that can be used with a number of Geographic Information System (GIS) software packages (e.g., ArcGIS, QGIS). Users have the flexibility to tailor InVEST models for specific needs or incorporate other models and functions in InVEST by modifying the open codes. The toolset currently includes seventeen distinct InVEST models suited to terrestrial, freshwater, and marine ecosystems, and additional supporting tools for scenario development. This toolbox enables analysis of benefits to specific groups of people from ecosystems according to stakeholder goals (Sharp et al. 2014).

InVEST includes models with different levels of complexity and data requirements. Tier 1 models are designed to operate with limited data requirements; Tier 2 models are more data-intensive and can provide more precise estimates at finer temporal scales. High quality input data for Tier 2 models may also improve the spatial resolution of model outputs. Users can choose between Tier 1 and Tier 2 models given data availability and the desired detail for model outputs in support of decisions. Both tiers of InVEST follow a three-step modeling process that connects biophysical processes within ecosystems to economic or social values (Figure 2.1.1).

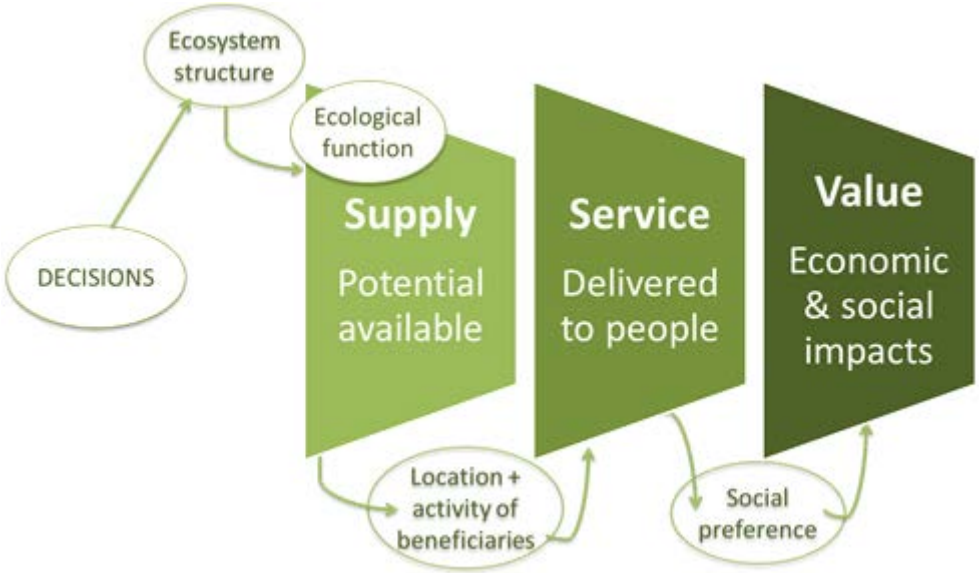

Figure 2.1.1. Flow diagram of InVEST models

First, InVEST constructs the biophysical processes that constitute the supply-side of the ecosystem service equation. These models draw heavily from existing knowledge. For example, the InVEST Water Yield model calculates the mean annual water yield based on the Budyko curve (Budyko and Zubenok 1961), while the Sediment Retention model draws heavily from the universal soil-loss equation (USLE) (Brooks et al. 1982) to estimate sediment export and retention. InVEST calculates habitat quality and rarity based on species-area relationships and species affinities to native and human-dominated habitats (Pereira and Daily 2006). Model parameters can be adjusted to reflect specific management practices (e.g., prescribed fire, sediment basins) or potential variations in ecological (e.g., vegetation species) and

meteorological factors (e.g., temperature, precipitation) driven by climate change. Detailed descriptions of individual InVEST models are provided in Section 5.

Second, to quantify ecosystem services delivered, InVEST combines supply-side models with likely levels of ecosystem service demand represented by locations and activities of beneficiaries. For example, by keeping sediment out of waterways, vegetation buffers and other best management practices can provide services to individuals and society, such as avoided flood risk and reduced costs of sediment control structures (e.g., sediment basins and rip rap) for compliance. To estimate these services, we ask how much sediment export and retention is provided in a river with flooding potential or water quality regulation needs for downstream beneficiaries.

Third, InVEST estimates the economic and social implications of ecosystem services by linking them with social preferences, such as market price or avoided cost. The benefit of sediment retention provided by vegetation buffers can be revealed by the cost of sediment control structures providing comparable benefit. The avoided flood risk can be estimated by potential property losses or cost of flood-control barriers.

The details of how supply and demand are combined in specific models for these and other services are documented in peer-reviewed, published literature (Nelson et al. 2008, Nelson et al. 2009, Kareiva et al. 2011, refs. in Sharp et al. 2014). Previous quantification of ecosystem services has tended to rely on acreage-based, unit-value transfer for ecosystems (e.g., marshes, forests, etc.), with little connection to specific land-use options (e.g., Costanza et al. 1997). The theoretical and practical problems associated with such approaches are reviewed by Bockstael et al. (2000) and Plummer (2009). In contrast, InVEST evaluates the differences in ecosystem service provision that arise from alternative land use and land management scenarios, recognizing the existence of site-specific attributes that may affect economic or social values. Furthermore, it provides estimates of service supply, use, and value that vary spatially, linking the InVEST model outputs with the decisions facing policy makers and resource managers.

Among existing InVEST terrestrial and freshwater models, two models package user-supplied data into spatially-explicit outputs to increase the understanding of land use and land cover (LULC) changes on service provision: Carbon Storage and Sequestration and Managed Timber Production. Other InVEST models transform user-supplied data into estimates of service provision (and value) using accepted ecological production functions and economic valuation techniques. InVEST currently contains both standalone tools in the Microsoft Windows operating system and ArcGIS-dependent script tools. Most models have full functionality as standalone tools for higher stability and efficiency in performance. GIS software (e.g., open source QGIS or ArcGIS) is required to compile data and visualize results for standalone tools.

The hydrological models have been tested and validated in a number of watersheds and have

shown consistent agreement with observed data or with the popular data-intensive Soil and Water Assessment Tool (SWAT) (Conte et al. 2011a, Mendoza et al. 2011). For example, the Water Yield model has been validated for five watersheds on Hainan Island, China, where the model performed at errors ranging from 5 to 10%, compared with observed data. The nutrient model was recently applied in North Carolina (Hamel 2014), where it was found that the model predictions were highly correlated with observations. In testing the model against SWAT outputs in the Willamette River Basin of Oregon, the total phosphorus export estimated by InVEST nutrient retention model reasonably correlates to the soluble phosphorus output simulated by SWAT in 111 sub-catchments (Figure 2.1.2; Conte et al. 2011a). The nutrient model was recently tested in a study in Scotland (Gimona et al. 2014), where good correlation was found between InVEST predictions and those of NIRAMS II, a physics-based model developed and calibrated for Scotland.

The Habitat Risk Assessment model has been tested in Belize for coral reef, seagrass, and mangrove habitats (Arkema et al. 2014) and the predicted risk estimates strongly correlate with the observed habitat quality. NatCap provides continued development and improvement of InVEST with user support and trainings. Our website (www.naturalcapitalproject.org) contains the latest versions of InVEST, a complete InVEST User Guide, case studies and publications, and previous training presentations and videos. In-person trainings are also available several times a year at various locations that are announced on our website. NatCap also provides user support through an actively-maintained online user forum (http://ncp-yamato.stanford.edu/natcapforums/). If arrangements for a more in-depth collaboration with NatCap have been made, individual assistance and consultation for running models and analyzing, visualizing and interpreting results is also possible. NatCap's science capacity is maintained and refreshed through collaborations with a large number of academic partners; through worldwide case studies and feedback from the field, and through workshops, major symposia, and high-profile, peer-reviewed publications that communicate our work and demonstrate our credibility.

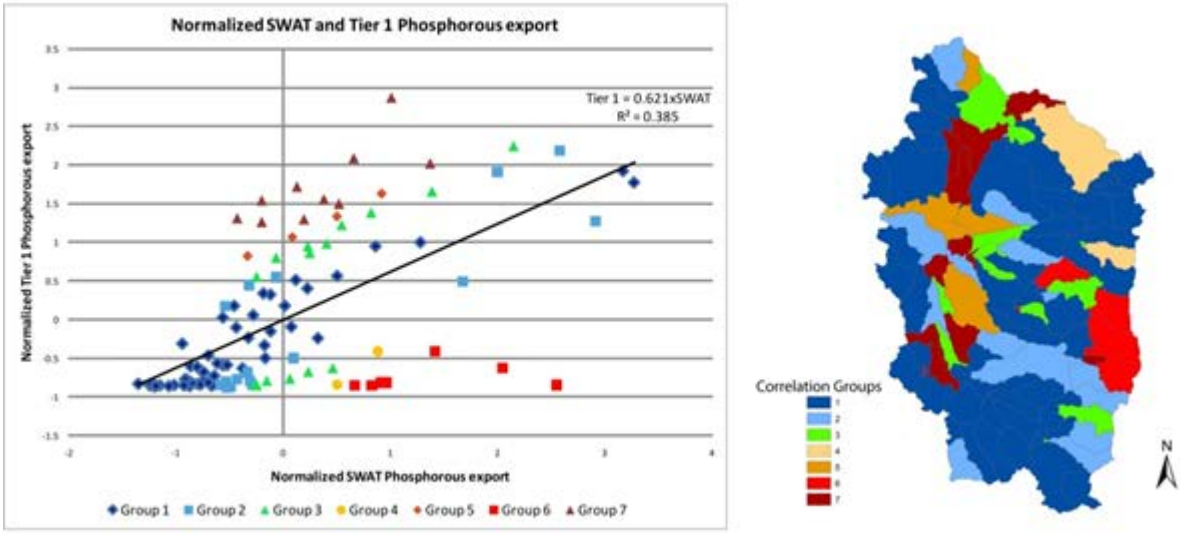

Figure 2.1.2. Comparison of normalized InVEST and SWAT phosphorous outputs in the Willamette River Basin, OR.

2.2 TECHNOLOGY/METHODOLOGY DEVELOPMENT

We did not conduct any development of the technology as part of the ESTCP project.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

Historically, detailed, data-intensive models have been developed to estimate individual ecosystem processes and ecosystem services (e.g., SWAT for water quality; the Century model for carbon). There are multiple efforts currently aimed at the development of software packages to facilitate increased understanding of the suite of impacts associated with land-use decisions. Notable alternatives to InVEST that focus on evaluating multiple services under different management scenarios and spatial scales include ARIES (ARtificial Intelligence for Ecosystem Services) and MIMES (Multiscale Integrated Model of Ecosystem Services).

ARIES is a 'machine-learning' modeling platform that quantifies and maps the provision, use, and benefit flows of different ecosystem services through artificial intelligence and semantic modeling with existing ecological and social/economic knowledge. ARIES is developed by the University of Vermont's Gund Institute for Ecological Economics and partners, and operates on an online user interface (www.ariesonline.org for alpha version). Compared with InVEST, ARIES' probabilistic modeling approach characterizes uncertainty more explicitly, and is more adaptable to data-sparse cases. Possible shortcomings of this approach include the high level of expertise needed to run the model, the lack of transparency to users regarding the model

assumptions, and the potential inaccuracy of conclusions due to unrecorded differences between the set of sites providing the data and the site at which they are being applied (i.e., problems associated with benefits-transfer approaches, as discussed above).

MIMES is a dynamic spatial modeling suite that simulates impacts of land and coastal/marine changes on ecosystem services and human well-being at multiple spatial scales. It is primarily developed by the AFORDable Futures LCC, and is designed to run with system dynamics software SIMILE and GIS tools (model code freely available at https://code.google.com/p/mimes/). While MIMES better accounts for the complex interaction of ecosystem components and provides more accurate time-series predictions compared with InVEST and ARIES, it is best suited for cases with high data availability, highly sophisticated users, and a high level of knowledge about ecological and social/economic processes.

Although InVEST and its two alternatives are all free and open-source tools, InVEST features four advantages. First, InVEST models utilize peer-reviewed, transparent ecological production functions and location-specific data in order to avoid potential pitfalls associated with benefits-transfer approaches, as encountered using ARIES. Second, current InVEST models can be specified at different levels of sophistication according to data availability and risk tolerance of decision makers. Third, InVEST is available for independent application anywhere in the world; users specify the areas and ecosystem services of interest. ARIES online data were primarily compiled for a few case studies, and MIMES models were designed for particular applications. Thus, users of either ARIES or MIMES tools would likely need to work with model developers for applications beyond their existing examples. Fourth, InVEST can be applied for a larger number of ecosystem services in terrestrial, freshwater, and marine ecosystems compared to its alternatives, with more models in development. InVEST also provides more comprehensive documentation, including peer-reviewed approaches, user support, and training materials for individual models compared to ARIES and MIMES.

However, InVEST has a few limitations about which users should be aware. As models are designed to require relatively few data to broaden the range of applicable locations and decision contexts, some simplifying assumptions are made in individual models. With sufficient local data and knowledge, models can be refined to some extent on a case-to-case basis. The majority of InVEST Tier 1 models are designed on an annual time step, which is reasonable for services such as carbon sequestration, but may be less relevant for analyzing water-related services in locations with heterogeneity in seasonal rainfall patterns or water use. NatCap is developing a monthly Water Yield model, which will be tested in the Fort Benning demonstration and officially released in 2014. In addition, based on our previous demonstration at the Joint Base Lewis-McChord (JBLM) during 2011-2012, we found that creating relevant and realistic scenarios for InVEST can be time-intensive - as is the case for all ecosystem service models - and successful independent model runs would require some site-specific data and GIS expertise at the installation.

3.0 PERFORMANCE OBJECTIVES

This section summarizes all performance objectives and their assessment results for our demonstrations at Joint-Base Lewis McChord, Fort Pickett, and Fort Benning.

3.1 JOINT BASE LEWIS-MCCHORD AND FORT PICKETT

The following table and subsequent text outline the performance objectives assessed during our demonstrations at Joint-Base Lewis McChord and Fort Pickett. Each of the rows in the table shows the assessment metric, data requirements, and success criteria for a specific performance objective and reports whether it was successfully achieved in each site.

Table 3.1. Joint Base Lewis-McChord and Fort Pickett performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
1. Quantify provision of ecosystem services using existing GIS data	Service provision estimate in relevant biophysical units		Convert GIS inputs into service-specific provision outputs using ecological production functions that are documented in the peer-reviewed literature	
Habitat Quality	Relative quality and rarity scores	LULC map; threat sources, magnitudes, and accessibility		JBLM and Fort Pickett: Criterion met
Carbon Sequestration and Storage	Mg of carbon sequestration and storage	LULC map; carbon pools		JBLM and Fort Pickett: Criterion met
Managed Timber	Mg of harvested wood	LULC map; production schedule		JBLM: Criterion met Fort Pickett: N/A
Sediment Retention	Tons of sediment retention	LULC map; DEM; R; K; slope threshold		JBLM: N/A Fort Pickett: Criterion met

Performance Objective	Metric	Data Requirements	Success Criteria	Results
2. Quantify value of ecosystem services using existing GIS data for at least two key ecosystem services of the following	Estimate of social value of ecosystem service		Convert GIS inputs into ecosystem services (above) and service-specific valuation outputs using economic valuation techniques that are documented in the peer-reviewed literature	
Carbon Sequestration and Storage	Social Cost of Carbon	SCC estimates		JBLM: Criterion met Fort Pickett: not met because of simplified application
Managed Timber	Returns from harvest or other agreed upon metric	Market prices and costs of production		JBLM: Criterion met Fort Pickett: N/A
Sediment Retention	Avoided dredging costs	Local dredging costs; sedimentation load thresholds		JBLM: N/A Fort Pickett: not met because of simplified application
3. Provide spatially-explicit rendering of service provision	Service-provision estimate in relevant biophysical units; maps of key ecosystem services by land-use/land cover categories that are relevant for decision-makers	As above under objective 1--LULC map; DEM; PET; etc.	Creation of one map for each focal ecosystem service that will illustrate how provision varies as a function of LULC category and location on the landscape. Map resolution will be at the pixel level (e.g., 30mx30m) for terrestrial models and at the HUC 12, or equivalent, level for water models	JBLM and Fort Pickett: Criterion met
4. Provide spatially-explicit rendering of the social value of at least two key ecosystem services	Estimates of ecosystem-service values to society	Location of beneficiaries, market values, avoided damages, discount rate, etc.	Creation of maps and tables that quantify spatially explicit economic/social value for at least two key ecosystem services in dollar terms.	JBLM: Criterion met Fort Pickett: not met because of simplified application

Performance Objective	Metric	Data Requirements	Success Criteria	Results
5a. Assess and report degree to which model results depict reality (partner installation data available; model previously tested in similar environment)	Correlation between modeled and observed outcomes for validation	Independent measures of observed environmental processes and/or conditions (e.g., sediment delivery to a water body or nutrient concentration in a water body)	Validate model outputs and report correlation between model outputs and observed outcomes; determine if model performance on partner installation meets or exceeds performance in similar environments	N/A because partner installation data were available, but relevant models were not previously tested in similar environment.
5b. Assess and report degree to which model results depict reality (no partner installation data available; model previously tested in similar environment)	Correlation between model outputs and observed outcomes at previous validation sites with relevant biophysical characteristics that are similar to those on partner installations	Results of previous validation efforts at previous validation sites with similar biophysical characteristics to partner installations	In cases where data necessary for validation do not exist, report model outputs at face value and document the certainty of model performance based on the past performance of model outputs at regions of testing with similar characteristics to the demonstration site	N/A because partner installation data were available, but relevant models were not previously tested in similar environment.
5c. Assess and report degree to which model results depict reality (partner installation data available; model not previously tested in similar environment)	Correlation between modeled and observed outcomes for validation	Independent measures of observed environmental processes and/or conditions (e.g., sediment delivery to a water body or nutrient concentration in a water body)	Validate model outputs and report correlation between model outputs and observed outcomes	JBLM: Criterion met for carbon and HRA model Fort Pickett: not met because of simplified application and lack of complete (i.e., observed) data
5d. Assess and report degree to which model results depict reality (no partner installation data available; model not previously tested in similar environment)	User confidence in model outputs		In cases where data necessary for validation do not exist, report model outputs at face value and allow user to interpret certainty of outputs	N/A because partner installation data were available, but relevant models were not previously tested in similar environment.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
6. Incorporate uncertainty into service-provision estimates for at least two key services	Bounds on service-provision estimates	High/low values for all data inputs or distributions of all data inputs	Identify the certainty of model estimates by providing quantitative bounds on outputs (using Monte Carlo and other techniques) or by depicting ranges of model outputs in maps	JBLM: Criterion met for carbon and timber models Fort Pickett: not met because of simplified application
7. Convert alternative management scenarios into realistic alternative LULC maps	Reflect key management initiatives under each scenario in pattern of LULC for that scenario	Conversation with relevant base personnel and access to base plan and INRMP (if available), land-use transition probabilities, etc.	Creation of one LULC map for each alternative management scenario at a scale relevant to decision makers. Consensus amongst relevant installation personnel will determine if the changes to LULC under each modeled management scenario are realistic	JBLM and Fort Pickett: Criterion met
8a. Estimate absolute changes in each ecosystem service that will result from alternative management options	Estimates of changes in ecosystem-service provision and value	As above	Creation of maps and tables depicting absolute change in ecosystem services in response to each of the proposed land management options (e.g., Provision(alt scenario)-Provision(baseline))	JBLM and Fort Pickett: Criterion met
8b. Estimate relative changes in each ecosystem service that will result from alternative management options	Estimates of changes in ecosystem-service provision and value	As above	Creation of maps and tables depicting relative change in ecosystem services in response to each of the proposed land management options (e.g., Provision (alt Scenario) - Provision(baseline))	JBLM and Fort Pickett: Criterion met
9. Use service maps to evaluate multiservice impact of alternative management options for at least two services	Spatially-explicit aggregation of multi-service value	Service value maps	Combining value of service maps for at least two services to identify areas with the greatest and fewest tradeoffs across scenarios	JBLM and Fort Pickett: Criterion met

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives				
10. Identify opportunities for InVEST to inform decision-making process	Fit of model results into current management/decision-making hierarchy	Organization charts and chain-of-command information, steps in decision-making process	Identification of one or more decisions or steps within the natural-resource management process for integration of information from InVEST	JBLM and Fort Pickett: Criterion met
11. Document whether information on ecosystem services is incorporated into decision-making process	Inclusion of ecosystem-services language in decision-making process (e.g., INRMP)	Documentation of base decision-making process pre and post-project	Documented consideration of ecosystem service information in at least one step of one base decision-making process	JBLM and Fort Pickett: Criterion met
12. Ease of Use	Personnel opinion on ease of applying InVEST	Discussion with relevant personnel about experience/opinion with InVEST	Positive comments about ability of independent InVEST application (e.g., amassing data, establishing scenarios, running InVEST, and reporting results)	JBLM and Fort Pickett: Criterion not fully met because intallations are not able to use InVEST currently

Performance Objective 1: Quantify provision of ecosystem services using existing GIS data
Using ecological production functions that have been vetted by the peer-reviewed literature, we will convert commonly-collected Geographic Information System (GIS) data, such as land-use and land-cover (LULC) maps and other biogeophysical information, into estimates of ecosystem-service provision. Understanding how the provision of different ecosystem services varies with LULC categories is essential to developing a more comprehensive view of the tradeoffs associated with land-use choices.

- Assessment Metric: The metric used to evaluate this performance objective will be the ability of the model to supply service-provision estimates in relevant biophysical units (e.g., outputs measured in Mg of C for carbon sequestration and storage, outputs measured in Tons of sediment for sediment retention).
- Required Data: The data required to provide estimates of service provision will differ across services, and the specific requirements for each of the potential models are listed in Table 1 above.
- Success Criteria: This performance objective will be deemed successful if we are able to convert GIS inputs into service-specific provision outputs using ecological production functions that are documented in the peer-reviewed literature.
- Results: Successful. For JBLM, we quantified habitat risk for the Puget Sound Prairie Ecosystem, carbon sequestration, timber production, and training capacity using InVEST models

(Section 6.1.2; Figures 6.1.2.5, 6.1.2.6, 6.1.2.9, 6.1.2.10, and 6.1.2.12; Tables 6.1.2.2, 6.1.2.3, and 6.1.2.4). For Fort Pickett, we quantified carbon storage and sediment export using InVEST models and quantified overall biodiversity using the GLOBIO3 model (Section 6.2.2; Tables 6.2.2.2, 6.2.2.6, and 6.2.2.6).

Performance Objective 2: Quantify value of ecosystem services for at least two ecosystem services

Using commonly-applied valuation techniques, including both market and non-market approaches, we will provide estimates of the social value of at least two different ecosystem services from the following group of services: (carbon sequestration and storage, managed timber, water yield, nutrient pollutant retention, or sediment retention). As described on page 8, social value refers to the full accounting of all costs and benefits associated with the production or consumption of a given product. The difference between private and social value is the external cost or benefit associated with a given decision. The goal of estimating the social value of service provision is to help increase the efficiency of land-use and natural resource management by specifying some of the costs of habitat conversion that are ignored in typical land-use decisions.

- Assessment Metric: The metric used to evaluate this performance objective will be the ability of the model to supply estimates of the social value of different ecosystem services measured in financial terms.
- Required Data: The data required to provide estimates of the social value of key ecosystem services will vary across the services, and the specific requirements for each of the potential models are listed in Table 1 above.
- Success Criteria: This performance objective will be deemed successful if we are able to convert GIS inputs into ecosystem services (above) and service-specific valuation outputs using economic valuation techniques that are documented in the peer-reviewed literature.
- Results: Successful for JBLM, but not Fort Pickett. For JBLM we quantified the social cost of carbon storage and sequestration and net present value of timber production using InVEST models (Section 6.1.2; Figures 6.1.2.5, 6.1.2.6, 6.1.2.9, and 6.1.2.10). In discussion with ESTCP, we scaled down the original demonstration plan for Fort Pickett to remain on schedule and budget due to delays in partner response and the Federal budget. We highlighted a simpler application that focuses on the management question of how to site new training ranges at the installation to sustain ecological integrity. We estimated ecosystem service metrics in biophysical terms, and did not quantify the value of ecosystem services at Fort Pickett due to simplification of the application. The biological measures we assessed are sufficient for comparing different siting choices to inform decisions.

Performance Objective 3: Provide spatially-explicit rendering of service provision

Using widely-accepted ecological production functions that relate LULC to the provision of different ecosystem services, we will provide maps of service provision for key ecosystem

services that illustrate how the quantity of provision varies across the landscape. Visualizing the location of service provision is a key step in prioritizing the location of different land-use activities: understanding how service provision varies across the landscape can identify areas where the tradeoffs of habitat conversion are greatest, as well as, those areas with relatively low costs of conversion, as measured by service provision.

- Assessment Metric: The metric used to evaluate this performance objective will be the ability of the model to output service-provision estimates in relevant biophysical units and to generate maps of key ecosystem services by LULC category that are relevant for decision-makers.
- Required Data: This performance objective requires the same input data as that listed for each service under the first performance objective.
- Success Criteria: This performance objective will be deemed successful if we are able to create one map for each focal ecosystem service that will illustrate how provision varies as a function of LULC category and location on the landscape. Map resolution will be at the pixel level (e.g., 30 m x 30 m) for terrestrial models and at the Hydrologic Unit Code (HUC) 12, or equivalent, level for freshwater models.
- Results: Successful. We provide spatially-explicit rendering of service provision for habitat risk for the Puget Sound Prairie Ecosystem, carbon sequestration, timber production, and training capacity at JBLM (Section 6.1.2; Figures 6.1.2.2, 6.1.2.3, 6.1.2.7, 6.1.2.11, 6.1.2.13, and 6.1.2.14). For Fort Pickett, we provide spatially-explicit rendering of service provision for loss of carbon sequestration, general biodiversity, and sediment retention and export (Section 6.2.2.2; Figures 6.2.2.1, 6.2.2.2, 6.2.2.3, 6.2.2.4, 6.2.2.5, and 6.2.2.6).

Performance Objective 4: Provide spatially-explicit rendering of the social value of at least two key ecosystem services

Using accepted valuation techniques, we will allocate the value of service provision across the landscape based on each measurement unit's contribution to total service provision (for terrestrial services, values will be assigned by pixel, while for freshwater services, values will be assigned by sub-watershed). Mapping the value of service provision makes it easier for decision-makers to evaluate the tradeoffs between intensive land use and habitat conservation, as the benefits of land use are often, though not always, expressed in dollar terms. As mentioned on page 8, social value refers to the full accounting of all costs and benefits associated with the production or consumption of a given product. The difference between private and social value is the external cost or benefit associated with a given decision.

- Assessment Metric: This performance objective will be evaluated based on the ability of the model to provide estimates of the social value of ecosystem-services, for at least two key ecosystem services, in which the values vary across the landscape in a way that corresponds to service provision.
- Required Data: This performance objective requires the same input data as that listed for each service under the second performance objective; potentially including the location of

beneficiaries, market values, avoided damages, discount rate, etc.

- Success Criteria: This performance objective will be deemed successful if we are able to create maps and tables that quantify spatially-explicit economic/social value for at least two key ecosystem services in dollar terms. For terrestrial services, the maps will vary at a pixel level (e.g., 30m x 30m), while for freshwater services, the maps will vary by sub-watershed.
- Results: Successful for JBLM, but not Fort Pickett. For JBLM we provide spatially-explicit rendering of the social cost of carbon for carbon sequestration and the net present value of timber production (Section 6.1.2; Figures 6.1.2.7 and 6.1.2.11). We do not provide spatially explicit rendering of the economic value of ecosystem services at Fort Pickett due to simplification of the application (see PO2 for details).

Performance Objective 5: Assess and report degree to which model results depict reality
For the freshwater services modeled by InVEST, it is possible to evaluate the model outputs relative to observed outcomes. This ability is contingent on the availability of data from stream gauges near the application site. Given the inherent stochasticity of hydrologic processes, the efforts to produce results that reflect reality will be more successful the longer the time series of observed data. For this reason, model performance in two sites with similar environmental conditions will vary significantly relative to observed outcomes if the sites have different amounts of recorded data for use in model validation. We consider four scenarios related to data availability and model validation: a) partner installation data available; model previously tested in similar environment b) no partner installation data available; model previously tested in similar environment c) partner installation data available; model not previously tested in similar environment d) no partner installation data available; model not previously tested in similar environment. Each of these scenarios will be associated with different performance objectives, as described below:

Performance Objective 5a: Assess and report degree to which model results depict reality (partner installation data available; model previously tested in similar environment)
When the required data are available at/around our partner installations, we will use standard regression techniques to evaluate the correlation between model outputs and observed outcomes at partner installations.

- Assessment Metric: This performance objective will be evaluated based on our ability to report the correlation between model outputs and observed outcomes at partner installations to determine if model performance on partner installations meets or exceeds performance in similar environments (e.g., R2=65-80% for water yield or R2=50-65% for phosphorous loading). We will also conduct hypothesis tests regarding our ability to distinguish between model outputs and observed data.
- Required Data: This performance objective requires independent measures of observed environmental processes and/or conditions at partner installations.
- Success Criteria: This performance objective will be deemed successful if we are able to

validate model outputs and report the correlation between model outputs and observed outcomes. We will also provide details about model performance in similar environments from previous validation efforts.

- Results: This objective is not applicable because partner installation data were available, but relevant models were not previously tested in a similar environment. See performance objective 5c for model validation results.

Performance Objective 5b: Assess and report degree to which model results depict reality (no partner installation data available; model previously tested in similar environment)

In the absence of data required to validate model performance for certain services or partner installations, we will provide an indication of the likely fidelity of modeled outputs to observed conditions using results of completed validation efforts and the similarity in site characteristics for validated locations and installations.

- Assessment Metric: This performance objective will be evaluated based on our ability to conduct statistical analysis and report the correlation between model outputs and observed outcomes at previous validation sites with relevant biophysical characteristics that are similar to those on partner installations.
- Required Data: This performance objective requires results of previous validation efforts at previous validation sites with similar biophysical characteristics to partner installations.
- Success Criteria: This performance objective will be deemed successful if we are able to report model outputs at face value and document the certainty of model performance based on the past performance of model outputs across all regions of testing with similar characteristics to the demonstration site.
- Results: This objective is not applicable because partner installation data were available, but relevant models were not previously tested in a similar environment. See performance objective 5c for model validation results.

Performance Objective 5c: Assess and report degree to which model results depict reality (partner installation data available; model not previously tested in similar environment)

When the required data are available at/around our partner installations, we will use standard regression techniques to evaluate the correlation between model outputs and observed outcomes at partner installations.

- Assessment Metric: This performance objective will be evaluated based on our ability to report the correlation between model outputs and observed outcomes at partner installations.
- Required Data: This performance objective requires independent measures of observed environmental processes and/or conditions at partner installations.
- Success Criteria: This performance objective will be deemed successful if we are able to validate model outputs and report the correlation between model outputs and observed outcomes.
- Results: Successful for JBLM, but not Fort Pickett. We assessed the degree to which model results depict reality for the HRA model by comparing the distribution of candidate

species of the Puget Sound Prairie Ecosystem with risk estimates at JBLM (Tables 6.1.2.4 and 6.1.2.5), and for the carbon sequestration by comparing the generalized aboveground carbon biomass estimates with site-specific estimates (Figure 6.1.2.4) in Section 6.2.1. We did not assess and report the degree to which model results depict reality at Fort Pickett due to simplification of the application (see PO2 for details) and lack of observed data.

Performance Objective 5d: Assess and report degree to which model results depict reality (no partner installation data available; model not previously tested in similar environment)

In the absence of data required to validate model performance for certain services or partner installations, the user confidence in model outputs will be based solely on satisfaction with model methodology.

- Assessment Metric: This performance objective will be evaluated based on user confidence in model outputs.
- Required Data: This performance objective requires that users describe their satisfaction with model outputs.
- Success Criteria: This performance objective will be deemed successful if the user chooses to accept model outputs to inform decision-making.
- Results: This objective is not applicable because partner installation data were available, but relevant models were not previously tested in a similar environment. See performance objective 5c for model validation results.

Performance Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest

The processes being modeled by InVEST are complex and the parameters that are used to generate model outputs can take on a range of values. In order to highlight the conditions under which model outputs are expected to be highly variable, we will report and display the range of model outputs that results from parameter uncertainty.

- Assessment Metric: This performance objective will be evaluated based on the ability of the model to provide bounds on service provision estimates based on the uncertainty in model parameters.
- Required Data: This performance objective requires the low and high values for all data inputs or distributions of all data inputs parameters in the models of interest or the distribution of these values, if available.
- Success Criteria: This performance objective will be deemed successful if we are able to identify the certainty of model estimates by providing quantitative bounds on outputs (using Monte Carlo and other techniques) or by depicting ranges of model outputs in maps.
- Results: Successful for JBLM, but not Fort Pickett. We incorporated uncertainty into service-provision estimates for carbon sequestration by estimating a range of outputs based on the upper and lower bounds of model inputs, and for timber production by providing 90% confidence intervals of the total net present value using Monte Carlo simulations. (Section 6.1.2;

Figures 6.1.2.4, 6.1.2.5, 6.1.2.6, 6.1.2.9, and 6.1.2.10). We did not incorporate uncertainty into service-provision estimates for ecosystem services at Fort Pickett due to simplification of the application (see PO2 for details).

Performance Objective 7: Convert alternative management scenarios into realistic alternative LULC maps

InVEST can assist decision-makers in their efforts to choose between alternative management options by evaluating the ecosystem-service impacts of the alternatives. This step requires that we are able to convert management scenarios into realistic land-cover maps.

- Assessment Metric: This performance objective will be evaluated based on our ability to reflect key management initiatives under each scenario in the LULC pattern for that scenario.
- Required Data: This performance objective requires conversations with relevant installation personnel and access to the installation plan, Integrated Natural Resource Management Plan (INRMP), and other data to identify key management scenarios and to identify their implications for the LULC pattern on the partner installation.
- Success Criteria: This performance objective will be deemed successful if we are able to create one LULC map for each alternative management scenario at a scale that is relevant to decision-makers. Consensus amongst relevant installation personnel will determine if the changes to LULC under each modeled management scenario are realistic.
- Results: Successful. We converted alternative management scenarios into realistic alternative LULC maps at JBLM and Fort Pickett (Sections 6.1.1 and 6.2.1). For JBLM, we developed a Business-As-Usual (BAU) scenario, and four alternative scenarios driven by variations in training intensity and budget for resource management , i.e., High Budget-Decreased Training [HBDT], High Budget-Increased Training [HBIT], Low Budget-Increased Training [LBIT], and Low Budget-Decreased Training [LBDT]. For Fort Pickett, we developed nine scenarios representing potential siting choices for a new training range.

Performance Objective 8a: Estimate absolute changes in each ecosystem service that will result from alternative management options

To aid in the evaluation and prioritization of management options, it is useful to explore changes in multiple ecosystem services for each land-use alternative. Depending on our ability to identify baseline conditions, we will calculate the absolute change in provision and value for all water-related services, carbon sequestration and storage, and managed timber.

- Assessment Metric: This performance objective will be evaluated based on our ability to estimate absolute changes in the ecosystem-service provision and value associated with each alternative management option.
- Required Data: The data required to provide estimates of service provision will differ across services, and the specific requirements for each of the potential models are listed in Table 1 above.
- Success Criteria: This performance objective will be deemed successful if we are able to

create maps and tables that depict absolute changes in the above ecosystem services in response to each of the proposed land-management options.

- Results: Successful. We estimated absolute changes that will result from alternative management options at JBLM in habitat risk for the Puget Sound Prairie Ecosystem, carbon sequestration, timber production, and training capacity (Section 6.1.1; Figures 6.1.2.2, 6.1.2.5, 6.1.2.6, 6.1.2.9, 6.1.2.10, and 6.1.2.12; Table 6.1.2.2) and in carbon sequestration, general biodiversity, and soil erosion, retention, and export at Fort Pickett (Section 6.2.1; Tables 6.2.2.2, 6.2.2.4, and 6.2.2.6).

Performance Objective 8b: Estimate relative changes in each ecosystem service that will result from alternative management options

To aid in the evaluation and prioritization of management options, it is useful to explore changes in multiple ecosystem services for each land-use alternative. We will calculate the relative change in service provision for our habitat quality and rarity model.

- Assessment Metric: This performance objective will be evaluated based on our ability to estimate changes in the ecosystem-service provision associated with each alternative management option.
- Required Data: The data required to provide estimates of service provision will differ across services, and the specific requirements for each of the potential models are listed in Table 1 above.
- Success Criteria: This performance objective will be deemed successful if we are able to create maps and tables that depict distinguishable relative changes in outputs from the habitat quality and rarity model in response to each of the proposed land-management options.
- Results: Successful. We estimated relative changes that will result from alternative management options at JBLM in habitat risk for the Puget Sound Prairie Ecosystem, carbon sequestration, timber production, and training capacity (Section 6.1.1; Figures 6.1.1.2, 6.1.2.7, 6.1.2.11, 6.1.2.13, and 6.1.2.14) and in carbon sequestration, general biodiversity, and soil erosion, retention, and export at Fort Pickett (Section 6.2.1; Figures 6.2.2.2, 6.2.2.4, and 6.2.2.6). We also conducted the tradeoff and synergy analysis by comparing the relative changes in ecosystem services across scenarios (Section 6.1.3 and 6.2.3; Figures 6.1.3.1 and 6.2.3.2).

Performance Objective 9: Use service maps to evaluate multi-service impacts of alternative management options for at least two services

Implications of alternative management options for social value, or the values of ecosystem services, can be helpful to decision makers. To help identify these implications, we will create a map showing the joint value of at least two services for each scenario. As discussed on page 8, social value refers to the full accounting of all costs and benefits associated with the production or consumption of a given product. The difference between private and social value is the external cost or benefit associated with a given decision.

- Assessment Metric: This performance objective will be evaluated based on our ability to

aggregate the values of at least two services in a spatially-explicit manner.

- Required Data: The service-value maps for the focal ecosystem services are required to achieve this objective.
- Success Criteria: This performance objective will be deemed successful if we are able to combine the value of service maps for at least two services to identify areas with the greatest and fewest tradeoffs across scenarios.
- Results: Successful. We used service maps to evaluate multi-service impacts of alternative management options for habitat risk for the Puget Sound Prairie Ecosystem, carbon sequestration, timber production, and training capacity at JBLM (Section 6.1.3; Figures 6.1.3.2 and 6.1.3.3) and for carbon sequestration, general biodiversity, and sediment export at Fort Pickett (Section 6.2.3; Figures 6.2.3.1 and 6.2.3.3).

Performance Objective 10: Identify opportunities for InVEST to inform decision-making process

As a decision–support tool, it is important to identify the steps in the decision-making process that can most be aided by InVEST outputs.

- Assessment Metric: This performance objective will be evaluated based on our ability to identify the fit of the model results into the current management/decision-making hierarchy at our partner installations.
- Required Data: Organization charts and chain-of-command information as well as the steps in the decision-making process, are required.
- Success Criteria: This performance objective will be deemed successful if we are able to identify one or more decisions or steps within the natural-resource management process for integration of information from InVEST.
- Results: Successful. We identified opportunities for InVEST to inform the decision-making process at JBLM (see discussion in Section 6.1.4; Figure 6.1.4) at Fort Pickett (see discussion in Section 6.2.4).

Performance Objective 11: Document whether information on ecosystem services is incorporated into the decision-making process

To estimate the potential uptake and utility of an ecosystem-services approach to natural resource management, we will document any changes in the language used by natural resource managers that indicates consideration of ecosystem-service information in management of natural resources in the future.

- Assessment Metric: This performance objective will be evaluated based on our ability to identify the inclusion of ecosystem-services language in the decision-making process (e.g., INRMP).
- Required Data: Documentation of installation decision-making process pre- and post-application of InVEST.
- Success Criteria: This performance objective will be deemed successful if we are able to

document consideration of ecosystem service information in at least one step of the natural-resource decision making process on our partner installations.

- Results: Successful. We documented whether information on ecosystem services is incorporated into the decision-making process at JBLM and Fort Pickett in Section 6.1.4.

Performance Objective 12: Ease of use

To estimate the potential uptake of InVEST specifically, we will report the perceived ease of use of the model through discussion with relevant personnel at our partner installations.

- Assessment Metric: This performance objective will be evaluated through personnel opinion on ease of amassing data, establishing scenarios, applying InVEST, and reporting results.
- Required Data: Discussion with relevant personnel about experience with and opinion of InVEST.
- Success Criteria: This performance objective will be deemed successful if we receive positive comments about the ability of independent InVEST application. The performance objective will also be deemed successful if we are able to adjust the user experience with the model in response to feedback.
- Results: Incomplete. Personnel at JBLM and Fort Pickett are not able to independently apply InVEST due to lack of GIS capacity at these installations and simplification of demonstration at Fort Pickett. However, we received positive feedback on the value of our analytical approach and the scenario generation process by installation personnel during our interaction with them (Sections 6.1.4 and 6.2.4).

3.2 FORT BENNING

The following table and subsequent text outline the performance objectives assessed during our demonstration at Fort Benning. Each of the rows in the table shows the assessment metric, data requirements, and success criteria for a specific performance objective and reports whether it was successfully achieved.

Table 3.2. Fort Benning Performance Objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
1. Quantify the provision of relevant ecosystem services for the following, using existing GIS data	Service provision estimate in relevant biophysical units		Compilation of high-resolution data inputs (≤ 30 m). Creation of tables and charts showing aggregate service provision (in biophysical units) and provision in sub-management units from GIS inputs using ecological models supported by peer-reviewed literature.	
Red-cockaded Woodpecker (RCW) Habitat (Tier 1)	Relative risk	LULC map; threat sources, magnitudes, and accessibility		Criterion met
RCW Habitat (Tier 2)	Population viability or total population size	Based on SERDP Projects RC-1541 "Forecasting the Relative and Cumulative Effects of Multiple Stressors on At-risk Populations"		Criterion met.
Carbon Sequestration and Storage	Mg of carbon sequestration and storage	LULC map; carbon pools		Criterion met

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Water Yield (annual model; Tier 1)	Volume of water per day and per year	LULC map; Digital Elevation Model (DEM), soil depth, mean annual precipitation (MAP), mean potential evapotranspiration per watershed (PET), root depth, crop coefficient, observed streamflow		Criterion met
Water Yield (daily model; Tier 2)	Volume of water per day and per year	LULC map; DEM, soil depth, daily precipitation, temperature, root depth, crop coefficient, observed streamflow		Criterion met
Sediment Retention (annual model; Tier 1)	Tons of sediment retention per year	LULC map; DEM; rainfall erosivity index (R); soil erodibility (K); slope threshold		Criterion met
Sediment Retention (daily model; Tier 2)	Tons of sediment retention per day and per year	LULC map; DEM, soil depth, daily precipitation, temperature, root depth, crop coefficient, observed streamflow		Criterion met
2. Quantify values of ecosystem services in metrics relevant to DoD using existing service provision data and social/economic data	Relevant social/economic metrics to be determined with Fort Benning and ESTCP staff	DoD instructions, Fort Benning INRMP, other social/economic data from installation	Creation of tables and charts showing DoD-relevant values of ecosystem services from service provision and social/economic data, using social science models supported in peer-reviewed literature	

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Carbon Sequestration and Storage	e.g., social value of long-term carbon stock	e.g., social cost of carbon, social discount rate, etc.		Criterion met
Sediment Retention (annual)	e.g., avoided cost of structural erosion controls	e.g., unit cost of structural controls (sediment basin, riverbank fence, etc.); reduction of sediment export from structural controls		Criterion met for marginal cost of retention. Total service value cannot be estimated due to lack of threshold information.
3. Provide spatially-explicit rendering of service provision	Service-provision estimate in relevant biophysical units; maps of key ecosystem services by land use/land cover categories or management units relevant for decision-makers	As above under Objective 1--LULC map; DEM; PET; etc.	Creation of one map for each focal ecosystem service that will illustrate how provision varies as a function of location on the landscape. Installation personnel acceptance of mapping outputs should score at least 4.0 in a 5-point Likert survey evaluated under Objective 13.	Criterion met for RCW habitat, carbon storage and sequestration, water yield, and sediment retention. Overall Likert score=4.09.
4. Provide spatially-explicit rendering of the DoD-relevant values of two key ecosystem services (sediment retention and carbon sequestration)	Estimate of DoD-relevant service value; maps of ecosystem service value by management units that are relevant for decision-makers	As above under Objective 2	Creation of one map for each focal ecosystem service that will illustrate how DoD-specific service value varies as a function of location on the landscape.	Criterion met for carbon storage, but not for sediment retention due to lack of threshold information to calculate total service value.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
5.Assess degree to which model results depict reality and compare Tier1 vs. Tier2 performances against observations	Degree of agreement between models, and between modeled and observed outcomes	Model outputs and observed data of sediment yields, carbon biomass in sample plots, and locations of RCW nests	(1) Statistical agreement between modeled and observed values is at least 60%[1]; (2) creation of tables, charts and maps showing percentage difference and spatial variation in magnitude between Tier 1 (annual/simplified) and Tier 2 (daily/complex) models; and (3) installation personnel acceptance of models given validation outputs should score at least 4.0 in a 5-point Likert survey evaluated under Objective 13.	
Annual Water Yield (Tier 1) vs. Daily-based Yearly Water Yield (Tier 2)				Criterion met; (not evaluated in user survey as it is an intermediate service)
Annual Sediment Retention (Tier 1) vs. Daily-based Yearly Sediment Retention (Tier 2)				Criterion met; Likert score for Tier 1 model = 4.33 and score for Tier 2 model = 4.13
RCW Habitat (Tier 1) vs. RCW Habitat (Tier 2)				Criterion not met; Likert score = 3.88 for Tier 1 model; Tier 2 modeling of RCW habitat was incomplete at time of survey.

[1] The acceptable model performance against empirical information should ultimately be determined by DoD personnel. We propose 60% as a starting point for discussion.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Carbon Sequestration and Storage				Criterion met; Likert score = 3.88
6. Incorporate uncertainty into service-provision estimates for at least two key services	Bounds on service-provision estimates	High/low values for sensitive data inputs or distributions of data inputs identified from literature or local expert opinion	Tables of quantitative bounds on outputs (using sensitivity analysis or other techniques) and maps depicting ranges of model outputs. Installation personnel acceptance of the representation of uncertainty should score at least 4.0 in a 5-point Likert survey evaluated under Objective 13.	Criterion met; Likert score = 4.56
7. Convert alternative scenarios (e.g., locations of new mission activities) into realistic LULC scenarios	LULC pattern under each scenario	Conversation with ESTCP and relevant installation personnel and access to installation plan and INRMP	Creation of one LULC map for each alternative management scenario at a scale relevant to decision makers, and a table showing key parameter values delineating LULC changes. Installation personnel acceptance of scenarios should score at least 4.0 in a 5-point Likert survey evaluated under Objective 13.	Criterion met; Average Likert score for three alternative scenarios = 3.96
8a. Estimate absolute changes in each ecosystem service that will result from alternative management options	Estimates of changes in ecosystem service provision and value	As above under Objectives 1 and 2	Creation of maps and tables depicting absolute change in ecosystem services in response to each of the proposed land management options (e.g., Provision ES [alt scenario]-Provision ES [baseline])	Criterion met

Performance Objective	Metric	Data Requirements	Success Criteria	Results
8b. Estimate relative changes in each ecosystem service that will result from alternative management options	Estimates of changes in ecosystem service provision and value	As above under Objectives 1 and 2	Creation of maps and tables depicting relative change in ecosystem services in response to each proposed land management option (e.g., Provision ES [alt scenario]-Provision ES [baseline])	Criterion met
9. Analyze trade-offs and synergies between ecosystem services	Installation wide and spatially-explicit information of multi-service values	Service provisioning and value maps	Combined service maps for at least two services to identify areas with the greatest and fewest tradeoffs and synergies across scenarios	Criterion met
Qualitative Performance Objectives				
10. Identify priority DoD management themes and ecosystem services to be used in modeling scenarios	Flow diagram connecting management themes and other drivers of interest to ecosystem services	Installation INRMP, discussion with installation staff and in ESTCP	Identification of two or more management themes (e.g., ecological forestry management, water management, wildlife management, etc.) and associated ecosystem services of importance specifically to DoD	Criterion met
11. Identify opportunity for ecosystem services approach in land management on base	Utility of scenario-based, spatially explicit ecosystem services mapping approach to decision making on base	Staff input during workshops on base	Identification of one or more decisions or steps within the natural-resource management process for integration of information from demonstrated approach and tools. Installation personnel acceptance of identified opportunities should score at least 4.0 in a 5-point Likert survey evaluated under Objective 13.	Criterion met; Likert score = 4.13

Performance Objective	Metric	Data Requirements	Success Criteria	Results
12. Ease of use of InVEST as compared with more complex models (SWAT and RCW models)	Model inputs availability, processing time, skill and knowledge requirement, relevance of outputs to decisions	Model running process from Objective 5, feedback of staff who have experience with InVEST, SWAT or RCW models	Creation of tables or charts comparing ease and relevance of using InVEST models versus other models for analyzing the same ecosystem service. Installation personnel evaluation of ease of use should score at least 4.0 in a 5-point Likert survey under Objective 13.	Criterion met; Likert score = 3.9
13. Assess user acceptance of project outcomes	Five-point Likert scale measuring user satisfaction of Objectives 3, 5, 6, 7, 11, and 12	Feedback from relevant Fort Benning staff in a post-demonstration survey	Clear information on acceptance of project outcomes as indicated in the installation personnel survey. Average acceptance score should be at least 4.0 for each question and across all questions.	Criterion met; overall Likert score = 4.13

Performance Objective 1: Quantify provision of ecosystem services using existing GIS data
Using ecological production functions that have been vetted by peer-reviewed literature, we will convert commonly collected Geographic Information System (GIS) data, such as land use / land cover (LULC) maps and other bio-geophysical information, into estimates of ecosystem service provision, including sediment retention and water yield, habitat for RCW, and carbon sequestration. Understanding how the provision of different ecosystem services varies with LULC categories is essential to developing a more comprehensive view of the tradeoffs associated with land-use choices.

- Assessment Metric: The metric used to evaluate this Performance Objective will be the ability of the model to supply service-provision estimates in relevant biophysical units (e.g., outputs would be measured in breeding pairs of RCW supported by its habitat, in Mg of C for carbon sequestration and storage, and in tons of sediment retention for sediment retention).
- Required Data: The data required to provide estimates of service provision will differ across services and the specific requirements for each potential model are listed in Table 3.1 above.
- Success Criteria: This Performance Objective will be deemed successful if we are able to compile high-resolution data inputs and create tables and charts showing the aggregate service provision in biophysical units using ecological production functions supported by peer-reviewed literature.
- Results: Successful. We quantified carbon sequestration, risk to RCW nesting habitat,

and sediment export and retention at Fort Benning using InVEST models (Section 6.3.2; Tables 6.3.2.2, 6.3.2.3, 6.3.2.7, 6.3.2.10).

Performance Objective 2: Quantify values of ecosystem services in metrics relevant to DoD using existing service provision data and social/economic data

Using commonly applied valuation techniques, including both market and non-market approaches, we will provide social/economic value estimates for carbon sequestration and storage and sediment retention services that are meaningful to DoD Installations. The goal of estimating the value of service provision is to help increase the efficiency of land-use and natural resource management by specifying some of the costs of habitat conversion that are ignored in typical land-use decisions.

- Assessment Metric: The metric used to evaluate this Performance Objective will be the ability of the model to supply estimates of the social/economic value of different ecosystem services (e.g., social cost of long-term carbon stock; avoided cost of structural erosion controls). Relevant metrics will be determined in discussion with Fort Benning and ESTCP staff.
- Required Data: The data required to provide estimates of the social/economic value of key ecosystem services will vary across services and specific requirements for each potential model are listed in Table 3.1 above.
- Success Criteria: This Performance Objective will be deemed successful if we are able to create tables and charts showing DoD-relevant ecosystem services values, drawn from measures of service provision and social/economic data using social science models supported in peer-reviewed literature.
- Results: Successful. We quantified the economic values of carbon sequestration as social cost of carbon (Section 6.3.2; Tables 6.3.2.2). We also estimated the marginal cost of sediment retention as the avoided cost on structural erosion controls. However, as the total value of sediment retention only applies to additional sediment removal above a threshold defined by water quality regulations, we were not able to assess the total economic value of this service due to lack of threshold information (Section 6.3.2; Table 6.3.2.11).

Performance Objective 3: Provide spatially-explicit rendering of service provision

Using widely accepted ecological production functions that relate LULC to the provision of different ecosystem services, we will provide maps of service provision for key ecosystem services that illustrate how the quantity of provision varies across the landscape. Visualizing the location of service provision is a key step in prioritizing the location of different land-use activities; observation of service provision variation can identify areas where the tradeoffs of habitat conversion are greatest, as well as those areas with relatively low costs of conversion as measured by service provision.

- Assessment Metric: The metric used to evaluate this Performance Objective will be the ability of the model to output service-provision estimates in relevant biophysical units and to generate maps of key ecosystem services by LULC category that are relevant for decision

makers.

- Required Data: This Performance Objective requires the same input data as that listed for each service under the first Performance Objective.
- Success Criteria: This Performance Objective will be deemed successful if we are able to create one map for each focal ecosystem service that will illustrate how provision varies as a function of location on the landscape. Installation personnel acceptance of mapping outputs and spatial resolutions in support of their management decisions will be assessed in a 5-point Likert survey under Objective 13, and the average acceptance score should be at least 4.0.
- Results: Successful. We provide spatially-explicit rendering of service provision for carbon sequestration, risk to RCW nesting habitat, and sediment export and retention at Fort Benning (Section 6.3.2; Figures 6.3.2.3, 6.3.2.7, 6.3.2.8, 6.3.2.16, 6.3.2.17, 6.3.2.18). Likert scale score representing acceptance of use of our ecosystem service approach at Fort Benning (i.e., averaged over all questions) = 4.13 (Section 6.3.4; Table 6.3.4.2).

Performance Objective 4: Provide spatially-explicit rendering of the DoD-relevant values of two key ecosystem services (sediment retention and carbon sequestration)

Using accepted valuation techniques, we will allocate the value of service provision across the landscape based on each measurement unit's contribution to total service provision for sediment retention and carbon sequestration. Mapping the value of service provision makes it easier for decision makers to evaluate the tradeoffs between intensive land use and habitat conservation, as the benefits of land use are often, though not always, expressed in dollar terms.

- Assessment Metric: This Performance Objective will be evaluated based on the ability of the model to provide estimates of DoD-relevant service value (i.e., maps of ecosystem service value by management units that are relevant for decision makers).
- Required Data: This Performance Objective requires the same input data as that listed for each service under the second Performance Objective, potentially including the social cost of carbon, avoided control cost of soil erosion, discount rate, etc.
- Success Criteria: This Performance Objective will be deemed successful if we are able to create maps that quantify spatially-explicit measures of value for sediment retention and carbon sequestration in dollar terms.
- Results: Incomplete. We provided spatially-explicit rendering of the social cost of carbon sequestration Fort Benning (Section 6.3.2; Figures 6.3.2.4). Because the total value of sediment retention only applies to additional sediment removal above a threshold defined by water quality regulations, we were not able to assess and map the total economic value of this service due to lack of threshold information (Section 6.3.2). However, if such information is available in future, the economic value mapping can be conducted at the sub-basin level, similar to Figure 6.3.2.18, using the marginal cost of erosion control derived in Table 6.3.2.11.

Performance Objective 5: Assess degree to which model results depict reality and compare Tier 1 vs. Tier 2 performances against observations

There is data available at and around Fort Benning, and we will use standard statistical techniques (coefficient regression, root mean square error, bias etc.) to evaluate the correlation between model outputs and observed data. This process will enable comparison between the performance of Tier 1 InVEST models (Sediment Retention and Habitat Risk Assessment) with more complex models (SWAT and HexSim) for quantifying the same services.

- Assessment Metric: This Performance Objective will be evaluated based on the degree of agreement between models, and between modeled and observed outcomes.
- Required Data: This Performance Objective requires independent measures of observed data sediment yields, carbon biomass in sample plots, and locations of RCW nests, in addition to model outputs. The observed data will be provided by Fort Benning.
- Success Criteria: This Performance Objective will be deemed successful if the statistical agreement between model outputs and observed outcomes is at least 60%. Tier 2 models (SWAT and HexSim) are likely to achieve a higher degree of correlation. We will also create tables, charts and maps showing percentage difference and spatial variation in magnitude between Tier 1 (annual/simplified) and Tier 2 (daily/complex) models. Acceptance of model performance by installation personnel given validation outputs will be assessed in a 5-point Likert survey under Objective 13, and the average acceptance score should be at least 4.0.
- Results: Successful for comparing model estimates with observed data and for comparing InVEST water yield and sediment models with SWAT (Tier 2), but not InVEST and HexSim (Tier 2) comparisons. We assessed the degree to which model results depict reality by comparing estimates of carbon sequestration, RCW habitat risk, and sediment export with observed data (Section 6.3.2, Figures 6.2.3.1, 6.3.2.7, 6.3.2.11) and found reasonable agreement (average user survey Likert score across models = 4.06; Section 6.3.4; Table 6.3.4.2). Likert scores of 4.33 (InVEST/Tier 1 sediment retention) and 4.13 (SWAT/Tier 2 sediment retention) indicate personnel found InVEST and SWAT model performance acceptable given the degree of agreement between model outputs and observed data. Likert score of 3.88 indicated personnel found HRA model and Carbon model performance somewhat acceptable given the degree of agreement between model outputs and observed data. HexSim modeling (Tier 2 model for habitat risk/quality) was not complete at the time of the user survey.

We compared Tier 1 vs. Tier 2 performances against observations in Section 6.3.2 (Figures 6.3.2.9, 6.3.2.10, 6.3.2.12, and 6.3.2.13). Although the comparison between InVEST water yield model and SWAT shows large divergence, InVEST's estimates of sediment export, which is the final service we assessed, highly agree with those from SWAT (correlation=0.87). HexSim (Tier 2) outputs resulting from a model run using HRA risk values (Tier 1) as inputs varied through time from HexSim outputs resulting from a model run using habitat quality values (Tier 2) estimated by Lawler et al. (2011), although the two outputs appear to converge around 2103.

Performance Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest

Like any model, InVEST carries numerous uncertainties that arise from various assumptions. To

manage uncertainties and make them more transparent for land managers, we will identify the certainty level of model outputs by using sensitivity analysis or other uncertainty assessment techniques.

- Assessment Metric: This Performance Objective will be evaluated based on the ability of the model to provide bounds on service provision estimates based on the uncertainty in model parameters.
- Required Data: This Performance Objective requires the distribution, or low and high values, for data inputs in the models of interest.
- Success Criteria: This Performance Objective will be deemed successful if we are able to identify the certainty of model estimates by providing quantitative bounds on outputs or by depicting ranges of model outputs in maps. Installation personnel acceptance of the way we represent uncertainty will be assessed in a 5-point Likert survey under Objective 13, and the average acceptance score should be at least 4.0.
- Results: Successful. We incorporated uncertainty into service-provision estimates for carbon sequestration using Monte Carlo simulation, and for sediment retention using sensitivity analysis (Section 6.3.2; Table 6.3.2.3; Figures 6.3.2.5, 6.3.2.14, and 6.3.2.15). Likert scores of 4.5 (carbon sequestration), 4.56 (InVEST/Tier 1 sediment retention) and 4.63 (InVEST/ Tier 2 sediment retention) indicate personnel acceptance of our representation of uncertainty (Section 6.3.4; Table 6.3.4.2).

Performance Objective 7: Convert alternative management scenarios into realistic alternative LULC maps

InVEST can assist decision makers in their efforts to choose between alternative management options by evaluating the ecosystem service impacts of the alternatives. This step requires that we are able to convert management scenarios into realistic land-cover maps.

- Assessment Metric: This Performance Objective will be evaluated based on our ability to reflect key management initiatives under each scenario in the LULC pattern for that scenario.
- Required Data: This Performance Objective requires conversations with relevant installation personnel and access to the Installation Master Planning, Integrated Natural Resource Management Plan (INRMP), and other data to identify key management scenarios and to identify their implications for the LULC pattern on the partner installation.
- Success Criteria: This Performance Objective will be deemed successful if we are able to create one LULC map for each alternative management scenario at a scale relevant to decision makers with consensus from relevant installation personnel about realistic changes from each modeled management scenario achieved through the use of our scenario-mapping tool. User acceptance of hypothetical scenarios will be assessed in a 5-point Likert survey under Objective 13, and the average acceptance score should be at least 4.0.
- Results: Successful. We converted alternative management scenarios into realistic alternative LULC maps at Fort Benning (Section 6.3.1). We developed three alternative scenarios relevant to military mission and resource management, i.e., Short-term Concentrated

Training [SCT], Short-term Diffuse Training [SDT], and Long-term Ecological Forestry [LEF]. The average Likert score for user acceptance of the three alternative management scenarios was 3.96, indicating personnel found the scenarios realistic and relevant to developing resource management strategies at Ft. Benning (Section 6.3.4; Table 6.3.4.2).

Performance Objective 8a: Estimate absolute changes in each ecosystem service that will result from alternative management options

To aid in the evaluation and prioritization of management options, it is useful to explore changes in multiple ecosystem services for each land-use alternative. The absolute change in services should be distinguishable for carbon sequestration and storage and all water-related services.

- Assessment Metric: This Performance Objective will be evaluated based on our ability to estimate changes in the absolute ecosystem service provision and value associated with each alternative management option.
- Required Data: The data required to provide estimates of service provision will differ across services, and the specific requirements for each of the potential models are the same as data necessary to estimate ecosystem service provision under Objectives 1 and 2 in Table 3.1.
- Success Criteria: This Performance Objective will be deemed successful if we are able to create maps and tables that depict distinguishable absolute changes in ecosystem services in response to each of the proposed land management options.
- Results: Successful. We estimated absolute changes in carbon sequestration, risk to RCW nesting habitat, and sediment export and retention that will result from alternative management options at Fort Benning (Section 6.3.2; Tables 6.3.2.2, 6.3.2.3, 6.3.2.7 and 6.3.2.10).

Performance Objective 8b: Estimate relative changes in each ecosystem service that will result from alternative management options

To aid in the evaluation and prioritization of management options, it is useful to explore changes in multiple ecosystem services for each land-use alternative. The relative change in service provision will be distinguishable for habitat risk, carbon sequestration, and water-related services.

- Assessment Metric: This Performance Objective will be evaluated based on our ability to estimate changes in the ecosystem service provision and value associated with each alternative management option.
- Required Data: The data required to provide estimates of service provision will differ across services, and the specific requirements for each of the potential models are the same as data necessary to estimate ecosystem service provision under Objectives 1 and 2 in Table 3.1.
- Success Criteria: This Performance Objective will be deemed successful if we are able to create maps and tables that depict distinguishable relative changes in ecosystem services in response to each of the proposed land management options.
- Results: Successful. We estimated relative changes in carbon sequestration, risk to RCW nesting habitat, and sediment export and retention that will result from alternative management

options at Fort Benning (Section 6.3.2; Figures 6.3.2.3, 6.3.2.4, 6.3.2.7, 6.3.2.17, and 6.3.2.18). We also conducted the tradeoff analysis across services using these relative measures (Section 6.3.3).

Performance Objective 9: Analyze trade-offs and synergies between ecosystem services
To provide decision makers with the best scientific information on land-use dynamics, we will quantitatively analyze the tradeoffs and synergies among training activities and key ecosystem services with each alternative management option.

- Assessment Metric: This Performance Objective will be evaluated based on presentation of the tradeoffs and synergies in a spatially-explicit manner.
- Required Data: Installation-wide, spatially-explicit information on multi-service values are required to achieve this objective.
- Success Criteria: This Performance Objective will be deemed successful if we are able to combine service maps for at least two services and identify areas with the greatest and fewest tradeoffs and synergies across scenarios.
- Results: Successful. We analyzed trade-offs and synergies between carbon sequestration, risk to RCW nesting habitat, and sediment export and retention at Fort Benning (Section 6.3.3; Figure 6.3.3.2).

Performance Objective 10: Identify priority DoD management themes and ecosystem services to be used in modeling scenarios).
To facilitate the integration of ecosystems services approach into existing DoD decision-making processes, it is useful to identify key management themes at Fort Benning that can be used in our modeling exercises. By using relevant themes, we will explore tradeoffs and changes in multiple ecosystem services for each land-use alternative.

- Assessment Metric: The metric used to evaluate this Performance Objective will be based on our ability to link current DoD management themes and other drivers of interest to the selected ecosystem services.
- Required Data: The linkage between management themes and ecosystem services will be derived from the latest Fort Benning INRMP and discussion with Fort Benning and ESTCP staff.
- Success Criteria: This Performance Objective will be deemed successful if we are able to identify two or more management themes and associated ecosystem services of importance to the DoD that can inform resource management decisions at Fort Benning.
- Results: Successful. We identified four priority DoD management themes (land deconfliction, forestry, soil conservation, threatened and endangered Species) and included three ecosystem services (carbon sequestration, risk to RCW nesting habitat, and sediment export and retention) in modeling scenarios intended to inform resource management decisions at Fort Benning (Section 6.3.4; Table 6.3.4.1).

Performance Objective 11: Identify opportunity for ecosystem services approach in land

management on base

As a decision–support tool, it is important to identify the steps in the decision-making process that can most be aided by InVEST outputs.

- Assessment Metric: This Performance Objective will be evaluated based on our ability to assess the fit of the model results into the current management/decision-making hierarchy at Fort Benning.
- Required Data: Discussion with Fort Benning staff and organizational documents are required.
- Success Criteria: This Performance Objective will be deemed successful if we are able to identify one or more decisions or steps within the natural resource management process for integrating information from InVEST. Potential utility of the ecosystem services approach in installation resource management will assessed by installation personnel in a 5-point Likert survey under Objective 13, and the average score should be at least 4.0.
- Results: Successful. We identified five opportunities (spatial planning and resource management, tradeoff analysis, environmental impact assessment, ecological forestry management, and regulation compliance) for including an ecosystem services approach in land management on Fort Benning (Section 6.3.4). A Likert score of 4.13 indicates personnel agreed these opportunities are appropriate for land management at Fort Benning (Section 6.3.4; Table 6.3.4.2).

Performance Objective 12: Ease of use compared with more complex models (SWAT and RCW models)

To estimate the potential uptake of InVEST specifically, we will evaluate the perceived ease of use of the models through discussion with relevant personnel at our partner installations.

- Assessment Metric: This Performance Objective will be evaluated based on the availability of model inputs, processing time, skill, and knowledge required to run other models as compared to InVEST.
- Required Data: Model running process from Objective 6, feedback of staff who have experience with SWAT or RCW models.
- Success Criteria: This Performance Objective will be deemed successful if we are able to create tables or charts comparing ease of using InVEST models versus other models for analyzing the same ecosystem services. Feedback from Fort Benning staff on ease of use will be assessed in a 5-point Likert survey under Objective 13, and the average score should be at least 4.0.
- Results: Successful. We compared perceived ease of use between InVEST and more complex models (SWAT and RCW models) for modeling sediment export and retention and risk to RCW nesting habitat (Section 6.3.4; Tables 6.3.4.3 and 6.3.4.4). A Likert score of 3.9 indicates Fort Benning personnel perceived InVEST models as useful alternatives to more complex models, given the time and effort it takes to run the various models (Section 6.3.4; Table 6.3.4.2).

Performance Objective 13: Assess user acceptance of project outcomes

To gauge user perception of success in several Performance Objectives (3, 5, 6, 7, 11, and 12), we will conduct a brief survey with relevant Fort Benning personnel before the demonstration completion for them to evaluate project outcomes.

- Assessment Metric: This Performance Objective will be evaluated based on the degree of user satisfaction with our project outputs measured at a five-point Likert scale.
- Required Data: User feedback will be collected from relevant Fort Benning staff in a post-demonstration survey.
- Success Criteria: This Performance Objective will be deemed successful if we provide clear information on user acceptance of project outcomes under Performance Objectives 3, 5, 6, 7, 11, and 12, and achieve an average acceptance score of 4.0 or higher for each question and across all questions in the 5-point Likert survey.
- Results: Successful. We assessed user acceptance of project outcomes at Fort Benning with a 5-point Likert survey and found the average Likert score was 4.13 (range = 3.56 - 4.63), indicating overall acceptance of project outcomes (Section 6.3.4; Table 6.3.4.2).

4.0 SITE DESCRIPTION

This section presents concise summaries of the demonstration sites' location, physical and environmental characteristics, and brief overview of management operations.

4.1 SITE LOCATION AND HISTORY

The three installation sites are located in different parts of the U.S. and are characterized by distinct environmental conditions and natural-resource management issues. By applying InVEST at each of these installations, we hope to demonstrate the flexibility of InVEST models and their relevance to decision-makers facing a range of decisions related to natural resources and environmental outcomes.

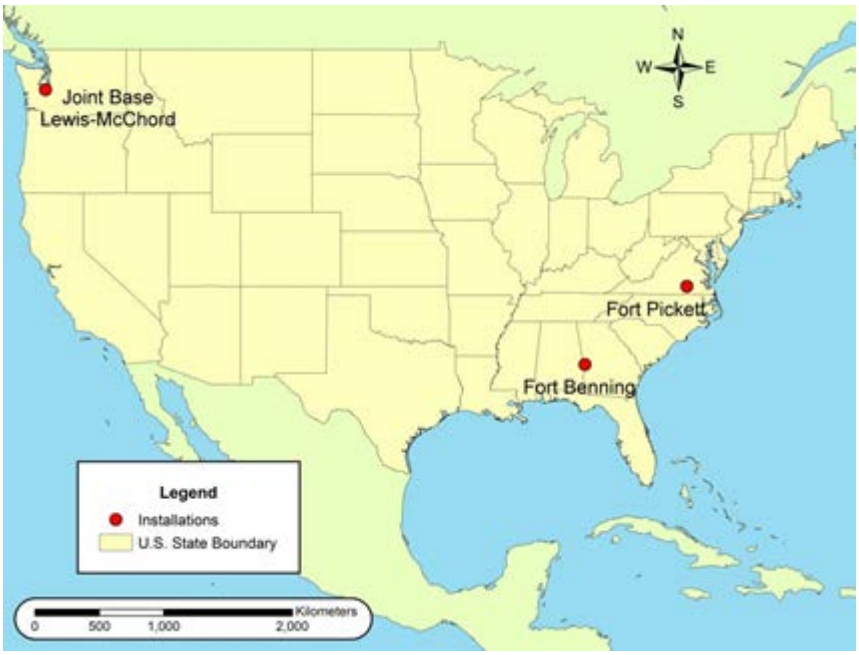

Figure 4.1.1. Map of installation locations in the U.S.

- **Joint Base Lewis-McChord**

The Joint Base Lewi-McChord INRMP of 2007 notes that Joint Base Lewi-McChord is an approximately 35,000-hectare military reservation located in western Washington, roughly 60 kilometers south of Seattle and 11 kilometers northeast of Olympia. The military mission at JBLM is to operate a state-of-the-art power projection and sustainment platform for warfighters by providing them with superior training support and infrastructure; support the transformation of 1st Corps and JBLM; ensure the well-being of its soldiers, civilians, retirees, and their families; and remain a committed Pacific Northwest neighbor. The JBLM vision is of an

enduring strategic installation, teamed and ready to project combat power for decisive victory. A primary intent of the INRMP is to help fulfill this vision by ensuring that natural resources on JBLM are managed to ensure no net loss in their capability for supporting the military mission. JBLM is a major facility for weapons qualification and field training. Training activities that characterize land use at JBLM include on/off-road vehicle movement, placement of temporary targets, gunnery practice, digging activities (vehicle positions, tactical operation centers, foxholes), unit assembly, and unit deployment exercises. Fort Lewis and Air Force Base McChord merged in 2010. There are approximately 445 hectares of prairie on AFB McChord, though there are no candidate species currently living there and the prairie has been invaded by Scott's broom.

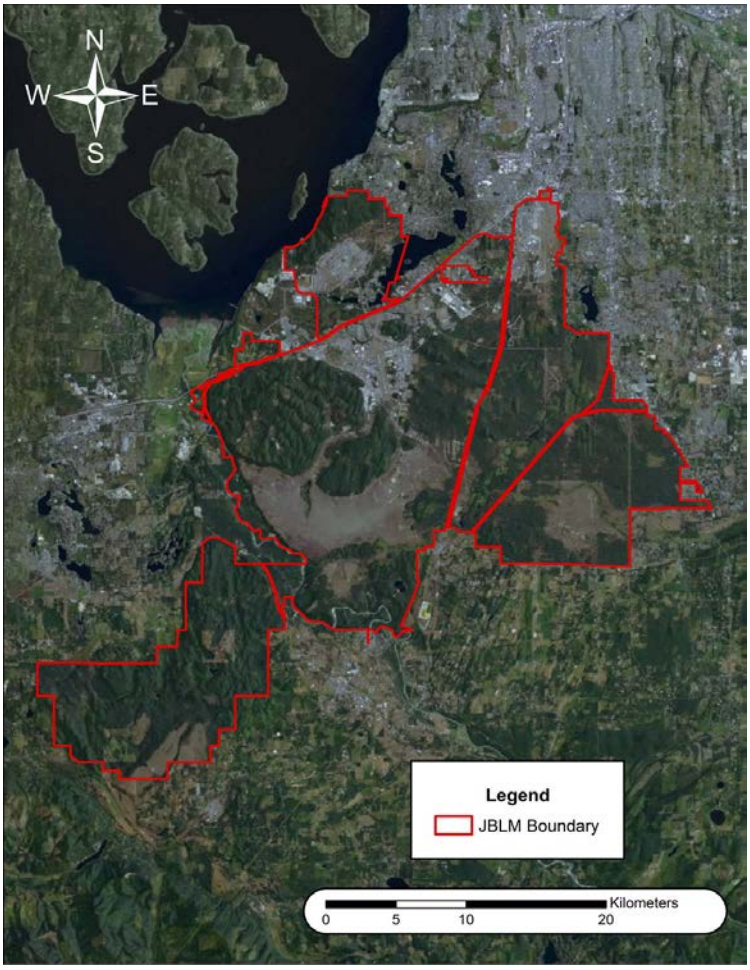

Figure 4.1.2. Footprint of Joint Base Lewis-McChord, WA.

- **Fort Pickett**

According to Chapter 1 of the Installation's INRMP, Army Reserve National Guard -MTC (ARNG-MTC) Fort Pickett is located in the Piedmont physiographic province of southeastern

Virginia, approximately 100 kilometers southwest of Richmond and 5 kilometers east of the town of Blackstone. ARNG-MTC Fort Pickett's primary objective is to support the training of active, reserve, and National Guard combat, combat support, and combat services support units in successful techniques of organization, deployment, and combat operations under as wide a variety of conditions as possible. In order to further this mission, the training areas must have a wide range of terrain features in order to more fully duplicate possible combat and support environments. The installation also provides administrative and logistical support and maneuver training areas for units of the U.S. National Guard, Reserve components, Active Army, and other military services. These requirements make the proactive management of natural resources necessary in order to fulfill the military mission of ARNG-MTC Fort Pickett.

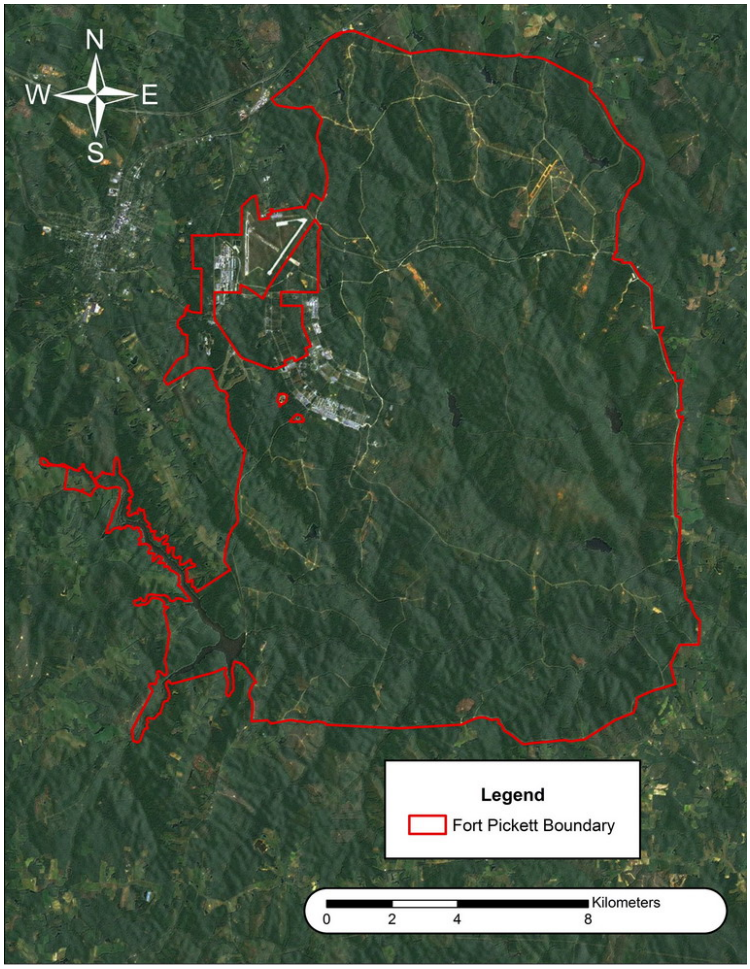

Figure 4.1.3. Footprint of Fort Pickett, VA.

- **Fort Benning**

Fort Benning is located in the lower Piedmont Region of central Georgia and Alabama (Figure 4.1), approximately 13 kilometers south of Columbus (32°25′05″-32°23′24″N, 84°45′37″-84°45′59″W). The installation occupies about 74,000 hectares of land; approximately 93% lies in Muscogee and Chattahoochee counties in Georgia, while the remaining 7% is in Russell County,

Alabama, divided by the Chattahoochee River (Fort Benning 2001, Sharif and Balbach 2008). Ft. Benning was established in 1918 as a temporary facility for the U.S. Army Infantry School and has transformed into the U.S. Army Maneuver Center of Excellence, hosting a number of tenant units, including the U.S. Army Armor School, U.S. Army Infantry School, and the Western Hemisphere Institute for Security Cooperation. The mission of the Fort Benning Maneuver Center of Excellence is to provide trained, agile, adaptive, and ready soldiers and leaders for an Army at war, while developing capabilities for the Maneuver Force and the individual soldier and providing a world-class quality of life for soldiers, civilians, and Army families. Over the last several years, the DOD has established several mission initiatives that require additional infrastructure, roads, cantonments, range establishments, impact zones, and training facilities at Fort Benning. Land disturbances due to the implementation of Base Realignment and Closure (BRAC) and transformation initiatives is estimated to affect over 19,000 acres throughout the entire Installation (Fort Benning 2001; Donigian 2013). If mitigation measures are not enforced, water quality and quantity, aquatic ecosystems, wildlife habitat, and other attributes of the installation will be severely impacted.

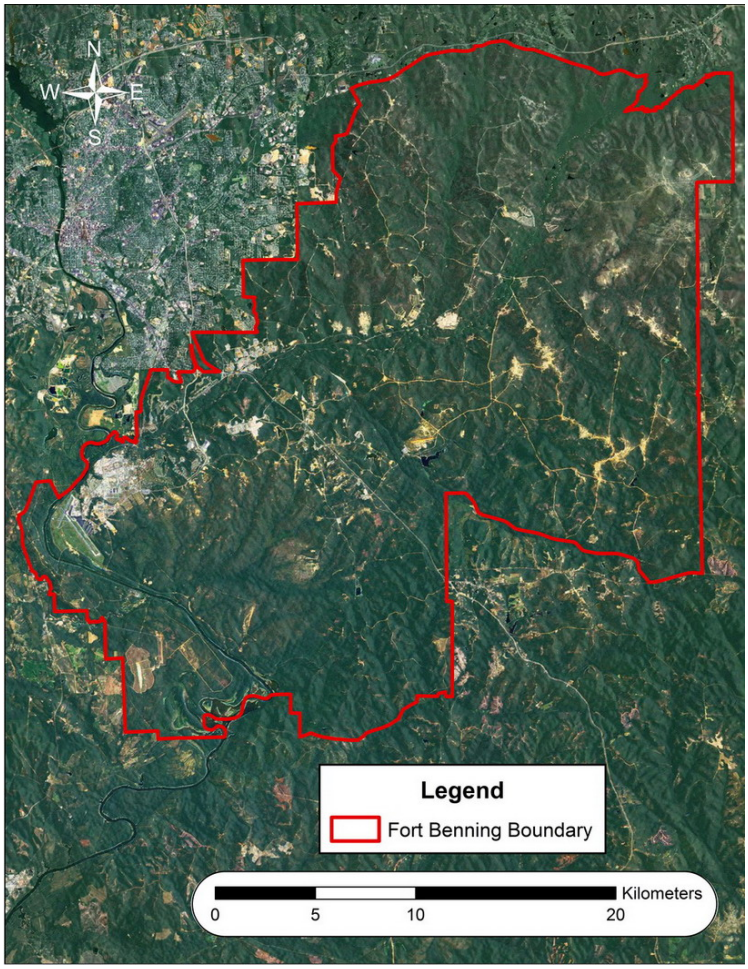

Figure 4.1.4. Footprint of Fort Benning, GA.

4.2 SITE CHARACTERISTICS

The installations included in this analysis are located in different ecological settings. We will contrast their settings and discuss the main environmental management issues relevant to each base.

- **Joint Base Lewis-McChord**

JBLM has a Mediterranean Oceanic climate with dry, warm summers and mild, wet winters. The area receives approximately 990 mm of rain and 203 mm of snow per year and temperature typically varies from 1°C to 25°C. Forests are the largest ecosystem type on JBLM, covering approximately 60 percent of the installation (21,286 ha). Over 18,615 ha of these forests are dominated by Douglas-fir (*Pseudotsuga menziesii*), the most common tree species on JBLM. The primary goal of forest management on the installation is to support the military mission by providing a variety of forested environments for military training. At the same time, forests are managed to develop and maintain late-succession forest habitats for the northern spotted owl and other species, to maintain and restore native biological diversity and unique plant communities, and to maintain low risk of catastrophic fire. Sale of timber provides the local community with wood for firewood and other uses. Approximately 5,666 ha on JBLM are covered by either prairie or grasslands ecosystems. An estimated 25% of prairie habitat on JBLM is considered high quality, dominated by Roemer's fescue (*Roemer's fescue*), a native species of bunchgrass. Prairies are managed to provide suitable open conditions for training, to maintain native populations and functions, and to control invasive species. Oak woodlands cover over four percent of JBLM (1,619 ha), occurring primarily as ecotones between open prairies and closed conifer forests. Oak woodlands are defined by the presence of Oregon white oak, (*Quercus garryana*) which is Washington's only native oak tree. Oak woodlands are managed to maintain their current extent on JBLM. Wetlands and other aquatic habitats are widely distributed over JBLM, covering roughly 1,821 ha of the installation. Wetlands are managed to maintain wetland training opportunities, enhance anadromous fish habitat, provide recreational opportunities, and control non-invasive species.

- **Fort Pickett**

ARNG-MTC Fort Pickett is generally composed of low, gently rolling terrain with level uplands and intermittent stream drainages. The elevation range within the installation is from 61 m above sea level along the Nottoway River to approximately 137 m above sea level north of the Blackstone Army Airfield. Approximately 90% of ARNG-MTC Fort Pickett is in the Nottoway River drainage basin, which consists of six small tributaries that flow into the Nottoway River. Whereas the northern training area of the installation is considered a level upland, the southern training area is characterized by steeper slopes and ravines. ARNG-MTC Fort Pickett is located on the boundary between the Piedmont and the Coastal Plain soil divisions. Soils at Fort Pickett generally consist of a quartz sandy loam surface layer ranging in depth from 15-46 cm over a micaceous clay loam, with a frost depth of 61 cm. Most of the upland soils found on ARNG-

MTC Fort Pickett are not frequently flooded, have a slow to moderate infiltration rate and are non-hydric. Loams and sandy loams are the most common soil type on ARNG-MTC Fort Pickett. Light-colored silt and clay loams contain approximately 2% organic matter, compared to dark-colored soils that contain 4-10% organic matter.

- **Fort Benning**

Fort Benning's climate is characterized by long hot summers and mild winters. Precipitation falls in the spring and summer as a result of thunderstorms. The annual precipitation averages approximately 1,295 mm, with the heaviest rainfall occurring in March, July, and December, but can occur in any month (Bhat et al. 2009). Fort Benning is located along the Fall Line of two physiographic provinces: the Piedmont Plateau to the north and the Coastal Plain to the south. The Fall Line represents distinct features of topography, geology and soils, and vegetation communities. Fort Benning is moderately sloped between 3 and 15 percent. Several streams originate from the dissected Fall Line topography and flow through installation lands, often supporting unique communities of aquatic flora and fauna (Fort Benning 2006). The rolling uplands are underlain with sandy to sandy clay loams derived primarily from the unconsolidated sand and clay beds of the Coastal Plain. The sandy nature of the soils allows storm water to easily dislodge and transport sand grains and erode surface soils (Sharif and Balbach 2008).

Fort Benning has diverse and dynamic ecosystems, heavily forested with pine, mixed pine and hardwoods, and deciduous forests (Figure 4.2). Much of the mature pine woodlands, especially those dominated by Longleaf Pine (*Pinus palustris)*, support Red-cockaded Woodpecker (RCW; *Picoides borealis)*, a federally endangered species. Woodlands at Fort Benning are managed to preserve the mature, large-diameter trees and the open mid-story lacking hardwoods, which the birds prefer for nesting and foraging (Walters 1990, Walters et al. 2002).

5.0 TEST DESIGN

The goal of the demonstration is to illustrate the utility of InVEST as a decision-support tool for evaluating the impacts of alternative management options on ecosystem-service provision and value. To successfully demonstrate the usefulness of InVEST, it is important to situate the biophysical and economic analysis with InVEST into the broader ecosystem service approach that also encompasses iterative stakeholder engagement, scenario development, and synthesis of results relevant to decision making.

5.1 CONCEPTUAL TEST DESIGN

NatCap's ecosystem services approach and the InVEST tool have been designed to provide policy-relevant information to interested parties (government agencies, non-governmental organizations, and private organizations) in the hope of achieving more efficient resource-use outcomes. Specifically, the tool is devised to compare the impacts of different management scenarios on a suite of ecosystem services so that the policy maker can choose the management option that meets his/her objectives. As highlighted in Figure 5.1, our analytical approach includes a number of key steps that must be achieved to ensure a successful application:

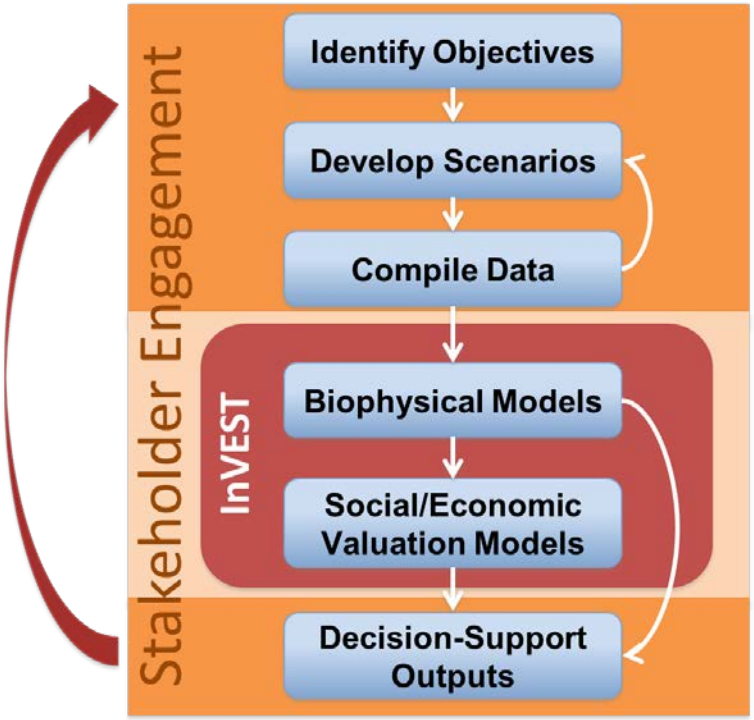

Figure 5.1. Conceptual design of demonstration steps and opportunities for evaluation

- **Identify objectives with Installation Personnel**

It is important to target ecosystem service analysis to each installation's specific decision context and environmental conditions. Through interactive discussions with installation personnel, we develop a clear understanding of major environmental problems, management practices, regulatory drivers, as well as focal ecosystem services, and then identify key objectives to guide our application of InVEST.

- **Develop scenarios**

The next step is the development of scenarios to represent possible future management plans. We work with installation personnel to create qualitative descriptions for the potential outcomes of different future management options, and then specify quantitative representations of the narratives. The potential management plans are depicted spatially on LULC maps that serve as inputs to InVEST models.

- **Compile data**

We collect data from installation personnel and other relevant public agencies to support scenario development and ecosystem service modeling with InVEST.

- **Analyze biophysical supply and economic value with InVEST models**

We apply the InVEST models for relevant ecosystem services to estimate the impacts of alternative management scenarios on service provision and value. We use observed data to calibrate our biophysical models and validate model outputs. Uncertainty in model inputs is incorporated by bounding model outputs and highlighting locations with consistently ranked service provision and value across the range of input combinations. We evaluate ecosystem service implication of management alternatives by identifying differences in service provision and value across the LULC types and management units associated with alternative scenarios.

- **Synthesize decision-support outputs**

We present the InVEST outputs in a manner that is most useful to the decision-making context. In particular we relate ecosystem services to management themes such as ecosystem-based forestry management, water resources management, species at risk management, etc.

Below, we describe the application of NatCap's ecosystem services approach to management at each of the three DoD installations included in this project.

- **JBLM: Conceptual test design**

Objectives for improved management and scenarios for future land use in JBLM were developed in a series of several workshops with base personnel. Our team interviewed several DoD staff about their knowledge of ecosystem services and key drivers that influence management at the base. An initial meeting was held on base in November 2011 to discuss the dynamics of these key drivers. This meeting resulted in the discussion of rare species and habitat limitations, invasive species management, and training capacity, as well as how such drivers influence each

other throughout the base.

Criteria for several land use scenarios were also discussed during the November 2011 meeting, including the spatial dynamics that lead to alternate future scenarios at the base. Draft scenarios and the resulting Land use Land Cover (LULC) maps were then developed by NatCap and presented to JBLM staff during meetings in March and April 2012 for their comments. After these meetings, our team revised the scenarios and the resulting LULC maps and presented findings regarding ecosystem services tradeoffs to the JBLM staff during a meeting in September 2012. During and following this workshop, we finalized 5 scenarios that are projected 20 years into the future from the current LULC: Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

Our analysis maps the provision and change of four ecosystem services—prairie habitat, infantry and vehicle training capacity, carbon sequestration, and timber production—under the BAU scenario and four alternative scenarios using the InVEST Habitat Risk Assessment Model, Training Ecosystem Services Model, the InVEST Carbon Storage and Sequestration Model, and InVEST Managed Timber Production model. We then evaluated synergies and trade-off analysis among multiple ecosystem services by 1) comparing the percentage change of aggregate ecosystem service provision for each alternative scenario relative to BAU; 2) mapping the spatial distribution of ecosystem benefits across the installation; and 3) examining the potential of ecosystem service improvement in specific training zones.

- **Ft. Pickett: Conceptual test design**

At Fort Pickett, a series of interviews and meetings with base personnel were conducted in order to discuss management goals. Interviews with DoD staff were conducted in June and July 2012 to discuss ecosystem services and environmental drivers that influence management at the base. An initial meeting was held at Fort Pickett in March 2013 and resulted in the discussion of exploring mitigation strategies for new projects (i.e., constructing corridors, training areas/facilities, and air runways), as well as the potential mitigation offsets to ecosystem services by increasing riparian buffers within the base. Fort Pickett personnel expressed interest in using multiple-scale static maps to assess impacts on sediment retention, species' habitat, and carbon storage and sequestration for the siting of new projects and training activities. In particular, a 35-ac firing range (FCC 17809 Qualification Training Range) was identified by the Army Headquarter Integrated Training Area Management (ITAM) manager as a possible future mission expansion. A series of multiple-scale static maps will allow staff at Fort Pickett to choose the appropriate scale for making effective management decisions and environmental assessments. Based on these suggestions, we focused on providing multiple-scale ecosystem service maps using the InVEST Sediment Retention Model, GLOBIO3, and InVEST Carbon Storage and Sequestration Model with scenarios that optimize locations for building new projects and training activities.

- **Ft. Benning: Conceptual test design**

The Natural Capital Project team interviewed Fort Benning staff through a series of interviews to discuss concerns and the key drivers that influence management at the base. An initial meeting was held on base in December 2013 to discuss the dynamics of these key drivers. Based on these meetings; the interactions between managing land to support habitat for the red-cockaded woodpecker, concentrating training activities in the Good Hope area, and converting declining loblolly pine forests to long-leaf pine forests emerged as important management concerns for base personnel. This meeting resulted in the discussion of maintaining rare species populations and habitat, mitigating soil erosion, and maintaining training capacity, as well as how such drivers affect each other.

Criteria for several land use scenarios were also discussed during the December 2013 meeting, including the spatial dynamics that lead to alternate future scenarios at the base. Draft scenarios and the resulting Land use Land Cover (LULC) maps were then developed by NatCap and presented to Fort Benning staff during meetings in April 2014 for their review. We finalized two scenarios that are projected 20 years into the future from the current LULC: Short-Term Diffuse Training (SDT), Short-Term Concentrated Training (SCT), and one scenario that is projected 100 years into the future, the Long-Term Ecological Forestry (LEF) scenario. Results for ecosystem services tradeoffs were presented to Fort Benning staff during a meeting in September 2014.

The analysis for Fort Benning maps the provision and change of three ecosystem services—rare species habitat, carbon sequestration, and sediment retention—under the baseline scenario and three alternative scenarios using the InVEST Habitat Risk Assessment Model, HexSim, the InVEST Carbon Storage and Sequestration Model, and InVEST Sediment Retention model. We then evaluated synergies and trade-offs among multiple ecosystem services by 1) comparing the percentage change of aggregate ecosystem service provision for each alternative scenario relative to baseline scenario; 2) mapping the spatial distribution of ecosystem benefits across the installation; and 3) examining the potential of ecosystem service improvement zones.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

The primary way InVEST can support decision-making is through the comparison of service provision on the landscape between current and alternative future management scenarios. The models allow for comparison of service provision and value due to land-cover change that results from either climate or management interventions. Depending on the management priorities at each partner installation, we used either the present land cover map, or a hypothetical future land cover map based on business-as-usual management as our baseline condition.

- **JBLM baseline biophysical conditions & assumptions**

The Business-As-Usual (BAU) scenario developed with installation managers describes a 20-year projection using current management practices being conducted at JBLM. This scenario assumes that training intensity and the installation budget will remain consistent with the 2010 levels. Training restrictions due to the listing of at-risk species occur in habitat that is occupied by the imperiled species in 2010. Prairies containing at-risk species are managed for invasive species, but nevertheless exhibit a Scotch broom infestation rate of 10%, which JBLM staff suggested as the baseline rate of infestation given management. The current budget scenario assumes unoccupied prairies contain a Scotch broom infestation rate of 25% and foresters replant 41 hectares per year of laminated root rot-infested areas with immune-resistant species. Given the natural spread of laminated root-rot within JBLM, foresters project that 30% (4,726 ha) of the susceptible Douglas-fir forest will be infected (Jeffery Foster, Personal Communication, November 1, 2012).

- **Ft. Pickett baseline biophysical conditions & assumptions:**

The baseline scenario for Fort Pickett includes current land-use and resource management for the installation as of 2012. We adjust parameters for the sediment model based on 2007 INRMP and professional judgment. High impact areas are considered areas that are used for vehicle and maneuver training and include TA 15 MPRC, TA 16 IPBC, maneuver corridors, open grasslands, and grasslands in High Hazard impact Area. For these areas we assume higher soil erosion due to heavier training use and adjust the sediment parameters to include +60% cover management soil loss, -60% soil retention, and +30% soil erodibility. Low Impact area include all other existing training ranges, are assumed to experience a slight increase in soil erosion due to heavier use than other open areas, and the parameters are adjusted to +20% cover management soil loss and -20% soil retention. Forest maneuver areas include forest stands thinned for vehicle maneuver training and the parameters are adjusted to include+20% cover management soil loss, -20% soil retention, and +30% soil erodibility due to heavier use.

- **Ft. Benning baseline biophysical conditions & assumptions:**

The 2013 baseline scenario for Fort Benning represents current land use, resource management, and training activities after major BRAC/MCoE transformations. New training ranges, tank

trails, and three new maneuver training areas have been built to the accommodate new training mission, particularly the major increase in mechanized training carried by the Armor School, which was relocated from Fort Knox to Fort Benning in 2010 under BRAC. There are approximately 23,500 acres of land protected under ACUB in the priority area to the northeast of Fort Benning, and 4,000 acres potential parcels to be protected with the current budget. Forestry management at Fort Benning focuses on longleaf pine (LLP) restoration and prescribed fire to support forest habitat for red-cockaded woodpecker and long-term ecological sustainability. We also assume all forest areas are managed by prescribed fire on an average three-year cycle continuing the current prescribed burn regime.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

We present a brief overview of the InVEST component models, followed by a description of the specific assumptions and inputs that guide their application on installation sites.
For each focal service, we collected the data necessary to run the models as well as information that can be used for model validation and uncertainty analysis. We then incorporated the model-specific outputs to provide information to support the process of selecting the preferred management alternative. Further details are available in the InVEST online user manual (Sharp et al. 2014).

5.3.1 InVEST Carbon Storage & Sequestration Model

The InVEST Carbon Storage and Sequestration model aggregates the amount of carbon stored in four carbon pools (aboveground biomass, belowground biomass, soil, and dead organic matter) according to the land-use maps and classifications produced by the user (Conte et al. 2011b). A fifth, optional, pool included in the model applies to parcels that produce harvested wood products (HWPs) such as firewood or charcoal or more long-lived products such as house timbers or furniture. Tracking carbon in this pool represents the amount of carbon kept from the atmosphere by a given product.

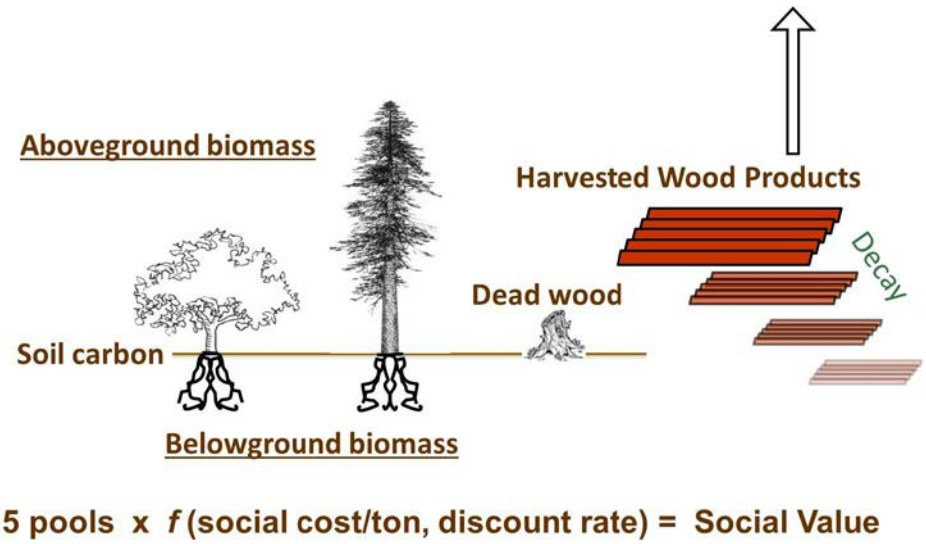

Figure 5.3.1. Schematic depicting InVEST Carbon Storage and Sequestration Model.

Using maps of LULC types and the amount of carbon stored in carbon pools, the InVEST model estimates: the net amount of carbon stored in a land parcel over time; the total biomass removed from a harvested area of the parcel, and the social value of the carbon sequestered in remaining stock. Avoided damages from climate change are used to estimate the social value of carbon storage over time (sequestration and loss) if users provide both a current and projected future LULC map. If multiple future scenarios are available, the differences between the current value of carbon and its value under alternate future landscape can be compared. This valuation component of the model estimates the economic value of sequestration (not storage) as a function of the amount of carbon sequestered, the monetary value of each unit of carbon, a monetary discount rate, and the change in the value of carbon sequestration over time.

The model oversimplifies the carbon cycle, which allows it to run with relatively little information, but also leads to important limitations. For example, the model assumes that none of the LULC types in the landscape are gaining or losing carbon over time. Instead, it is assumed that all LULC types are at some fixed storage level equal to the average of measured storage levels within that LULC type. A second limitation is that because the model relies on carbon storage estimates for each LULC type, the results are only as detailed and reliable as the LULC classification used. Another limitation of the model is that it does not capture carbon that moves from one pool to another. For example, if trees in a forest die due to disease, much of the carbon stored in aboveground biomass becomes carbon stored in other (dead) organic material. Also, when trees are harvested from a forest, branches, stems, bark, etc. are left as slash on the ground. The model assumes that the carbon in wood slash “instantly” enters the atmosphere. To account for these limitations, the user may offset values for LULC types to account for decomposition, forest growth, and other forest dynamics.

With respect to its estimates of carbon in HWPs, the model is constrained by the fact that users

may assign only one harvest rate (e.g., 50 Mg of wood per harvest where a harvest occurs every 2 years) and only one decay rate (e.g., the wood harvested from the parcel over the years is always used to make the same product that decays at the same rate) to each parcel. In reality, harvested parcels will exhibit variation in harvest and decay rates over time. The model also does not account for the greenhouse gasses (GHGs) emitted from the transportation of harvested wood from its initial harvest site to its final destination, the conversion of raw wood into finished products, or agriculture-related activities such as from tractors and livestock.

5.3.2 InVEST Managed Timber Production

The InVEST Managed Timber Production model is designed for cases where an entity (e.g., a government, a community or tribe, a private timber company) has a formally recognized right to harvest roundwood from a forest. The model structure is very simple to suit contexts where little data on harvest practices and tree stand management exists. It can be applied to timber harvest from either forest plantations, which are regularly harvested and replanted to maximize income from forest products, or from natural forests, which retain much of their original structure and function while small scale harvests are taking place.

The model runs on a vector GIS dataset that maps timber management zones on the landscape that are currently or expected to be used for legal timber harvest over a user-defined period. Each timber management zone is characterized by its total area, proportion of the total area that is harvested each period, biomass or volume of wood harvest each period, frequency of harvest, and harvest and maintenance costs. The timber management zone map can either be associated with a current land use land cover (LULC) map or with some future LULC scenario maps. With inputs of timber price and a discount rate, the model calculates, for each timber management zone, the net present value of harvests that occurred between the current/future year and some user-defined date, assuming harvest practices and prices are static over the time interval modeled.

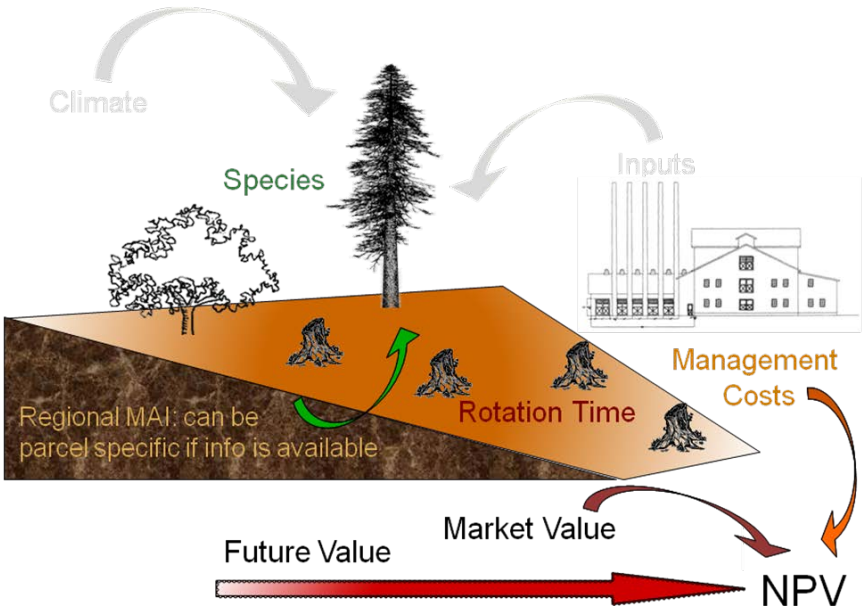

Figure 5.3.2. Schematic depicting InVEST Managed Timber Production Model.

This model assumes that the percent of the forest harvested each harvest period, the mass of timber harvested each harvest period, the frequency of each harvest period, and harvested related prices and costs remain constant in each timber parcel over the user-defined time period. In reality, each of these variables can change from year to year. For example, the mix of species harvested from a forest could change from one harvest period to the next and this could affect everything from the amount of wood harvested to the composite price received for the timber. In addition, un-modeled disturbances, such as forest fires or disease, or occasional managed thinning can have a major impact on harvest levels from a forest parcels.

Some of these limitations can be addressed by constraining the length of the time period used to assess harvests in parcels. For example, if the current year is 2000 and only the expected harvests until 2010 are valued, any unaccounted changes in timber harvest management or price changes may be minor. At this point a future 2010 LULC and timber parcel map could be evaluated with the timber model looking 10 years ahead again, from 2010 to 2020. The future timber parcel map could include any changes in timber management and prices that occurred between 2000 and 2010. This process could be repeated for successive decades until, for example, 2050. Successive model runs with decadal time intervals until 2050, and the ability to change harvesting behavior and prices, will better approximate harvesting practices on the landscape than just running the model once from 2000 to 2050.

Further, given the expected variation in harvest management practices and prices over the modeled time interval, it is suggested that the user use mean values for each model input. The mean is typically the best summary of the distribution of expected values for a variable. For example, if it is known that harvests from a timber parcel over time will involve various species

it is possible to set the timber price for that parcel equal to the average expected price for all harvested species.

5.3.3 InVEST Habitat Risk Assessment (HRA) model

The InVEST HRA model combines information about the degree to which the habitat of a given species is exposed to a stressor with information about consequences of exposure for the species (Hobday et al. 2011 Arkema et al. 2014, Sharp et al. 2014). Exposure is a function of the degree of spatial and temporal overlap between habitat and a stressor, stressor intensity, and effectiveness of management strategies mitigating stressor impacts (Figure 5.3.3). The consequence of exposure is a function of the extent of change in area and structure due to the stressor, the frequency of disturbance relative to the historical disturbance regime (e.g., a fire-adapted habitat such as prairie would be less sensitive to burning than a habitat that rarely experiences fire), and attributes of the species either composing or residing in the habitat that influence the likelihood of its recovery from effects of the stressor (i.e., natural rates of dispersal, maturity, reproduction, and mortality) (Figure 5.3.3). Exposure (*E*) and consequence (*C*) values are then combined to produce a risk (*R*) value for each stressor-habitat combination (Figure 5.3.3).

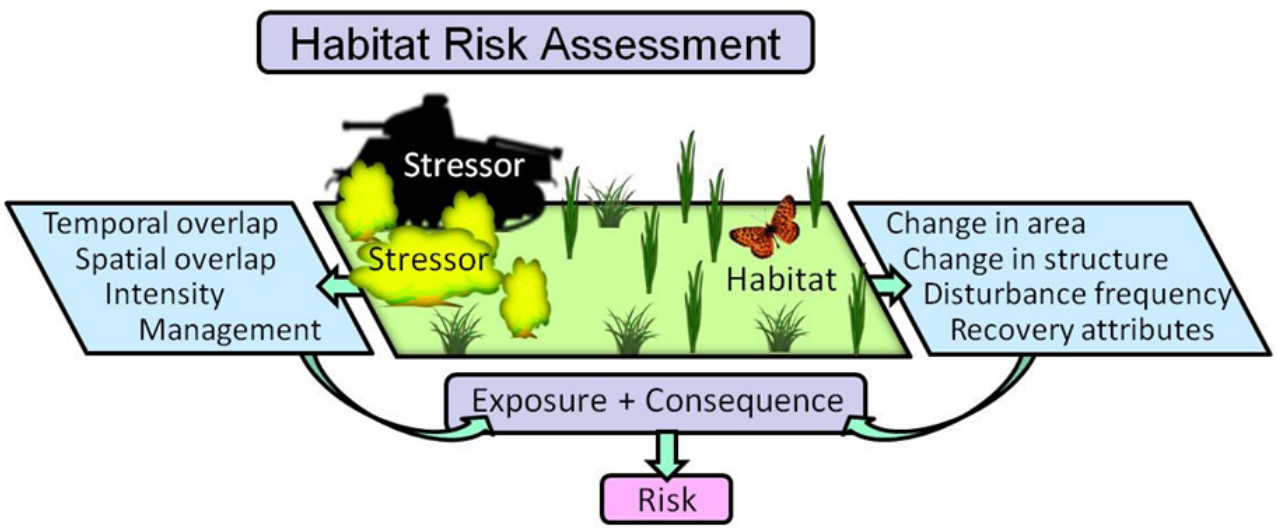

Figure 5.3.3. Schematic depicting InVEST Habitat Risk Assessment (HRA) Model.

Risk to habitat *i* caused by stressor *j* is calculated as the Euclidean distance from the origin in exposure-consequence space (Sharp et al. 2014).

$$R_{ij} = \sqrt{(E-1)^2 + (C-1)^2}$$

Last, cumulative risk for habitat *i* is the sum of all risk scores for that habitat. Model outputs include maps illustrating cumulative risk summed for each habitat in each grid cell within a

study region.

The model screens habitat risks under current and future scenarios of land use and its output can provide guidance for natural resource managers to tailor land uses to avoid impairment to quality and function of critical habitat. The HRA modeling approach is flexible and accommodating to varied levels of data-richness; if any of the factors that influence exposure and consequence are irrelevant in a particular case, they need not be included. The HRA model enables the visualization of areas on the landscape where impacts due to training and testing activities, development projects, or other anthropogenic uses of installation lands may create tradeoffs between these activities and the provision of habitat for species at risk.

5.3.4 Training Capacity model

The training capacity model is designed to quantify the extent of military training supported by natural habitats on DoD installations. It calculates the percentage of suitable natural landscape for infantry and vehicle training in each of the sub-training areas. Two categories of training are defined in the model: Infantry training refers to training activities involving field operations and maneuver on foot, and vehicle training refers to activities involving tracked (e.g., tanks) or wheeled (e.g., strykers) motor vehicles. Live fire training is not included because it primarily occurs on specified impact areas, and is not likely to be affected under alternative natural resource and land use policies.

Training capacity is influenced by three factors as illustrated in the Figure below: 1) Accessibility implies suitable landscapes for infantry and vehicle training activities would not support training if they are isolated by unsuitable landscapes and inaccessible by road. 2) Training restrictions, imposed on soil-disturbing training activities to protect habitat for at-risk species, primarily prohibits off-road vehicle movement. 3) Frequency of training use characterizes troop demand for a realistic training and testing environment.

Figure 5.3.4. Schematic depicting Training Capacity Model.

5.3.5 InVEST Water Yield Model

Water yield is an essential input to other water-related models even though it is not always an ecosystem-service end point. The InVEST tier 1 water yield model uses an index of dryness (i.e., ratio of potential evapotranspiration to precipitation) to partition annual precipitation to evapotranspiration and runoff. The dryness index is a dominant factor that controls watershed water balance at annual time scale, making the water yield model valid for quantifying impacts of land use on runoff at a watershed scale. The model neglects extremes and does not consider the temporal dimensions of water yield. The model assumes that all water produced in a watershed in excess of evapotranspiration arrives at the watershed outlet, assuming no change in storage. The surface water-ground water interactions are not included (Fig. 5.3.5).

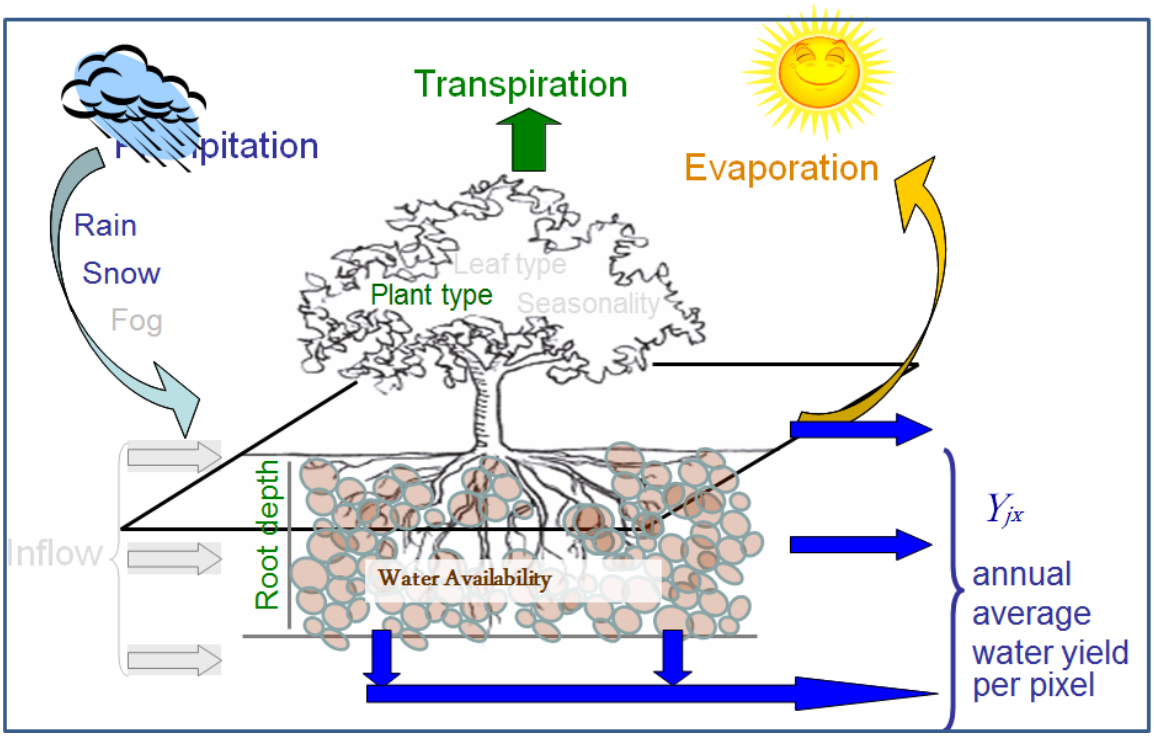

Figure 5.3.5. Schematic depicting the water balance model used in the InVEST Water Yield Model. The model includes the parameters shown in color and ignores the parameters shown in gray.

Data requirements include soil depth, mean annual precipitation, plant available water content, average annual potential evapotranspiration, land cover map, crop evapotranspiration, root depth and shape file of (sub) watersheds. Model outputs include maps and tables of total and mean gross water yield per sub-watershed, total and mean water consumption per sub-watershed, total and mean net water yield per sub-watershed.

This model has been tested and verified in several different watersheds. For example, the model was run in five major watersheds within Hainan Island, China for five separate (discontinuous time series) years; the model performed at errors ranging from 5 to 10%, compared with observed data (Zheng et al. 2013). In the Texas Gulf Basin, there was a strong agreement (R^2 = 0.84) between InVEST outputs in 122 sub-catchments and annual average water yield generated by the widely used SWAT model (Arnold et al. 1998). In Iowa, the model showed consistent agreement when compared to observed runoff in 5 major watersheds (R^2 = 0.80 to 0.95), and in New Mexico, the model outputs compared satisfactorily to observed runoff in 6 major watersheds. We are in the process of testing this model further in Colombia and several other U.S. watersheds.

5.3.6 InVEST Sediment Retention Model

The InVEST tier 1 sediment retention model predicts soil erosion, sediment yield and sediment retention based on the Revised Universal Soil Loss Equation (RUSLE) (Wischmeier and Smith 1978) and retention capacity of land uses. The USLE predicts sheet wash erosion based on the energetic ability of rainfall to move soil and cause erosion (R), the erodibility of a given soil type (K), slope length (LS), erosion protection provided by the presence of vegetation (C), and management practices (P). In the past two years, the InVEST sediment retention model has been considerably updated. Some of the updates include: (1) the D-8 single flow algorithm is replaced by D-Infinity (Tarboton 1997) multi-flow direction algorithm to capture the geometry of divergent flow over hillslopes. The D-Infinity algorithm allows continuous flow angles and flow partitioning between one or two neighbor grid cells; (2) the effect of convergence and divergence is fully considered by calculating LS from upslope area and aspect for two-dimension surface. This LS equation fully accounts for topographic complexity by considering both the profile curvature (in the downhill direction) and the tangential curvature (perpendicular to the downhill direction), and it requires no adjustments when slope is greater than 9% and slope length is different than 22.12m; (3) in the original InVEST model, retention was mainly an outcome of physical filtration and slowing down of overland flow by vegetation. A new algorithm is being added to account for factors such as slope, soil permeability and area in the sediment transport and deposition processes (Figure 5.3.6.1).

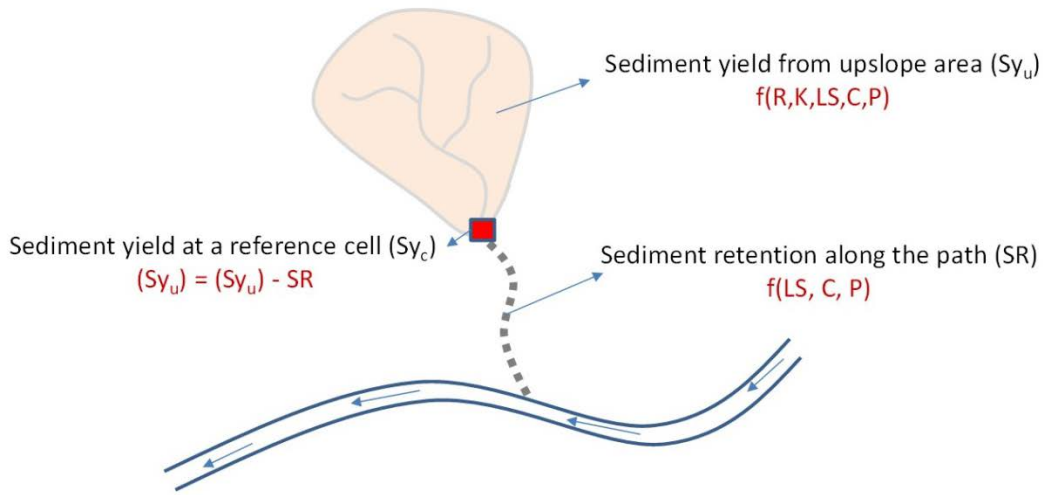

Figure 5.3.6.1. Components of a cell-based sediment export calculation.

The sediment retention model has three main components. The first component of the model accounts for a soil detachment and erosion. In areas where rainfall intensity is high and less vegetated, there is a high chance that soil particles will become detached and transported by overland runoff. Also, in areas where the soil has a high proportion of sand and less organic matter, soil particles will easily detached from the soil pack and transported by overland runoff. The second component of the model deals with the ability of vegetation to keep soil in place on a given pixel by comparing erosion rates on that pixel to what erosion rates would be on that pixel with no vegetation present (bare soil). Vegetation does not only keep sediment from eroding where it grows, it also traps sediment that has eroded upstream. So, the model also estimates how much of the sediment eroded on all pixels will be trapped by downstream vegetation based on the ability of vegetation in each pixel to capture and retain sediment. The final component of the model provides the option to value two services associated with the retention of sediments on the landscape; improved water quality and avoided sedimentation of streams and reservoirs based on allowed annual sediment loadings. For improved water quality, annual load may be obtained from national or local drinking water standards. For avoided sedimentation of reservoirs, there is usually an engineered reservoir dead volume built to capture sediment which can be used for calculating service and valuing retention for dredging (Figure 5.3.6.2). For this study, costs of planned best management practices (BMPs) for erosion control is used to value the service provided by landscape.

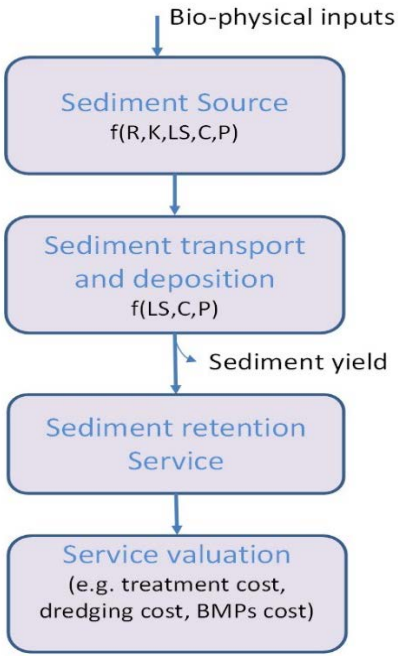

Figure 5.3.6.2. Schematic depicting InVEST Sediment Retention Model.

Data requirements for sediment retention model include rainfall erosivity (*R*), soil erodibility (*K*), slope length and steepness factor (*LS*), crop/vegetation and management (*C*) and support practice (*P*) in addition to digital elevation model (DEM), LULC map, shapefiles of watersheds and a table with retention capacity of the land uses, threshold flow accumulation value, water purification threshold value and treatment and/or dredging costs for valuation. Outputs are provided in both map and tabular form which include: total adjusted sediment load per sub-watershed, total and mean sediment retention by each sub-watershed, and total and mean sediment export per sub-watershed. Economic benefits of sub-watershed filtration are also provided in both map and tabular form.

Recently, the model has been tested in Baoxing County, China, a watershed with steep slopes in the Upper Yangtze River Basin (Wang et al. 2010). The model estimates of erosion reaching the watershed mouth agreed well with observed annual average sediment loads (5% error). This watershed has little erosion from gullies and low stream bank erosion or deposition, which are conditions that favor our approach. The model has also been successfully applied at the HUC 8 level in the Midwestern and Western U.S. (Ziv et al. 2012), in the Willamette Basin in the Pacific Northwest of the U.S (Nelson et al. 2009), in Oregon (Hoyer and Chan 2014), in Argentina (Izquierdo et al. 2012), and in the Llobregat River Basin of Spain (Terrado et al. 2014). We also continue to test this model in a set of domestic and international watersheds that exhibit a range of environmental conditions.

5.3.7 Other ancillary models

Other models we used to assess ecosystem services outside the InVEST software package include Soil Water Assessment Tool (SWAT), GLOBIO3, and HexSim.

- **Soil Water Assessment Tool (SWAT)**

The InVEST tier 1 sediment retention model is designed to function at an annual time step, which is reasonable for estimating long term mean sediment yield and retention. In data rich environments, a process-based modeling approach (tier 2) can provide a sound basis for determining the complex interactions of hydrologic processes and generate a more refined estimate of sources and sinks of eroded materials. We selected SWAT (Soil and Water Assessment Tool), a semi-distributed catchment-scale model that operates on daily time steps, for this study (Neitsch et al. 2011) because of its wide use in management. SWAT is a multi-purpose model which integrates various water budgeting and runoff-producing components of the terrestrial hydrological system, including hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing. In SWAT a catchment is divided into multiple sub-catchments that are connected through a stream channel. Each sub-catchment is further divided into Hydrologic Response Units (HRU). Each HRU is a unique combination of a soil and vegetation types within the sub-catchment.

Climatic data inputs in SWAT include daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data. SWAT soil-water budgeting routines use a DEM, soil data (e.g., soil texture, soil depth, hydraulic conductivity, edibility factors, etc.) and land use information (LULC, LAI, root depth, interception etc.) for modeling the hydrological responses required to simulate flows and loadings/concentrations of sediment, nutrient, pesticide, and bacteria for each HRU. Sediment yield is then estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE) developed by Williams and Berndt (1977). Outputs from each HRU are then summed at the sub-catchment level, and the resulting water, sediment, or nutrients are routed through channels, reservoirs, and wetlands to the watershed outlet. Sediment deposition and degradation in the stream channel are both calculated during the sediment routing (Neitsch et al. 2011).

- **GLOBIO3**

GLOBIO3 is a spatially-explicit model that approximates biodiversity contained in different habitats and resulting from a change in the structure of ecosystems. The GLOBIO3 model (Alkemade et al. 2009) predicts mean species abundance (MSA) in response to land-use, fragmentation, infrastructure, climate change, and pollution threats, through a meta-analysis of the impact of each of these threats on individual species abundances. The basic principle is that different stressors that impact an ecosystem decrease its “nativeness” and that these impacts are mostly synergistic. Therefore, the intrinsic MSA of a pixel is 1, regardless of the type of ecosystem (i.e., an uninterrupted arctic desert has MSA of 1, as does a pristine tropical

rainforest) or its productivity (such as Net Primary Productivity) and ecological carrying capacity. Each threat provides a weight that diminishes the level of MSA in 'pristine' conditions, and the weights are multiplied together to produce an overall index of change in MSA in response to change in threats. The stressors included are land use/land cover (LU), excess atmospheric nitrogen deposition (N), proximity of infrastructure (mainly roads; I), fragmentation (F), and climate change (CC). These terms correspond to the terms in the following equation:

$$MS_{Ai} = MSA_{LUi} \cdot MSA_{Ni} \cdot MSA_{Ii} \cdot MSA_{Fi} \cdot MSA_{CCi}$$

- **HexSim**

HexSim is a spatially-explicit, individual-based modeling framework that simulates dynamics of one or more populations over time, given life cycle structure, event data, spatial data layers (e.g., landscape structure, habitat quality, stressor distribution), and basic simulation criteria, such as the length of each simulation. HexSim is well suited for assessing risk posed to populations by multiple interacting stressors because each individual simulated in a population has multiple, dynamic attributes that capture its unique history of exposure to stressors. HexSim includes a variety of data analysis tools allowing output maps that illustrate model dynamics and reports that track population size. HexSim can be used to quantify the consequences for wildlife populations of multiple training and testing activities, as well as the impacts of development projects such as roads. HexSim can also be used to assess which habitat components are most critical for maintaining wildlife populations and to design restoration, mitigation, or reintroduction strategies for species-at-risk.

HexSim simulations are built around a user-defined life cycle consisting of a sequence of life-history events selected from a list (e.g., survival, reproduction, movement, resource acquisition, species interactions). The user can impose yearly, seasonal, daily, or other temporal events on a portion, or all of a simulated population and each event can be linked to static or dynamic spatial data layers. HexSim is a flexible modeling framework; simple scenarios may use few events with minimal parameterization and little spatial data, but when complexity is warranted, detailed data and behaviors can be added to simulations.

5.4 FIELD TESTING

Successful application of InVEST and the ecosystem services approach at DoD installations requires five general operational phases. Below, we briefly outline these phases as applied to each installation. Depending on the complexity of the analyses and integrated training and ecosystem objectives, these steps are often best conducted in an iterative fashion, whereby management scenarios or model inputs are refined in response to results from early model runs.

- **Identifying goals/objectives, focal ecosystem services, and drivers of future scenarios**

First, at each installation, we held initial meetings with relevant personnel and NGO partners in which we discussed major resource management goals, ecosystem services of interest, and potential policies/initiatives/management changes that could influence future land-use and environmental management at the installation.

- **Learning relevant InVEST and auxiliary models**

Next, during each application, team members learned about the latest InVEST models, and auxiliary models (e.g., HexSim for modeling provisioning of habitat for the red-cockaded woodpecker) relevant to the ecosystem services of interest at the installation.

- **Compiling data and creating scenario maps**

During each application, we collected relevant data inputs for creating scenarios and running InVEST models based on the InVEST user guide and scenario guidelines (Sharp et al. 2014). We are providing spatially explicit representations of future land use and resource-management plans/policies generated through iterative discussion with installation stakeholders for future reference in each demonstration.

- **Running, calibrating, and validating InVEST models**

Following data compilation, we ran both InVEST and auxiliary models for baseline and alternative scenarios to quantify provision of the ecosystem services of interest in biophysical and economic (when desirable) metrics at each installation. Furthermore, to improve the accuracy and credibility of these model outputs, we conducted calibration and validation using empirical data collected on or near installations when it was available.

- **Synthesizing model outcomes and incorporating in decisions**

The final phase included synthesis and interpretation of model outputs relevant to the decision context and objectives outlined in the first step. We are providing information with this report that will allow resource managers to incorporate analytical results into relevant decision-making processes with relative ease.

5.5 SAMPLING PROTOCOL

As noted in Section 4, data collection is a key step in the application of InVEST models within our ecosystem service approach. Data were collected from several existing data sources, including ESTCP/SERDP projects previously conducted at JBLM and Fort Benning, and through contacts with installation personnel and partnered NGOs and environmental consultants. We used collected data in two ways. First, when possible, we used collected data to calibrate and validate InVEST models applied at each installation. Second, we used collected data to quantify and map the ecosystem services of interest under alternative management scenarios at each

installation. Below, we describe the methodology for collection of data to calibrate and validate InVEST models (i.e., Hydrology models, Carbon Sequestration, and Habitat Risk Assessment models), and in Section 5.6 we describe the outcome of data collection. We present methods and results for calibration and validation, as well as quantification and mapping of ecosystem services, in separate sections describing applications for each installation.

- **Calibration and validation of hydrology models**

We installed Isco-sediment samplers at three major rivers (Randall, Ochille and Upatoi) at Fort Benning in October 2011 to conduct comprehensive calibration and validation of hydrology models. The monitoring system consisted of an Isco Model 6712 automatic sampler (24-bottle configuration) for sampling suspended sediment concentration (SSC) and Isco Model 720 and 750 Area-Velocity flow modules to measure stream gage and velocity. Both the 750 and 720 modules were programmed to trigger the 6712 sampler at a 6" rise in stream level. Unfortunately, the region experienced severe drought in 2012, thus the data we collected using our gauges were sparse and inadequate. Thus, we used data on streamflow and SSC archived previously by other SERDP/ESTCP projects and the USGS for calibration and validation. The USGS gauge at McBride Bridge (USGS # 02341800) was used as a boundary condition for model calibration and validation because quality-checked streamflow and SSC were available and recorded at the site. The SSC record at this site begins on October 1, 1977 and extends to 1984; and the streamflow has been collected at this site from 1968 - present (the description, location, and period of record data for the gauge can be viewed at the USGS website (http://waterdata.usgs.gov). A rating curve developed by USGS was used to generate a series of daily SSC as a function of flow rates. This rating curve has previously been used and verified by other researchers (e.g., Sharif and Balbach 2008, Donigian 2013) and it is found to be adequate to determine SSC as a function of changes in daily streamflows.

- **Validation of Carbon Storage and Sequestration model**

For the calibration of the Carbon Sequestration model, we collected carbon biomass data from two existing sources. First, we used aboveground biomass data from the National Biomass and Carbon Dataset (NBCD), a radar-derived, 30m-resolution, year-2000 baseline carbon estimate for the continuous United States (Kellndorfer et al. 2000). Second, we gathered aboveground carbon biomass estimates on 110 Douglas-fir forest plots for JBLM and 216 longleaf pine plots at Fort Benning, which were collected by project RC-2118 (M. Hurteau, Penn State University, Unpublished Data). We adopted the NBCD data for carbon analysis, but validated them by comparing the mean values and standard deviation with the Hurteau sampling data for various LULC classes (see details in sections 6.1.2 and 6.3.2)[2].

[2] Note: Project RC-2115 also provided carbon estimates and generalized carbon value equations for aboveground and belowground biomass, understory, detritus, and soils based on five longleaf pine samples plots (Samuelson et al. 2014). However, we did not adopt this dataset for validation because of

- **Validation of Habitat Risk Assessment model**

To validate the use of the Habitat Risk Assessment (HRA) model in predicting risk to either ecosystems (i.e., the Puget Sound Prairie Ecosystem at Joint Base Lewis-McChord [JBLM]) or habitat provision for species (i.e., red-cockaded woodpecker [RCW] at Fort Benning), we collected data available on the current distribution of species associated with either the ecosystem or habitat examined using the HRA model. We used statistical analyses to test if current species distributions varied significantly with risk predicted to ecosystems or habitat under current conditions, assuming species should generally have the highest likelihood of occurrence where risk is lowest. At JBLM, we used chi-squared tests to determine if the occurrence of each of three candidate species was greater than expected in areas of low risk than high risk, given the availability of low-risk habitat across the installation. At Fort Benning, we used a logistic regression to test if risk to habitat was a significant predictor of the presence-absence of RCW clusters.

5.6 SAMPLING RESULTS

- **Hydrology models**

For calibration of hydrology models, we generated daily SSC curves for 1996-2006, using the rating curve method described above. Descriptive statistics and monthly series of streamflow and SSC provided in Table 5.6.1 and Figure 5.6.2 give a sense for the SSC range (lowest to highest), and central tendency (mean and median) for this period. As expected, the watershed tends to exhibit higher SSC during wet days. The average daily SSC for the wet and dry seasons of this period were 437.5 and 13.3 tons, respectively. The maximum daily SSC (51,097 tons) occurred during the 1998 El Niño on a day when gauge flow averaged ~12,500 cfs. Generally, the interquartile range in SSC for wet seasons (February and March) varies from 33.2 to 201.8 tons per day. The dry season interquartile range in SSC interquartile is from 5.1 to 15.0 tons per day, with the lowest value occurring during the dry periods of 2000 and 2002.

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limited data size and additional field data required (tree height and diameter at breast height) for applying site-specific regression equations developed in that project.

Table 5.6.1. Descriptive statistics for dry and wet season suspended sediment concentration (SSC) (tons/day) for the period 1996-2006 at the McBride Bridge gauge station of Upatoi Creek.

Season	Mean	StDev	Min	P_{25}	Median	P_{75}	Max
Dry SSC (tons/day)	13.3	5.1	6.6	9.6	12.5	15.0	28.5
Wet SSC (tons/day)	437.5	2298.8	9.3	33.2	72.6	201.8	51097.8

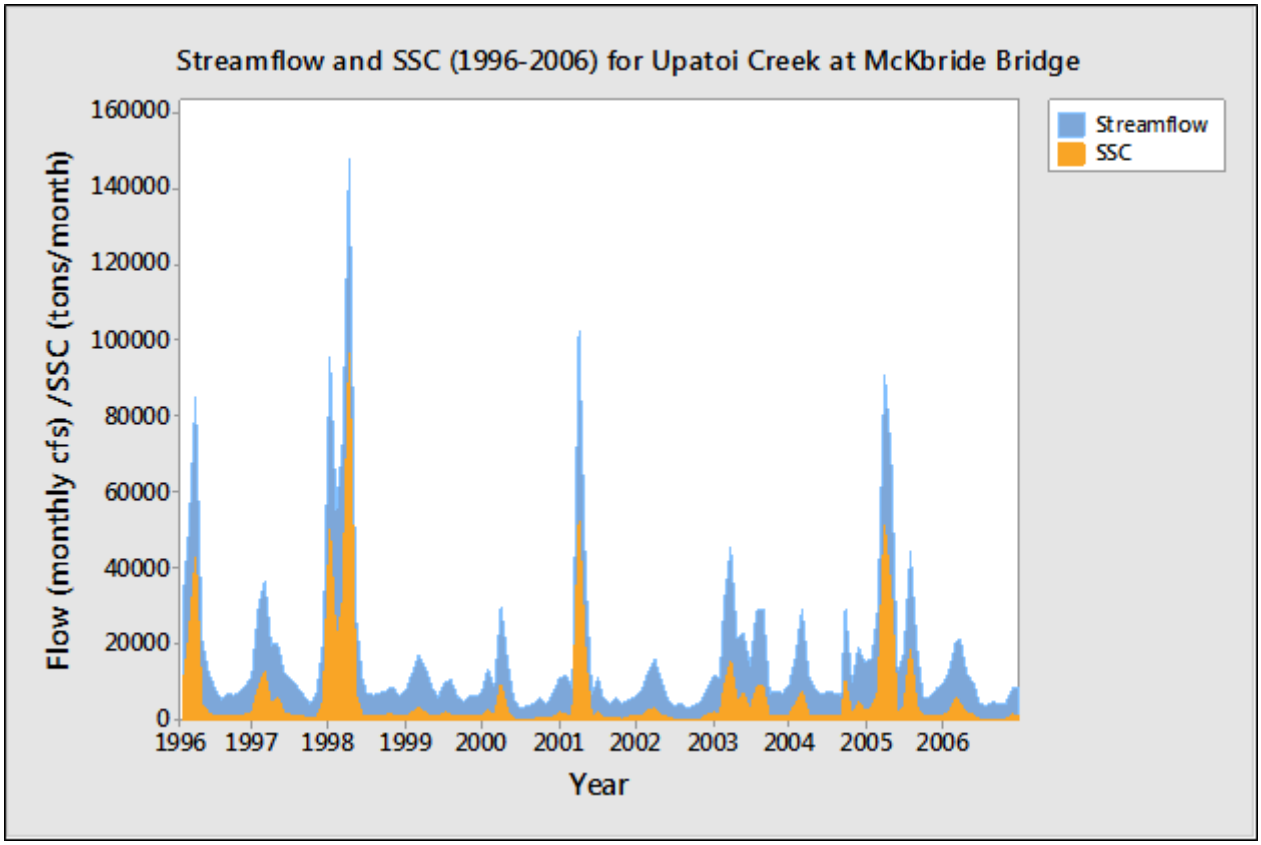


Figure 5.6.1. Monthly time series of streamflow and suspended sediment concentration (SSC) at the McBride Bridge gauge station of Upatoi Creek for the period 1996-2006.

We calibrated the SWAT and InVEST models by adjusting factors in the model until the simulated SSC closely approximates the observed SSC. Calibration for InVEST was conducted manually through the adjustment of input parameters; and the SWAT input parameters are optimized with the aid of an automatic calibration system. In general, the models made good use of the available data at Fort Benning, and were calibrated well enough to identify locations of sediment sources and sinks, and to quantify erosion rates and sediment exports to water bodies. To improve the usefulness of InVEST outputs in the decision-making process, we also conducted sensitivity and uncertainty analysis on each input parameter. These outputs are briefly described

in Section 6.3.2.2.

- **Carbon Storage and Sequestration**

The spatial distribution of the NBCD data and the sampling plots for carbon biomass are shown in Figure 5.6.2 and Figure 5.6.3 for JBLM and Fort Benning respectively. On JBLM, the 110 plots are distributed evenly, and exhibit a mean aboveground carbon estimate of ~186 Mg/ha and standard deviation ~72 Mg/ha (Table 5.6.2). On Fort Benning, the 216 longleaf pine plots cluster in areas with abundant longleaf forest and longleaf plantation stands. The mean aboveground carbon estimate is ~28 Mg/ha and the standard deviation is 20 Mg/ha (Table 5.6.2).

Table 5.6.2. Descriptive statistics for aboveground carbon estimates (Mg/ha) from sampling plots

	Sample size	Mean	Standard Deviation	Max	Min
JBLM	110	186	73	412	8
Fort Benning	216	28	20	104	0.0

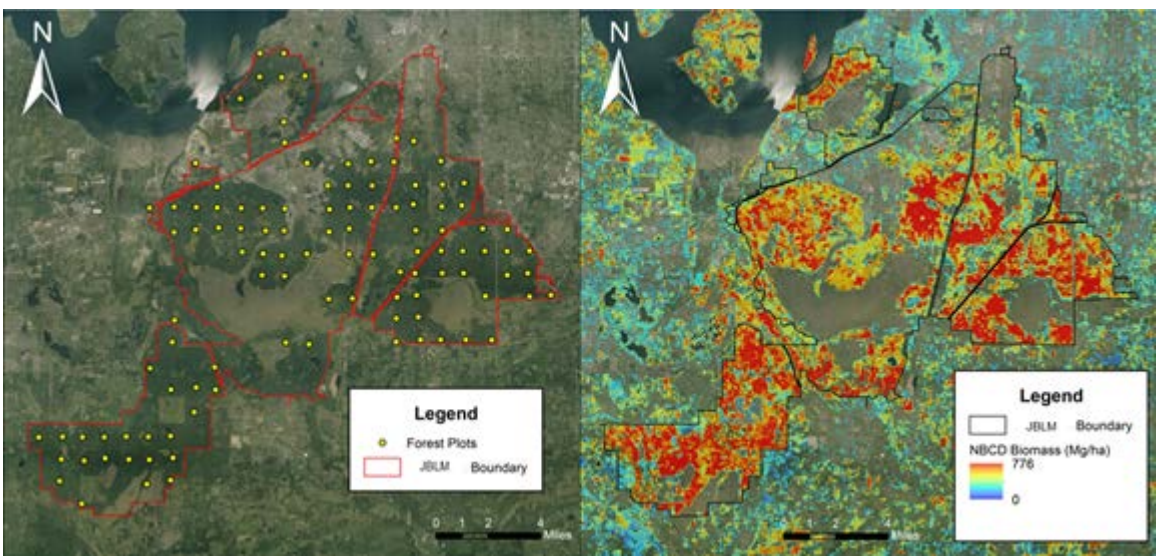


Figure 5.6.2. Sampling plots and National Biomass and Carbon Dataset (NBCD) data used in the InVEST Carbon Storage and Sequestration Model at Joint Base Lewis-McChord, WA.

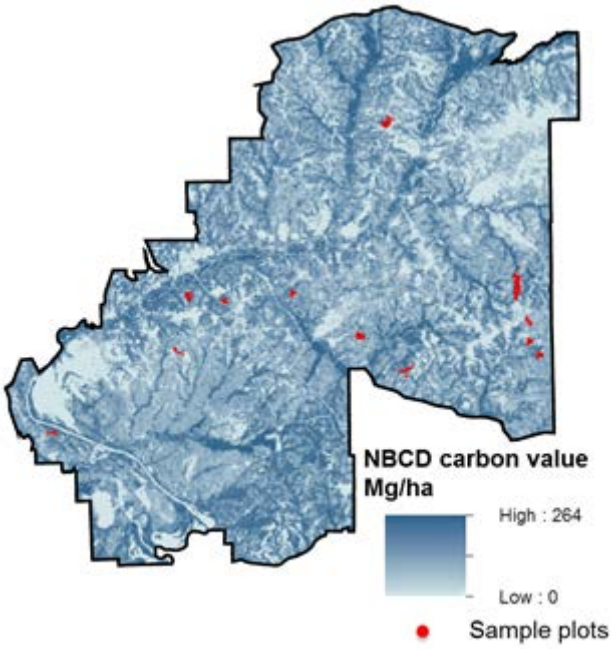


Figure 5.6.3. Sampling plots and National Biomass and Carbon Dataset (NBCD) data used in the InVEST Carbon Storage and Sequestration Model at Fort Benning, GA.

- **Habitat Risk Assessment (HRA) model**

At JBLM, current species occurrence data for three candidate species representing "characteristic native biota" of the Puget Sound Prairie Ecosystem (i.e., Taylor's checkerspot butterfly, Mazama pocket gopher, and streaked horned lark) were provided by JBLM personnel (Figure 6.1.2.3).
At Fort Benning, data for the centroids of 2013 red-cockaded woodpecker (RCW) clusters were provided by Fort Benning personnel (Figure 6.3.2.7). Data for RCW cluster absences were generated following methods used by Lawler et al. (2011) and described in Section 6.3.2 (Figure 6.3.2.7)

6.0 PERFORMANCE ASSESSMENT

In the sections below, we provide detailed descriptions of data analysis for all performance objectives. We present assessments for each of the three demonstration sites separately to allow for variation in the objective definitions and application scales. We order performance objectives in a manner that maintains consistency and clarity of assessments for each demonstration.

6.1 JOINT BASE LEWIS-MCCHORD

6.1.1 Summary of scenarios

This section presents the assessment results for our demonstration at Joint Base Lewis-McChord.

Objective 7: Convert alternative management scenarios into realistic alternative LULC maps

Scenarios for future land use in JBLM were developed iteratively in a series of several workshops with base personnel. DoD staff were interviewed to discuss ecosystem services and key drivers that influence management at the base. An initial meeting was held on base in November 2011 to discuss the dynamics of key drivers. Priority targets identified for modeling included rare species located in the Puget Sound Prairie Ecosystem and their habitat requirements, invasive species management, and training capacity, as well as how such drivers influence each other throughout the base (Figure 6.1.1.1).

The primary invasive species/disease at JBLM include laminated root rot (*Phellinus weirii*), a fungus causing tree mortality in Douglas-fir forest (connection #1 in Figure 6.1.1.1), and Scotch broom (*Cytisus scoparius*), an invasive shrub that infests grassland habitat (#2) and forest openings (#3). Laminated root rot infestation occurs mainly through root-to-root contact in Douglas-fir forests, but expansion in new forest patches can occur when infected woody debris is carried long distances by motor vehicles and foot traffic (#4; Foster 2009). As existing root rot cannot be effectively eliminated, current forest management focuses on replanting root rot-immune and -resistant tree species (e.g., red alder, ponderosa pine) in gap areas (#5), and control of subsequent Scotch broom (#6) and other invasive shrubs and grass, which can inhibit forest regeneration by competing with native tree species (#3; Peterson and Prasad 1998, Foster 2009). Scotch broom can grow up to 1 meter in height per year and completely dominate a site within three years. It forms dense thickets that degrade the Puget Sound Prairie Ecosystem by altering vegetation structure and outcompeting plants that act as hosts for species of conservation concern (#2; Haubensak et al. 2004); and reduce the area suitable for training by impeding foot and vehicle traffic (#7). Maintaining native plant communities through removal of Scotch broom and other invasive species is a priority for managing the Puget Sound Prairie Ecosystem at JBLM (JBLM 2007).

Diverse natural habitats, such as grassland and forest, comprise essential ecosystems (#8 and #9) to support required military training exercises (#10). Sufficient protection of the Puget Sound Prairie Ecosystem may reduce future training restrictions potentially imposed by the U.S. Fish and Wildlife Service on grasslands designated as either occupied or potential habitat for candidate species (#11 and #12). Potential increases in the number of troops and frequency of training activities will likely intensify threats to Puget Sound Prairie (#13), and thus lead to restrictions that are more stringent on training lands. Additionally, increased training intensity may either enlarge scotch broom expansion through more soldier and vehicle movement (#14) or suppress scotch broom encroachment by firing practices and vehicle disturbance (#15).

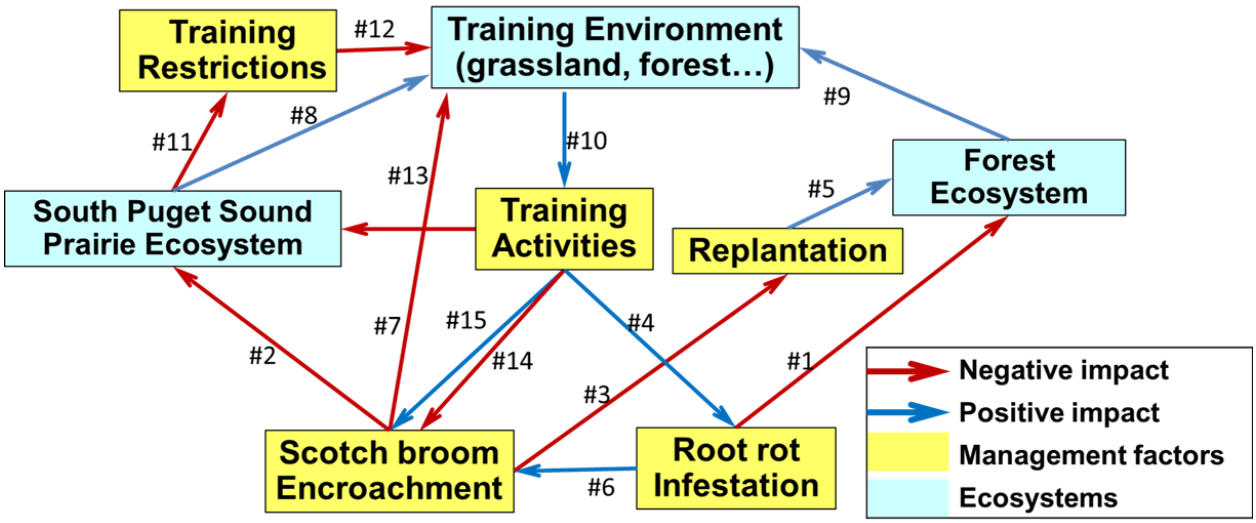


Figure 6.1.1.1. Ecosystem management dynamics at Joint Base Lewis-McChord, WA.

Building narratives and quantitative criteria for scenario generation

We generated a current land use land cover (LULC) map using a JBLM vegetation map combining vegetation plots and remotely sensed imagery from 2007 and 2008 (Chastain 2008). We then updated the vegetation map to include gaps created by laminated root rot mapped by JBLM staff in 2010. Foresters at JBLM believe that symptomatic laminated root rot areas (i.e., dead and dying trees) are well-mapped at the installation, occupying about 2% of conifer-dominated forest, but estimate that a total of 20% of conifer-dominated forest is actually infected, most of this area not yet being symptomatic. We converted the current LULC to a raster file format at a resolution of 28.5-meters (m) in ArcGIS software and used it as a baseline for creating 2030 scenarios. Draft scenarios and the resulting LULC maps were then developed by NatCap and presented to JBLM staff during meetings in March and April 2012 for revisions. Revisions to scenarios and the resulting LULC maps were made and findings regarding ecosystem services tradeoffs were presented to the JBLM staff during a meeting in September 2012. During and following this workshop, we finalized 5 scenarios that are projected 20 years

into the future from the current LULC: (1) Business-As-Usual (BAU), (2) High Budget-Decreased Training (HBDT), (3) High Budget-Increased Training (HBIT), (4) Low Budget-Decreased Training (LBDT), and (5) Low Budget-Increased Training (LBIT) (Figure 6.1.1.2). High Budget reflects an increase in funds relative to current levels available to the environmental division at JBLM, whereas Low Budget indicates a decrease in funds. Budget level is assumed to affect the extent of invasive species control (mostly Scotch broom) and restoration of candidate species habitat on and off base. Under guidance from base personnel, we also assumed that training restrictions on species habitat would be more stringent under the circumstance of insufficient habitat restoration and maintenance. Increased Training indicates a 20% increase in force and training intensity throughout JBLM while Decreased Training indicates a 20% decrease in force and training intensity. Training intensity is correlated with the impact of training activities on plant and animal species. Increased training intensity and troop number also drives the expansion of laminated root rot, a root disease causing severe mortality in Douglas-fir forests, via the dissemination of infected woody debris by motor vehicles and foot traffic (Foster 2009). All scenarios assume that species considered candidates for listing during the study will be listed, but with varying levels of training restrictions according to budget allotment.

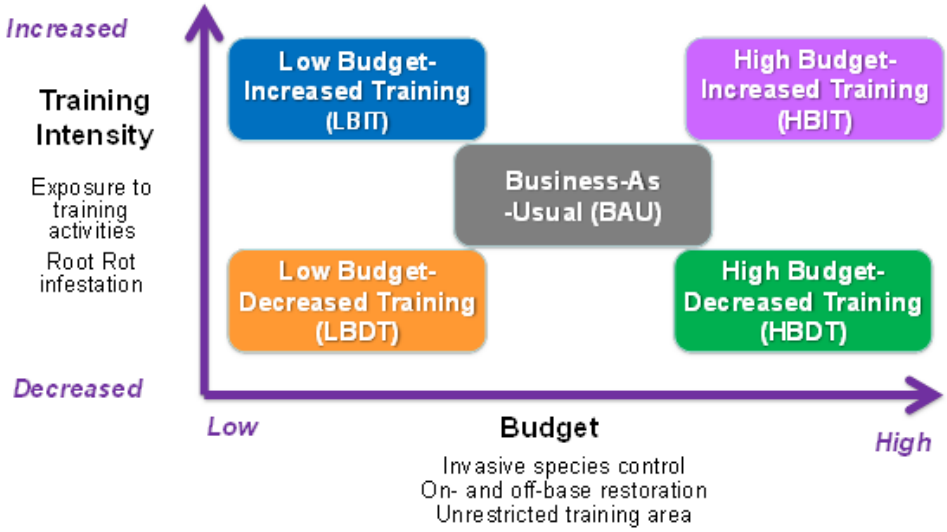


Figure 6.1.1.2. Relative levels of budget and training intensity for four alternative scenarios relative to the Business-As-Usual scenario at Joint Base Lewis-McChord, WA.

Criteria for building future scenarios are presented in Table 6.1.1.1 and individually explained below:

- "Budget for natural resource management" represents change in the amount of funds available for invasive species control, forest replantation efforts for areas infected by laminated root rot, as well as grassland habitat maintenance both on base by Fish and Wildlife program and Integrated Training Area Management (ITAM) program, and off base through land/easement acquisition by the Army Compatible Use Buffer (ACUB)

program.

- "Training intensity" represents change in the number of troops actively deployed at JBLM and their frequency of training.

These two policy drivers lead to changes in four features of LULC.

- "Restricted training area" refers to lands where vegetation-disturbing activities (e.g., off-road maneuvering, digging, and bivouacking) are prohibited to protect species that were candidates for listing during the study, cultural resources, and wetlands. We delineated training restrictions based on current restrictions, habitat occupied by the candidate species, and/or potential habitat for candidate species.
- "Laminated root rot area" represents the proportion of susceptible forest infected by root rot. Susceptible forests on JBLM are those dominated by conifer species with low resistance to root rot infection, such as Douglas-fir, *western hemlock (Tsuga heterophylla*), and grand fir (*Abies grandis*). Western red cedar (*Thuja plicata*) is affected by a different Phellinus species with low presence on JBLM; pine species (*Pinus ponderosa, P. monticola*) are resistant to infection and hardwoods, such as bigleaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), and Oregon white oak (Quercus garryana) are immune. We assume areas of new infections have an expansion rate of 3 meters/year and expand from both existing infected areas and randomly placed new infection sites. The spread rate of laminated root rot is difficult to define as it depends on a number of factors, such as stand density, host species composition, inoculum density of the pathogen, and stress placed onto host trees (A. Kroll and D. Omlan, personal communication, February 20, 2014). Studies conducted in the Oregon Cascades showed an average spread rate of the fungus ranged from 5 cm to 58 cm per year via root-to-root contact (McCauley and Cook 1980, Nelson and Hartman 1975). Root rot sporophores are also found on woody debris from infected trees (Washington Academy of Sciences 2013) and may be carried via motor vehicles during training activities (Foster 2009), but dispersal rates via spores are not well documented. We chose a higher rate of 3 meters/year to reflect both natural root-to-root contact and the increased stress on infected trees and dispersal of infected woody debris containing spores from training activities.
- "Forest replantation area" represents the proportion of laminated root rot infected areas replanted with immune or resistant tree species and given an LULC classification of conifer plantation. We randomly selected canopy gaps formed by root rot over 0.4 ha in size for planting until scenario criteria were met. Gaps less than 0.4 ha are usually not planted because there is insufficient direct sunlight for adequate growth of planted trees.
- "Scotch broom-dominated area in grassland" represents the extent of Scotch broom in grassland habitat. It was simulated by randomly selecting pixels within grasslands to match scenario criteria. We assume that Scotch broom and grassland vegetation can occur interchangeably under different management scenarios. JBLM and other grassland owners in the South Puget Sound have been controlling Scotch broom for up to 20 years.

Experience to date indicates that: 1) Scotch broom can invade grasslands dominated by native or non-native grasses. 2) If a grassland area already has heavy Scotch broom infestation, initial efforts at control (usually mowing or prescribed fire) are followed by rapid conversion back to Scotch broom dominance via seed germination and/or stump resprouting. 3) After multiple cycles of control, Scotch broom dominance will not return as quickly, but will return especially where ground disturbance and seed transport are frequent, as on the training lands at JBLM.

We made two additional assumptions on land conversion in discussion with foresters at JBLM:

- All scenarios assume areas infected with laminated root rot, but not replanted with immune or resistant tree species, will become 50% Scotch broom, 25% native shrubs, and 25% pre-commercial conifer from natural regeneration, and infected forest pixels are randomly converted to meet these criteria. Scotch broom inhibits tree sapling growth in forest plantations (Peterson and Prasad 1998, Foster 2009). It readily invades forest soils, provided seeds are present, overstory cover is low (< 50% is a rule of thumb), and competition from native shrubs is low. Experience at JBLM indicates that, unless there is a pre-existing native shrub layer, Scotch broom will germinate in nearly all logging- or root rot-mortality openings and compete with natural and planted tree regeneration. Multiple plantations on JBLM established following clearcutting in the 1980s are still dominated by Scotch broom, and Scotch broom competition in clearcuts on private forest lands results in significant control costs and loss of timber value (Hulting et al. 2008). Native shrubs are established understories of Douglas-fir forest at JBLM. If there is a pre-existing native shrub layer, it is likely to persist, suppressing Scotch broom. If sufficient advance regeneration is present, trees will dominate the site.
- 50% of an existing ~260 ha clearcut area in the west region of JBLM will convert to mature conifer plantation for all five future scenarios, while the other 50% will convert to Scotch broom.

We assume stochastic biological (e.g., species invasions and extirpations) and climatic forces (e.g., droughts, early/late frosts, etc.) affect habitat conditions and management effectiveness of alternative scenarios with equal probabilities, and thus will not trigger cross-scenario variations. In reality, differential effects are likely, and interactions between climate factors and management would occur.

Table 6.1.1.1. Summary of assumptions for 2030 management scenarios at Joint Base Lewis-McChord, WA.

Scenarios	Policy Drivers		LULC Features			
	Budget for natural resource management	**Training intensity** troop number & training frequency	**Restricted training area** for candidate species protection	**Laminated Root Rot (LRR) area** infected in 20 years	**Forest replantation area** with immune species	**Scotch broom** -dominated area in grassland
High Budget-Decreased Training	High	20%↓	Reduced restrictions in occupied habitat (4,904 ha)	20% susceptible forest (3,151 ha)	80.9 ha/year of LRR-infested area	10% everywhere (522 ha)
High Budget-Increased Training	High	20%↑	Reduced restrictions in occupied habitat (4,904 ha)	40% susceptible forest (6,301 ha)	80.9 ha/year of LRR-infested area	10% everywhere (522 ha)
Business-As-Usual	Medium	Medium	Most occupied habitat (5,904 ha)	30% susceptible forest (4,726 ha)	40.5 ha/year of LRR-infested area	10% occupied; 25% elsewhere (1,013 ha)
Low Budget-Decreased Training	Low	20%↓	All occupied & potential habitat (8,730 ha)	20% susceptible forest (3,151 ha)	20.2 ha/year of LRR-infested area	25% restricted area; 75% elsewhere (2,282 ha)
Low Budget-Increased Training	Low	20%↑	All occupied & potential habitat (8,730 ha)	40% susceptible forest (6,301 ha)	20.2 ha/year of LRR-infested area	25% restricted area; 75% elsewhere (2,282 ha)

6.1.2 Quantification, valuation and mapping of individual ecosystem services

This section presents our assessments for Performance Objectives 1-6, and 8. For each ecosystem service, we first summarize the assessment results for all relevant objectives. Next, we describe the model inputs and assumptions supporting data analyses for these objectives. Last, we provide the analysis results for individual objectives.

We modeled five services identified as priorities for JBLM: sustainability of Puget Sound Prairie, carbon sequestration, timber production, infantry training capacity, and vehicle training capacity. Training capacity and sustainability of the Puget Sound Prairie Ecosystem reflect the DoD's direct focus on maintaining military mission while complying with environmental regulations. Because Puget Sound Prairie includes multiple species of conservation concern, we use "ecosystem provision of habitat" as a proxy for biodiversity (i.e., persistence of candidate, proposed, or listed species) and refer to sustainability of Puget Sound Prairie as an ecosystem service (Keith et al. 2013). Timber production from Douglas-fir forest provides income for natural resource management at JBLM. Finally, prospects of regulation for carbon sequestration on public lands drive DoD to consider how their management affects carbon dynamics. These services are interconnected via their dependence on LULC, providing an opportunity to observe tradeoffs and synergies among services that can inform management decisions.

- **Habitat risk assessment**

✓ Objective 1: Quantify provision of ecosystem services using existing GIS data
✓ Objective 3: Provide spatially-explicit rendering of service provision
✓ Objective 5c: Assess and report degree to which model results depict reality (partner installation data available; model not previously tested in similar environment)
✓ Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

To meet Objectives 1, 3, and 8, we used the HRA model to assess risk posed by stressors to the Puget Sound Prairie Ecosystem at JBLM under current conditions, a Business-As-Usual (BAU) scenario, and four alternative scenarios (High Budget-Decreased Training [HBDT], High Budget-Increased Training [HBIT], Low Budget-Increased Training [LBIT], and Low Budget-Decreased Training [LBDT]) at a 28.5-m resolution. To meet Objective 5c, we tested if the current distribution of candidate species considered "characteristic native biota" of the Puget Sound Prairie Ecosystem differed among high- and low-risk categories from that expected given total availability of high- and low-risk area predicted across potential habitat at JBLM under current conditions.

<u>Model inputs and assumptions</u>

Model inputs include maps of stressors, training areas, and training restrictions, which were combined to express spatial overlap between stressors and habitat, as well as a table defining temporal overlap between stressors and habitat, stressor intensity, effectiveness of management strategies mitigating stressor impacts, change in vegetation area and structure, natural disturbance frequency, and habitat resilience (based on natural rates of mortality, recruitment, maturity, and dispersal). Below, we describe each of these inputs and assumptions associated with their use.

We defined stressors as any factor that might threaten persistence of the Puget Sound Prairie Ecosystem at JBLM and therefore, persistence of candidate, proposed, and listed species associated with the ecosystem. At the time of this study, Taylor's checkerspot butterfly (*Euphydryas editha taylori*), streaked horned lark (*Eremophila alpestris strigata*), and Mazama pocket gopher (*Thomomys mazama* subspecies) were candidates for listing associated with the Puget Sound Prairie Ecosystem, and we refer to them as such hereafter. However, since completion of the study the butterfly has been listed as endangered, the lark as threatened, and the gopher is proposed for listing (USFWS 2013a, b). Significant stressors that could be modeled were identified by biologists at JBLM. Stressors included seven training activities (digging, off-road vehicles, bivouacking, flight operations, foot training, ordnance firing, small-arms range training) and the presence of invasive Scotch broom.

We used maps of training areas and training restrictions, JBLM training manuals, and interviews with JBLM personnel to determine which training activity stressors occurred in each training area, as well as the extent of spatial and temporal overlap between training stressors and grassland habitat representative of the Puget Sound Prairie Ecosystem. Spatial overlap between training activity stressors and grassland habitat remained the same in all scenarios. However, spatial overlap between Scotch broom and grassland habitat was greater in low budget than high budget scenarios. To classify temporal overlap between training activity stressors and grassland habitat, we multiplied the percent of a year in which an area was unrestricted (year-round restriction = 0%, seasonal restriction = 67%, unrestricted = 100%) by the frequency of training use per year (high $\geq$ 40%, low < 40%). We scored values from 0.67-1.00 as "high", values from 0.33-0.66 as "medium", and values below 0.33 as "low". We classified temporal overlap between a training activity stressor and grassland habitat as "none" where year-round restrictions eliminated presence of the stressor. We assumed greater training restrictions, and thus less temporal overlap, in low budget than high budget scenarios. We assumed year-round overlap between Scotch broom and grassland habitat in all scenarios.

The exposure of a habitat to a stressor depends not only on spatial and temporal overlap, but also on the intensity of the stressor and effectiveness of management strategies mitigating stressor impacts. We varied the intensity of training activity stressors with scenario so that intensity was classified as "medium" under the BAU scenario, "low" under scenarios with decreased training, and "high" under scenarios with increased training (Table 6.1.2.1). We classified the intensity of

Scotch broom as "high" under all scenarios because detrimental effects of the shrub on the Puget Sound Prairie Ecosystem are well documented (Table 6.1.2.1; JBLM 2007). Management at JBLM includes removal of invasive species using hand pulling, mowing, and herbicide treatments, as well as restoration using seeding and plugging of native grassland species following soil disturbance. Whereas inputs to the HRA model typically include values that classify the intensity of a stressor with management strategies implemented (i.e., "low" when management is very effective, "medium" when it is somewhat effective, and "high" when management is not effective), we instead used the scores to emphasize the positive effects of some stressors on the Puget Sound Prairie Ecosystem. Thus, we scored intensity "with management" for off-road vehicles and ordnance training lower than other stressors because periodic disturbance by these activities provides openings in grassland habitat beneficial to nesting and movement of candidate species (Table 6.1.2.1; Pearson et al. 2005, JBLM 2007).

Table 6.1.2.1. Habitat Risk Assessment Model inputs for A) exposure to and B) consequences of stressors, categorized as High, Medium (Med), or Low for each scenario at Joint Base Lewis-McChord, WA.

A) Exposure*	Stressor intensity			Management effectiveness		
Scenarios / Stressors	BAU	HBDT and LBDT	HBIT and LBIT	BAU	HBDT and LBDT	HBIT and LBIT
Off-road vehicles	Med	Low	High	High	High	Med
Digging	Med	Low	High	Med	High	Low
Bivouacking	Med	Low	High	Med	High	Low
Foot training	Med	Low	High	Med	High	Low
Ordnance	Med	Low	High	High	High	Med
Small-arms ranges	Med	Low	High	Med	High	Low
Flight operations	Med	Low	High	Med	High	Low
Scotch broom	High	High	High	Med	High	Low

B) Consequences	Change in area	Change in structure	Increase in frequency	Natural mortality rate	Recruitment rate	Recovery time	Connectivity
Scenarios / Stressors	All	All	All	All	All	All	All
Off-road vehicles	Low	Med	Med	Med	Med	Med	High
Digging	Med	High	Low	Med	Med	Med	High
Bivouacking	Low	Low	Low	Med	Med	Med	High
Foot training	Low	Low	Med	Med	Med	Med	High
Ordnance	Med	Low	Low	Med	Med	Med	High
Training range	Med	Med	Med	Med	Med	Med	High
Flight operations	Low	High	Med	Med	Med	Med	High
Scotch broom	High	High	Low	Med	Med	Med	High

We scored change in grassland area and structure caused by each stressor based on literature and discussion with biologists at JBLM (Table 6.1.2.1; Chappell and Crawford 1997, Crawford and Hall 1997, Whitecotton et al. 2000, Quist et al. 2003). Following standard criteria in the model, for each stressor we scored loss in both area and structure from 0-20% as “low”, 20-50% as “medium”, and greater than 50% as “high” (Table 6.1.2.1; Sharp et al. 2014). We also reviewed literature to determine sources and frequency of historic disturbance in the Puget Sound Prairie Ecosystem (Chappell and Crawford 1997, Crawford and Hall 1997). We classified the effect of a stressor as “high” when analogous historic disturbances (e.g., foot traffic, digging by Native Americans, interspecific competition) occurred much less frequently than stressor disturbance, “medium” when historic disturbances occurred slightly less frequently, and “low” when disturbance frequencies were similar (Table 6.1.2.1). We reversed the scoring for the effect of stressors analogous to wildfire, as fire suppression has decreased the frequency of fires that maintained Puget Sound Prairie historically (Table 6.1.2.1).

Last, we reviewed literature to assess the resilience of grassland habitat based on natural rates of mortality, recruitment, maturity, and dispersal for native grasses, with special consideration given to Roemer's fescue (*Festuca roemeri*), the dominant plant in the Puget Sound Prairie Ecosystem (30-70% cover in high-quality native prairie; Chappell and Crawford 1997) (Table 6.1.2.1; Chappell and Crawford 1997, Crawford and Hall 1997, Darris et al. 2012). We assigned resilience scores of “high”, “medium”, or “low” to classify the impact of stressors, given likelihood of recovery, assuming a habitat with rapid lifecycles (i.e., high mortality and recruitment rates and short times until maturity) and high connectivity (i.e., frequent dispersal between populations) should be those most resilient to the effects of stressors. (Sharp et al. 2014). Whereas habitats least impacted by stressors have annual mortality rates > 80%, annual recruitment, maturity rates < one year, and dispersal distances > 100 km, habitats highly impacted by stressors have annual mortality rates < 20%, recruitment rates > two years, maturity rates > 10 years, and dispersal distances < 10 km (Sharp et al. 2014). Resilience values are based on biological attributes inherent to a species or habitat and did not vary among scenarios (Table 6.1.2.1).

To classify model output into low- or high-risk areas, we examined relationships between risk and vegetation cover in 25-m quadrats surveyed across JBLM (Olson 2010, Inger Gruhn, Personal Communication, August 6, 2012). We converted information about vegetation sampled from 2008-2011 in 25-m quadrats placed throughout JBLM from point shapefiles to a raster with a resolution of 28.5 m to match other rasters used as input for the HRA model. During this conversion, we used the average quadrat values for the percent native grass cover for each raster cell, as multiple quadrats sometimes occurred with a 28.5-m raster cell. We used raster centroids as sampling units for predicted risk values output from the HRA model (N = 32,132). Predicted risk varied from 0-16, and many raster centroids were associated with the same risk values. Therefore, for each risk value, we averaged associated raster centroid values (i.e., percent native grass cover). Predicted risk values with < 100 associated raster centroids were pooled with the

next largest predicted risk value until achieving a pool with > 100 associated raster centroids. A regression analysis indicated a negative relationship between predicted risk and percent native grass cover (Figure 6.1.2.1; Nagelkerke's $R^2 = 0.24$, $F_{1,23} = 8.64$, $P < 0.007$). Using this relationship, we determined the percent native grass cover (~16%) associated with zero-risk habitat (i.e., no modeled stressors present). Where stressors were present, we summarized habitat as high- or low-risk using a threshold value of 7.6, which was associated with a 33% decrease in native grass cover from zero-risk habitat. Last, we examined our characterization of risk by using chi-square analyses to test if the current distribution of each candidate species, which we consider "characteristic native biota" of the Puget Sound Prairie Ecosystem (Rodríguez et al. 2012, Keith et al. 2013), differed among high- and low-risk categories from that expected given total availability of high- and low-risk area predicted across potential habitat at JBLM under current conditions.

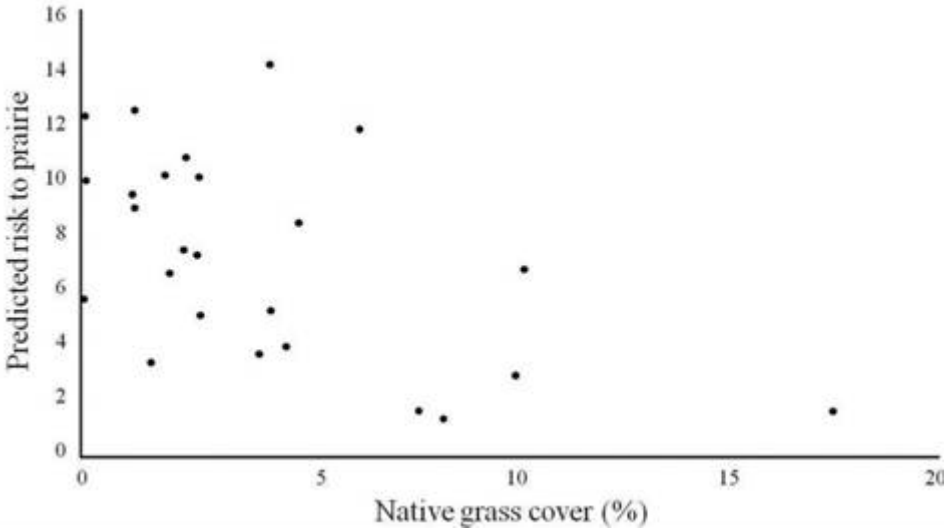


Figure 6.1.2.1. Relationship between predicted risk to prairie under current conditions and the percent native grass cover in 25-m quadrats surveyed from 2008-2011 at Joint Base Lewis-McChord, WA (N = 25).

Results

Objective 1: Quantify provision of ecosystem services using existing GIS data
Objective 3: Provide spatially-explicit rendering of service provision
Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management options

We assessed these objectives together in the section below as they are closely related.
Of the approximately 7,015 ha of prairie habitat on JBLM, the HRA model predicted that under current conditions 64% occurs in areas at low risk of loss/degradation and 36% at high risk

(Table 6.1.2.2). The distribution of prairie habitat between low-risk and high-risk categories remains similar in the BAU, HBIT, and LBDT scenarios (Table 6.1.2.2; Figure 6.1.2.2). The occurrence of prairie habitat in low-risk area is greatest under the HBDT scenario (84%), indicating positive effects of high budget (i.e., increased management of invasive Scotch broom) and decreased training on habitat quality are cumulative (Table 6.1.2.2; Figure 6.1.2.2). Likewise, the occurrence of prairie habitat in low-risk areas is lowest under the LBIT scenario (57%), reflecting cumulative negative effects of low budget (i.e., decreased management of invasive Scotch broom) and increased training on prairie habitat quality (Table 6.1.2.2; Figure 6.1.2.2). A comparison of the two intermediate scenarios reveals greater prairie occurrence in high-risk areas in the HBIT (36%) than LBDT scenario (35%), suggesting training has slightly more impact on prairie habitat than budget (Table 6.1.2.2). Overall, the most potential for change in risk with alternative management scenarios occurs across the eastern portion of JBLM, especially in Training Areas 11, 13, and 14 (Figure 6.1.2.2).

Table 6.1.2.2. Percent of prairie habitat (7,015 ha) at Joint Base Lewis-McChord, WA occurring within modeled low- and high-risk areas under current conditions and in each alternative management scenario.

	Scenario					
Risk	Current	BAU	HBDT	HBIT	LBDT	LBIT
Low	0.64	0.65	0.84	0.64	0.65	0.57
High	0.36	0.35	0.16	0.36	0.35	0.43

Each of the candidate species at JBLM occupy relatively small patches of the prairie habitat available on the installation (Taylor's checkerspot butterfly = 119 ha, Mazama pocket gopher = 1,251 ha, streaked horned lark = 344 ha [plus an additional 444 ha occurring on unmodeled areas]; Table 6.1.2.3; Figure 6.1.2.3; Foster, Personal Communication). The predicted distribution of habitat occupied by Taylor's checkerspot butterfly into risk categories does not differ among current conditions and alternative management scenarios; 100% of occupied habitat occurs within low-risk areas (Table 6.1.2.3; Figures 6.1.2.2 and 6.1.2.3). For Mazama pocket gopher, 100% of occupied habitat occurs within low-risk areas only under the HBDT scenario (Table 6.1.2.3; Figures 6.1.2.2 and 6.1.2.3). Under current conditions and intermediate scenarios, 99% of occupied habitat occurs within low-risk areas, and under the LBIT scenario, the amount of occupied habitat predicted to occur in low-risk areas decreases to 97% (Table 6.1.2.3; Figures 6.1.2.2 and 6.1.2.3). In contrast to the other species, much of the habitat occupied by the streaked-horned lark occurs within high-risk areas, particularly in Training Area (TA) 14 (Figures 6.1.2.2 and 6.1.2.3). Under current conditions, as well as the HBIT and Low Budget scenarios, only 50% of occupied habitat occurs within low-risk areas (Table 6.1.2.3; Figures 6.1.2.2 and 6.1.2.3). However, the amount of occupied habitat occurring within low-risk areas increases to 96% under the HBDT scenario (Table 6.1.2.3; Figures 6.1.2.2 and 6.1.2.3).

For each candidate species at JBLM, potential habitat on the installation covers much of the prairie habitat present (Taylor's checkerspot butterfly = 5,410 ha, Mazama pocket gopher = 5,776 ha, streaked horned lark = 2,859 ha; Figure 6.1.2.3; Foster, Pers. Comm.). The predicted distribution of potential habitat into risk categories is similar for the three candidate species with 67-75% occurring in low-risk habitat under current condition, as well as the BAU and intermediate scenarios (Table 6.1.2.4). For all three species, potential habitat occurring in low-risk habitat increases under the HBDT scenario (83-91%) and decreases under the LBIT scenario (63-74%; Table 6.1.2.4). Overall, the most potential for change in risk to prairie habitat designated within potential distributions of the three species occurs in Training Area 14 (Figures 6.1.2.2 and 6.1.2.3).

Table 6.1.2.3**.** Percent of prairie habitat (7,015 ha) within the current distribution of each candidate species at Joint Base Lewis-McChord, WA that occurs within modeled low- and high-risk areas under current conditions and in each alternative management scenario.

		Scenario					
Species	Risk	Current	BAU	HBDT	HBIT	LBDT	LBIT
Taylor's checkerspot butterfly	Low	1.00	1.00	1.00	1.00	1.00	1.00
	High	0.00	0.00	0.00	0.00	0.00	0.00
Mazama pocket gopher	Low	0.99	0.99	1.00	0.99	0.99	0.97
	High	0.01	0.01	0.00	0.01	0.01	0.03
Streaked horned lark	Low	0.50	0.50	0.96	0.50	0.50	0.50
	High	0.50	0.50	0.04	0.50	0.50	0.50

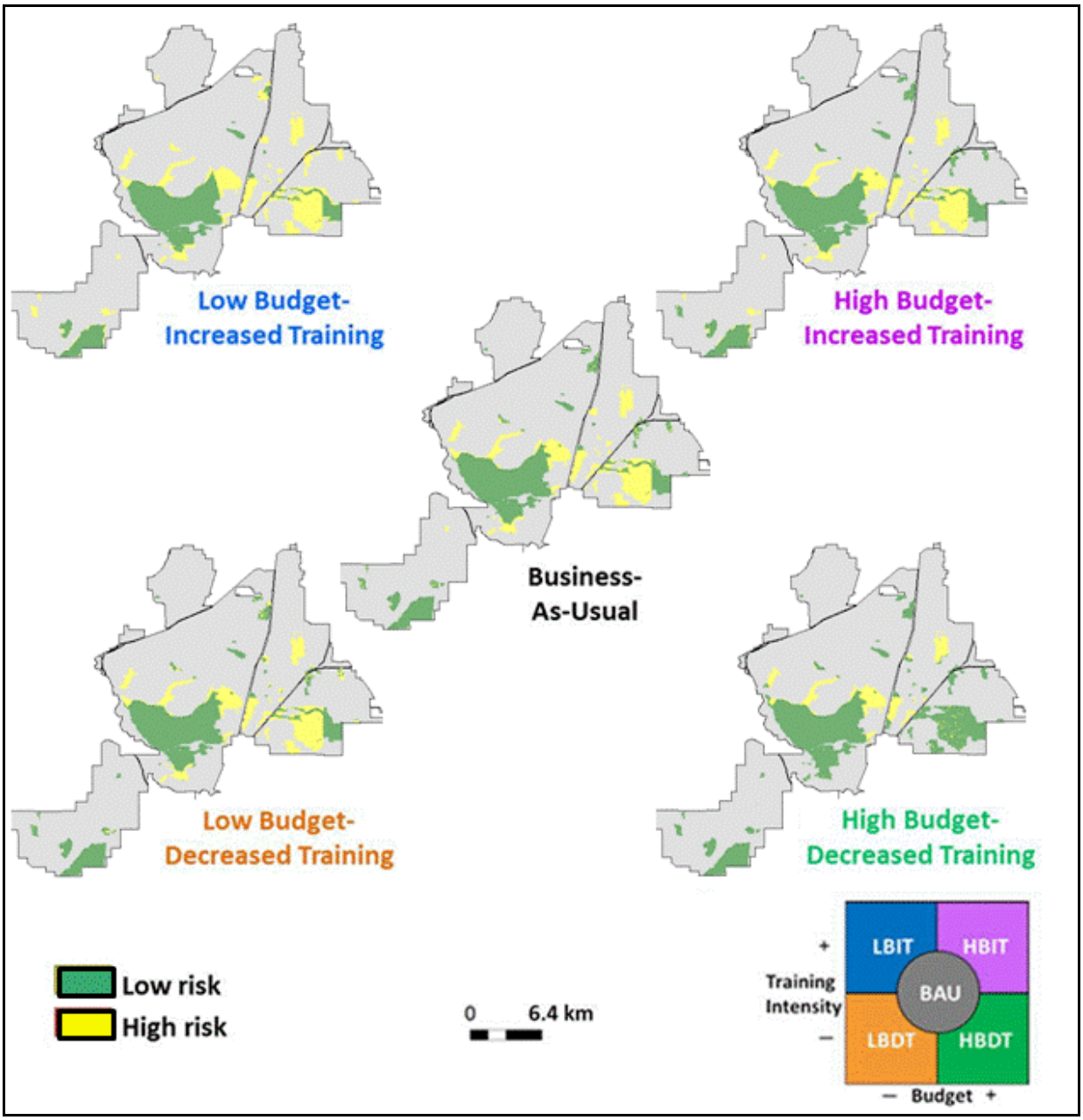


Figure 6.1.2.2. Distribution of prairie habitat into low- and high-risk areas across Joint Base Lewis-McChord, WA under five alternative management scenarios.

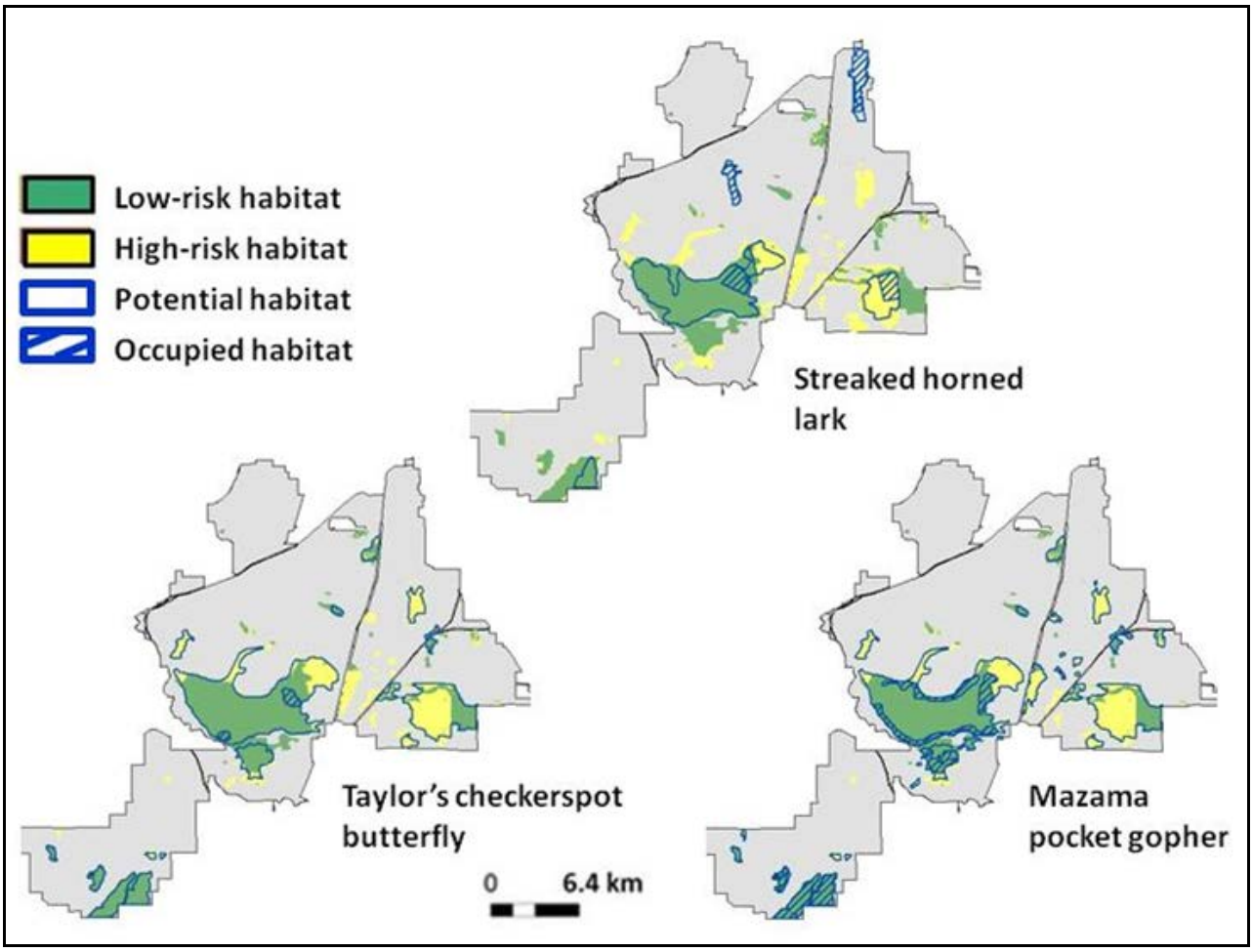


Figure 6.1.2.3. Distributions of occupied (blue hatching) and potential habitat (blue outline) for Taylor's checkerspot butterfly, streaked horned lark, and Mazama pocket gopher across low-risk (green) and high-risk (yellow) prairie habitat at Joint Base Lewis-McChord, WA under current conditions.

Objective 5c: Assess and report degree to which model results depict reality

For all three candidate species at JBLM, chi-square tests indicate a statistically significant difference between the distribution of occupied habitat in low- and high-risk areas and the distribution expected given availability of potential habitat in low- and high-risk areas under current conditions (Table 6.1.2.5). The significant differences in distributions between occupied and potential habitat demonstrate all species are using habitat modeled in low-risk areas to a greater degree than expected by chance, suggesting HRA models effectively predicted risk (i.e., habitat quality) across JBLM in two broad categories (i.e., low risk versus high).

Table 6.1.2.4. Percent of prairie habitat (7,015 ha) within the potential distribution of each candidate species at Joint Base Lewis-McChord, WA that occurs within modeled low- and high-risk areas under current conditions and in each alternative management scenario.

		Scenario					
Species	Risk	Current	BAU	HBDT	HBIT	LBDT	LBIT
Taylor's checkerspot butterfly	Low	0.70	0.70	0.85	0.70	0.70	0.66
	High	0.30	0.30	0.15	0.30	0.30	0.34
Mazama pocket gopher	Low	0.67	0.68	0.83	0.68	0.68	0.63
	High	0.33	0.32	0.17	0.32	0.32	0.37
Streaked horned lark	Low	0.75	0.75	0.91	0.75	0.75	0.74
	High	0.25	0.25	0.09	0.25	0.25	0.26

Table 6.1.2.5. Chi-square tests comparing the current distributions of habitat occupied by candidate species (Taylor's checkerspot butterfly, Mazama pocket gopher, and streaked horned lark) over low- and high-risk areas to distributions expected given total availability of low- and high-risk areas within potential distributions at Joint Base Lewis-McChord, WA under current conditions.

	Species					
	Butterfly		Gopher		Lark	
Risk	Observed	Expected	Observed	Expected	Observed	Expected
Low	117.36	81.72	1253.88	846.06	172.80	259.72
High	0.00	35.64	8.46	416.28	172.53	85.61
Total ha	117.36	117.36	1262.34	1262.34	345.33	345.33
Chi-square test	$\chi^2_1 = 49.76$		$\chi^2_1 = 594.65$		$\chi^2_1 = 116$	
	$p < 0.0001$		$p < 0.0001$		$p < 0.0001$	

- **Carbon sequestration**

✓ Objective 1: Quantify provision of ecosystem services using existing GIS data
✓ Objective 2: Quantify value of ecosystem services for at least two ecosystem services
✓ Objective 3: Provide spatially-explicit rendering of service provision
✓ Objective 4: Provide spatially-explicit rendering of the social value of at least two key ecosystem services
✓ Objective 5c: Assess and report degree to which model results depict reality (partner installation data available; model not previously tested in similar environment)
✓ Objective 6: Incorporate uncertainty into service-provision estimates for at least two key

services of interest

- ✓ Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

To meet Objectives 1, 2, 3, 4, and 8, we used the InVEST carbon model to assess carbon biomass and its economic value (i.e., social cost of carbon) at JBLM under current conditions, a Business-As-Usual (BAU) scenario, and four alternative scenarios (High Budget-Decreased Training [HBDT], High Budget-Increased Training [HBIT], Low Budget-Increased Training [LBIT], and Low Budget-Decreased Training [LBDT]) at a 28.5-m resolution. To meet Objective 5c, we compared the generalized aboveground carbon biomass estimates with site-estimates under current conditions. To meet Objective 6, we estimated a range of carbon biomass and economic value outputs based on the upper and lower bounds of model inputs.

Model inputs and assumptions

The InVEST Carbon Sequestration Model was used to calculate carbon storage and sequestration for scenarios at JBLM. We derived carbon values for LULC classes using the National Biomass and Carbon Dataset (NBCD; Kellndorfer et al. 2000). The NBCD is a 30-m resolution raster that depicts aboveground biomass (Mg/ha) for tree species within the contiguous U.S. for the year 2000. We calculated aboveground biomass by aggregating vegetation types into structural classes and averaging biomass values for each structural class. We converted mean values to carbon (Mg/ha) for LULC classes and uncertainty was calculated by using the 25% lower bound and 75% upper bound of the mean carbon value for each LULC class (Table 6.1.2.6). Since the NBCD only provides values for tree and some shrub species, we valued aboveground biomass for Scotch broom at 47.0 Mg/ha (Wheeler et al. 1987, Bossard and Rejmanek 1994) and cold temperate prairies at 2.4 Mg/ha (IPCC 2006) based on available scientific literature. We converted mean aboveground biomass to carbon storage (Mg/ha) by multiplying the aboveground biomass value by 0.5 (IPCC 2006). We multiplied aboveground carbon by a root to shoot ratio of 0.3, the average for temperate forest species, or 4.0 for grassland species (IPCC 2006) to estimate belowground biomass.

Table 6.1.2.6. Mean values, upper bounds, and lower bounds for Land Use and Land Cover (LULC) structural classes and types at Joint Base Lewis-McChord, WA, derived from the National Biomass and Carbon Dataset (NBCD) and Intergovernmental Panel on Climate Change (IPCC) root-to-shoot ratios.

LULC Type	Aboveground C (Mg/ha)	Belowground C (Mg/ha)	Lower/Upper Bounds Aboveground C (Mg/ha)	Lower/Upper Bounds Belowground C (Mg/ha)
Bare ground	0.0	0.0	-	-
Built-up in training area	0.0	0.0	-	-
Conifer plantation	110.6	33.2	(94.5, 127.5)	(28.4, 38.3)
Conifer riparian forest	188.4	56.5	(150.0, 228.5)	(45.0, 68.6)
Deciduous forest	95.8	28.7	(89.0, 104.0)	(26.7, 31.2)
Deciduous plantation	72.8	21.8	(52.5, 87.5)	(15.8, 26.3)
Deciduous woodland	92.5	27.8	(68.0, 114.0)	(20.4, 34.2)
Developed	0.0	0.0	-	-
Douglas-fir forest	180.8	54.2	(140, 222.5)	(42, 66.8)
Douglas-fir woodland	130.9	39.3	(96.5, 156.0)	(28.9, 46.8)
Grassland	1.2	4.8	-	-
Hardwood riparian forest	114.5	34.4	(96.5, 132.0)	(28.9, 39.6)
Lake	0.0	0.0	-	-
Mixed forest	120	36	(91.0, 145.0)	(27.3, 43.5)
Mixed woodland	117	35.1	(82.0, 140.0)	(24.6, 42.0)
Native shrubland	83.9	25.2	(63.0, 102.0)	(18.9, 30.6)
Recent burn/clearcut	111.7	33.5	(49.5, 153.5)	(14.9, 46.1)
Savanna	93.4	28	(64.0, 119.0)	(19.2, 35.7)
Scotch broom	23.5	7.1	-	-
Stream	0.0	0.0	-	-
Wetland (Non-forested)	0.0	0.0	-	-

JBLM foresters estimated around 5,694 m^3 wood product was salvage logged every year from root rot-infested trees (~10% of all currently infested trees) within harvestable areas, while remaining infested trees decayed naturally on site. We adopted this salvage logging volume under decreased training scenarios, which remain at current root rot infestation rates. This salvage volume increases to 11,390 m^3/year under increased training scenarios and 8,542.5 m^3/year under BAU, proportional to their root rot infestation rates. The recent clearcut land cover was given a value only for belowground biomass of the conifer matrix forest since the aboveground biomass had been harvested. Studies suggest soil carbon and dead organic matter can fluctuate slightly following afforestation and clearcut management for Pacific Northwest Douglas-fir forests (Smith et al. 2006), but given difficulties calculating the age of forests at JBLM, we ignored this parameter in our analysis.

We calculated harvested carbon pools using the timber product estimate from the InVEST

Timber Production Model and decay rates for Douglas-fir saw wood (34 year half-life) and pulpwood (1 year half-life) (Smith et al. 2006). We evaluated carbon sequestration for each scenario as the total biomass stored between 2010 and 2030. Due to data limitations, we assume carbon accumulation in intact secondary and old-growth forests did not change spatial forest classifications or scenario parameters.

We assessed the economic value of carbon sequestration in the form of social cost of carbon, which represents the social damage (health, property value, agriculture, ecosystems, etc.) avoided by not releasing one additional ton of carbon into the atmosphere. Compared with the carbon market price, the social cost of carbon is more suitable for government decision contexts as it reflects the true economic impacts of climate change. The United States Interagency Working Group on the Social Cost of Carbon (USIWGSCC) provides guidance for the appropriate carbon cost through time for regulatory cost-benefit analyses by synthesizing three integrated assessment models with commonly agreed climate sensitivity, socio-economic trajectory, and discount rates (USIWGSCC 2013). We used $115.34/Mg C social cost of carbon (converted from 2007 USD to 2010 USD) based on a 3% discount rate, the middle rate among all three provided by USIWGSCC, and applied a 2.3% annual rate of change in the price of carbon based on 2010-2030 estimates from USIWGSCC.

Results

Objective 5: Assess and report degree to which model results depict reality

We tested the InVEST Carbon Sequestration Model at JBLM by comparing the mean values of aboveground carbon biomass, estimated from 2000 NBCD data, with those estimated from field sampling data acquired in 2012 (M. Hurteau, Penn State University, Unpublished Data). InVEST estimates do not differ significantly from estimates based on field sampling, although values are slightly lower (Figure 6.1.2.4), which may be a result of growth in tree biomass given the 12-year difference in the datasets. This comparison suggests the InVEST carbon model with NBCD data reasonably estimates carbon biomass stored in various vegetation types, and it can be used for decisions relying on relative estimates.

Objective 1: Quantify provision of ecosystem services using existing GIS data
Objective 2: Quantify value of ecosystem services for at least two ecosystem services
Objective 3: Provide spatially-explicit rendering of service provision
Objective 4: Provide spatially-explicit rendering of the social value of at least two key ecosystem services
Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest
Objective 8: Estimate absolute and relative changes in each ecosystem service that will result

from alternative management option

We assessed these objectives together in the section below as they are closely related.

The forested landscape of JBLM is an important resource for carbon storage and JBLM stores a substantial amount of carbon under the different management scenarios (Figure 6.1.2.5). Including uncertainty in our analyses, JBLM stores as little as ~3.7 million Mg C (~$283,000,000) in the LBIT scenario and up to 5.3 million Mg C (~$411,000,000) in the HBDT scenario. By incorporating uncertainty into our analysis, each scenario has a +/- ~700,000 Mg C (~$50,000,000) variation from the output using the mean NBCD carbon values. Douglas-fir forests are the biggest carbon sources on base and cover a large percentage of the base, thus scenarios with decreased training tend to provide a greater benefit for carbon since they minimize the spread of laminated root rot. Our results suggest maintaining the forested landscape could be an important asset for JBLM in terms of carbon storage.

We evaluated carbon sequestration for the HBDT, HBIT, LBDT, and LBIT scenarios using the BAU as the baseline for comparison (6.1.2.6). Decreased training yielded positive carbon sequestration across the base, and increased training yielded negative values compared to the BAU. Budget accounted for minor differences in carbon sequestration; however, the combination of both reduced budget and increased training intensity in LBIT resulted in the lowest amount of sequestered carbon. HBDT yielded a 57% increase in carbon sequestration and LBDT yielded a 45% increase. Conversely, HBIT yielded a 47% decrease and LBIT resulted in a 61% decrease in carbon sequestration. While carbon storage is presented here to compare the magnitude of values across the 2030 scenarios (Figure 6.1.2.5), the ecosystem service provided is the sequestration of carbon (Figure 6.1.2.7).

Results suggest that carbon sequestration is largely driven by training intensity within our scenarios at JBLM. Training intensity is correlated with spread of laminated root rot throughout the base, resulting in tree mortality for Douglas-fir forests, which is a significant source of carbon storage on the base. Changes in budget levels have a smaller effect on carbon sequestration; however, a decreased budget does result in lower carbon sequestration due to decreased tree replantation rates in root rot-infested areas. If training intensity increases at JBLM, practices designed to reduce the spread of root rot as a result of training exercises would help to conserve carbon stocks.

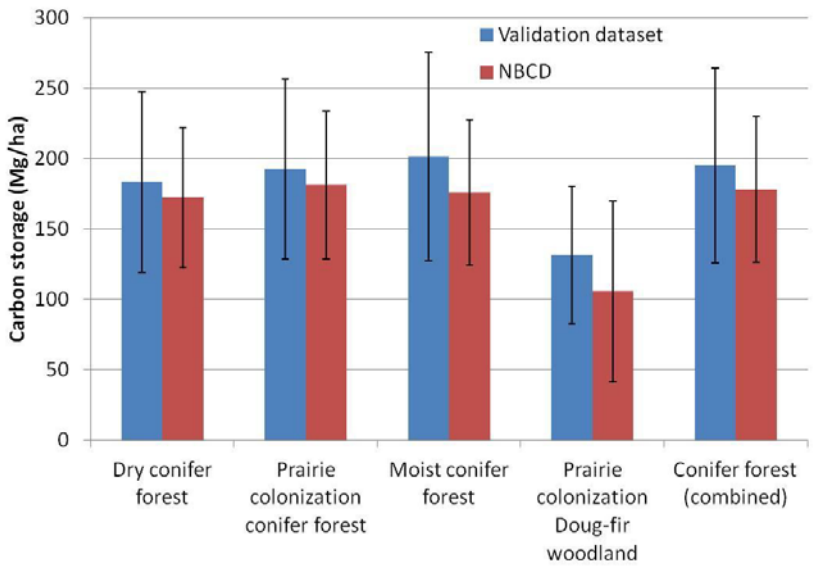
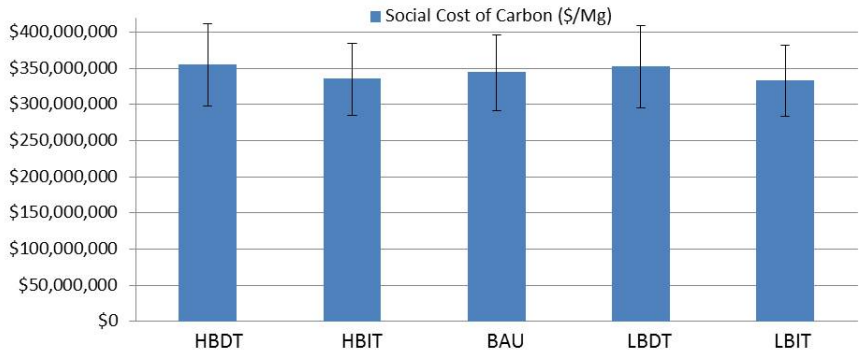
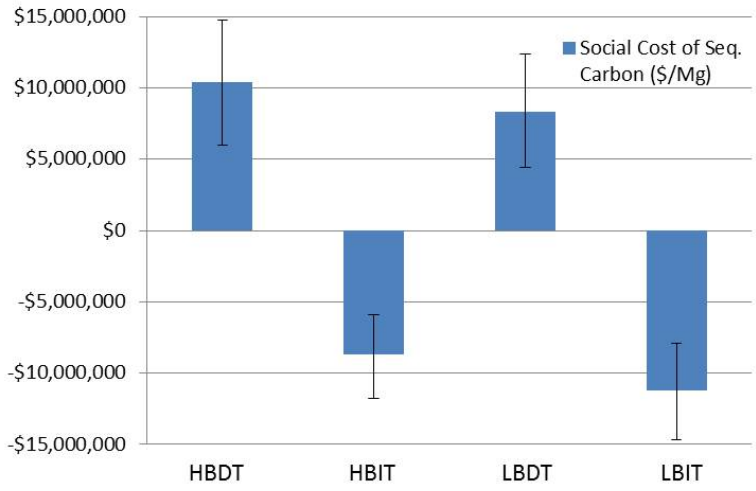


Figure 6.1.2.4. Mean carbon storage of vegetation classes using a 2012 validation dataset and the 2000 National Biomass and Carbon Dataset (NBCD) at Joint Base Lewis-McChord, WA. Error bars represent one standard deviation from the mean carbon storage.



	HBDT	HBIT	BAU	LBDT	LBIT
Stored Carbon (Mg)	4,616,364	4,367,945	4,481,134	4,589,683	4,334,972
25% Lower Bound Stored Carbon (Mg)	3,863,835	3,709,347	3,786,021	3,843,453	3,682,892
75% Upper Bound Stored Carbon (Mg)	5,344,942	5,000,135	5,152,843	5,313,260	4,961,846
Social Cost of Carbon ($/Mg)	$355,275,372	$336,157,030	$344,868,103	$353,222,038	$333,619,474
25% Lower Bound Social Cost of Carbon ($/Mg)	$297,360,742	$285,471,345	$291,372,176	$295,792,143	$283,435,368
75% Upper Bound Social Cost of Carbon ($/Mg)	$411,346,736	$384,810,390	$396,562,797	$408,908,490	$381,863,668

Figure 6.1.2.5. Carbon storage (Mg) and social value of carbon storage ($) for 2010 and five 2030 scenarios at Joint Base Lewis-McChord, WA. Error bars represent uncertainty with upper (75%) and lower (25%) bounds of mean National Biomass and Carbon Dataset (NBCD)-derived values. 2030 scenarios include High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).



	HBDT	HBIT	LBDT	LBIT
Stored Carbon (Mg)	135,230	-113,189	108,549	-146,162
25% Lower Bound Stored Carbon (Mg)	77,814	-76,674	57,432	-103,129
75% Upper Bound Stored Carbon (Mg)	192,099	-152,708	160,417	-190,997
Social Cost of Carbon ($/Mg)	$10,407,269	-$8,711,073	$8,353,935	-$11,248,629
25% Lower Bound Social Cost of Carbon ($/Mg)	$5,988,565	-$5,900,831	$4,419,967	-$7,936,808
75% Upper Bound Social Cost of Carbon ($/Mg)	$14,783,939	-$11,752,408	$12,345,692	-$14,699,129

Figure 6.1.2.6. Carbon sequestration (Mg) and social value of carbon sequestration for 2030 scenarios compared to Business-As-Usual (BAU) at Joint Base Lewis-McChord, WA. Error bars represent uncertainty with upper (75%) and lower (25%) bounds of mean National Biomass and Carbon Dataset (NBCD)-derived values. 2030 scenarios include High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

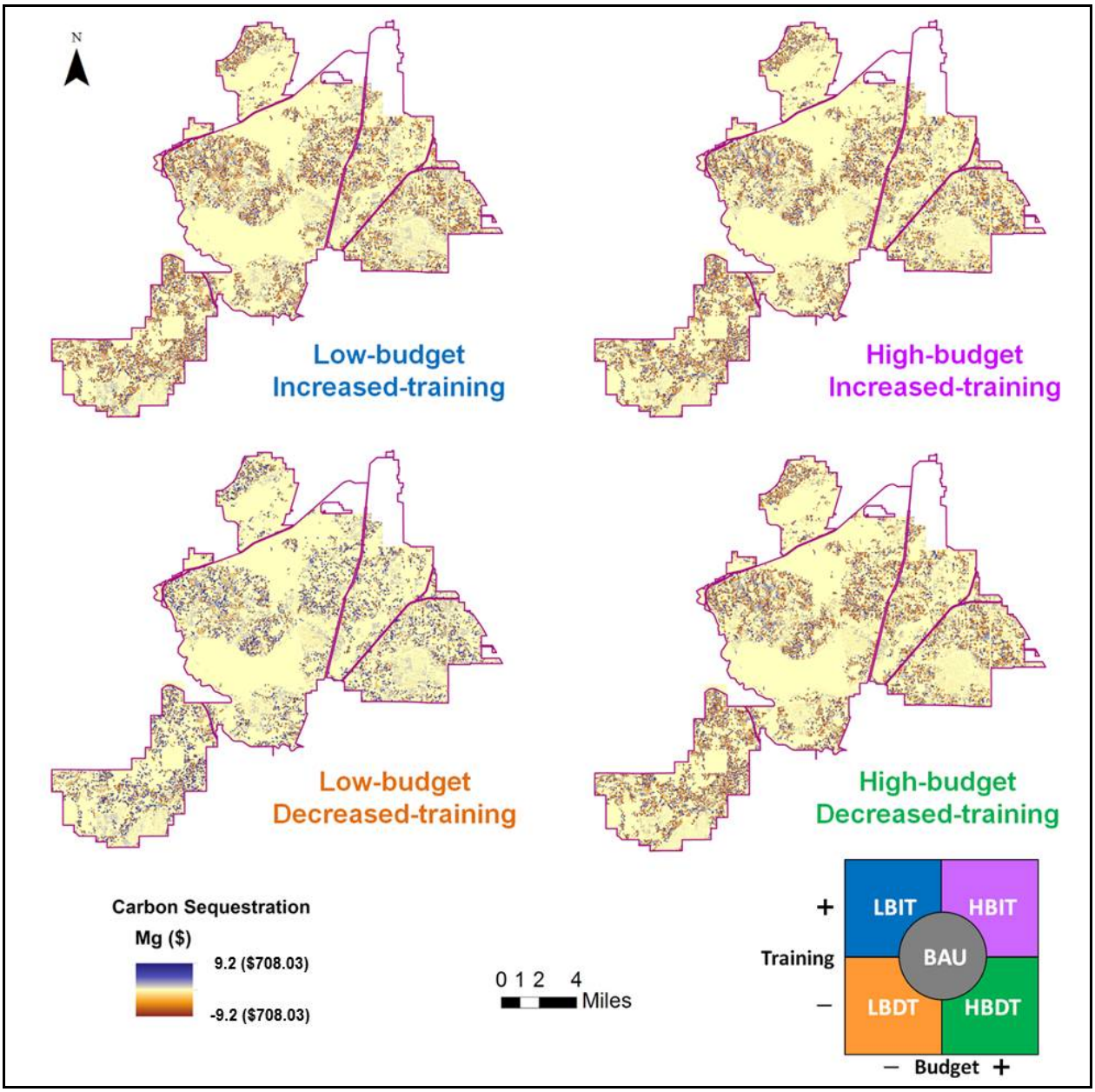


Figure 6.1.2.7. Carbon sequestration (Mg/0.08ha-pixel) and social value ($/0.08ha-pixel) compared to Business-As-Usual (BAU) for 2030 scenarios at Joint Base Lewis-McChord, WA. 2030 scenarios include High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

- **Timber production**

- ✓ Objective 1: Quantify provision of ecosystem services using existing GIS data
- ✓ Objective 2: Quantify value of ecosystem services for at least two ecosystem services
- ✓ Objective 3: Provide spatially-explicit rendering of service provision
- ✓ Objective 4: Provide spatially-explicit rendering of the social value of at least two key ecosystem services
- ✓ Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest
- ✓ Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

To meet Objectives 1, 2, 3, 4, and 8, we used the InVEST timber production model to assess harvest wood biomass and its economic value (i.e., total net present value) at JBLM under current conditions, a Business-As-Usual (BAU) scenario, and four alternative scenarios (High Budget-Decreased Training [HBDT], High Budget-Increased Training [HBIT], Low Budget-Increased Training [LBIT], and Low Budget-Decreased Training [LBDT]) for three timber management zones. To meet Objective 6, we calculated 90% confidence intervals for total timber value and per-ha value driven by yearly variations in harvest practice and timber price using Monte Carlo simulations.

Model inputs and assumptions

We applied the InVEST Timber Production model to calculate expected net present value (NPV) of timber harvested during 2010-2030 from Douglas-fir forests at JBLM. As timber harvest at JBLM is mainly thinning and selective cutting to maintain a diverse tree structure, the majority of harvest areas remain natural forests. The production inputs for over 700 forest stands were not constant across years because many stands were not regularly managed and timber sales often spatially overlapped. In order to obtain well-defined management zones and relative consistent timber production measures, individual harvest parcels are aggregated into three large management zones, i.e., Rainier, North Central and Northeast, based on the Ecological Landscape Units (ELUs) defined by JBLM for forest management (Figure 6.1.2.8; JBLM 2005). Year-to-year variation in harvest was less for these management zones than for individual forest stands. We estimated net return of timber for each year by subtracting total maintenance costs (reforestation, roads, etc.) from total timber sale revenue, which was calculated as the product of harvest area, wood volume per unit area, and timber price corrected for inflation. We obtained the NPV of timber by discounting flow of future net returns to the base year 2010.

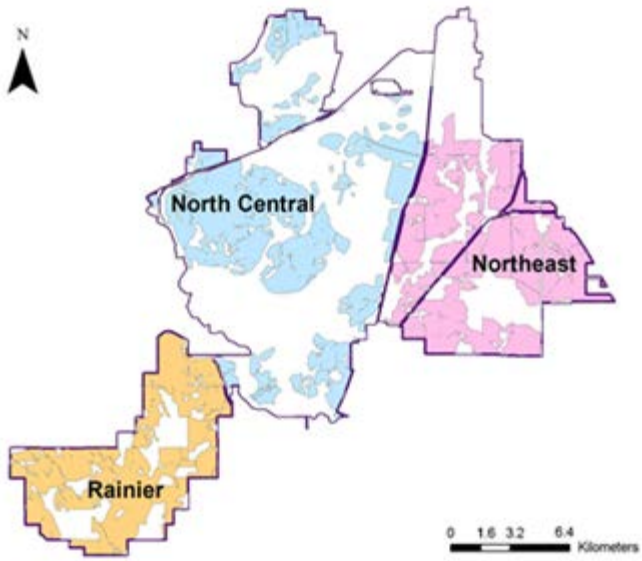


Figure 6.1.2.8. Timber management zone based on Ecological Landscape Units at Joint Base Lewis-McChord, WA.

For all scenarios, we assumed timber volume harvested per unit area was consistent with historical practices for each zone, which was estimated as a ten-year average based on 2002-2011 JBLM timber sale records (JBLM 2012c). Substantial, year-to-year variation in harvest can occur, but in the long run, there is little change in total harvest. However, total area of each zone and percentage of total area harvested each year were assumed to vary across scenarios, and were determined by the availability of forest resources. In decreased training scenarios (HBDT and LBDT), in which root rot infestation remains at its current rate (20% of susceptible forest), we calculated total harvest area and harvest percentage as ten-year averages of 2002-2011 data (JBLM 2012b). As infestation rate increased to 30% under BAU and 40% under increased training scenarios, total harvest area decreased annually by 0.31%–0.38% in the three zones under BAU and by 0.67%–0.79% under HBIT and LBIT. Based on discussion with JBLM foresters, total timber harvest would remain at the current level in BAU despite a slight decline in forest resources caused by root rot, but would decrease in the two increased-training scenarios due to a large increase in root rot-created tree mortality pockets. Thus, the percentage of total area harvested increased by 0.31%–0.38% each year in BAU to completely offset the reduction in total area, while for the HBIT and LBIT scenarios, we assumed increased harvest percentages by 0.58%–0.67%/year and 0.33%–0.44%/year, respectively, to maintain the same harvest per unit area as BAU (Table 6.1.2.7).

Table 6.1.2.7. InVEST Timber Production Model inputs under Business-As-Usual (BAU) and four alternative scenarios at Joint Base Lewis-McChord, WA. Alternative scenarios include High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

Inputs	Unit	BAU, HBDT, and LBDT			HBIT			LBIT		
		West	Central	East	West	Central	East	West	Central	East
Area of timber management zone	ha	5061	7440	6643	5061	7440	6643	5061	7440	6643
(annual decrease)		*0*	*0*	*0*	*0.79%*	*0.67%*	*0.69%*	*0.79%*	*0.67%*	*0.69%*
Proportion of area harvested each period	%	5.53	4.12	4.86	5.53	4.12	4.86	5.53	4.12	4.86
(annual increase)		*0*	*0*	*0*	*0.67%*	*0.62%*	*0.58%*	*0.44%*	*0.33%*	*0.35%*
Volume harvested per ha each period	cubic meter/ha	31.2	33.9	21.1	31.2	33.9	21.1	31.2	33.9	21.1
Frequency of harvest periods	year	1	1	1	1	1	1	1	1	1
Marketplace value of wood harvested	dollar/ cubic meter	120	110	113	120	110	113	120	110	113
Annualized maintenance cost	dollar/ha	9.9	7.4	8.7	9.9	7.4	8.7	9.9	7.4	8.7
Number of years valued	year	20	20	20	20	20	20	20	20	20

The inputs on price and cost were consistent across scenarios. We assumed no harvest costs for JBLM, as timber is mostly harvested by logging companies or individuals who won timber sale auctions. We calculated maintenance cost, which covers small-scale reforestation and control of invasive plants (e.g., Scotch broom) and disease (e.g., laminated root rot), based on 2007-2011 data from the JBLM Forestry program (JBLM 2012a)[3]. We estimated baseline timber price as

[3] The average annual maintenance cost is divided into the three zones proportional to harvest area assuming more maintenance takes place in areas with more harvest. The per-ha cost for each zone is calculated by dividing the zone

the ten-year average of per-volume bid revenue based on the 2002-2011 timber bid report (JBLM 2012b). It was deflated by the all-commodity producer price index (BLS 2012) and adjusted by regional stumpage price index to account for timber market fluctuation (Washington State Department of Revenue 2012). We projected future price variation during 2010-2030 based on the 2005 USDA Forest Service's Renewable Planning Act Timber Assessment Update (Haynes et al. 2007). We derived the NPV of timber using a discount rate of 3% recommended by the Office of Management and Budget (OMB 2011).

Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest

To account for yearly variation in harvest practice and timber price, we conducted Monte Carlo simulations to calculate the 90% confidence intervals for total timber value and per-ha value for each zone and each scenario using the excel-based risk analysis software @risk 6.0. We assume the three presumably independent variables, i.e., total harvest area, volume harvested per hectare, and timber price per volume, all follow a normal distribution. The mean and variance of their actual distributions were fitted using timber sales data reported for 2002-2011. As the data suggest actual correlation among the three variables, a correlation matrix is incorporated in the simulation for each timber zone under every scenario. The 90% confidence interval is calculated based on 1000 interactions.

Results

Objective 1: Quantify provision of ecosystem services using existing GIS data
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Objective 4: Provide spatially-explicit rendering of the social value of at least two key ecosystem services
Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

We assessed these objectives together in the section below as they are closely related.

The per-acre total net present value (TNPV) and total biomass for three large timber management zones and for the entire installation are shown in Figure 6.1.2.9. Comparing across five scenarios, the BAU and scenarios with decreased training (HBDT and LBDT) have the same

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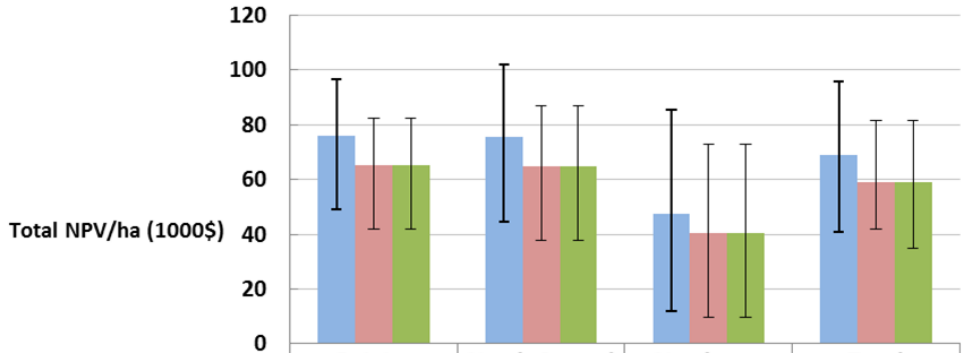
cost by the total area in each zone, as maintenance should cover all forest areas.

TNPV, around 69 thousand dollars, because the current timber harvest practice is continued under these scenarios. The two scenarios with increased training intensity (LBIT and HBIT) have similar TNPV, around 59 thousand dollars, which is ~14% lower than the decreased training and BAU scenarios, reflecting impact on harvest from root rot-created tree mortality. There is no significant difference in per-acre TNPV between LBIT and HBIT. The wood biomass harvest per ha is generally consistent across scenarios by assumption on harvest practice. Comparing the three timber management zones, per-acre TNPV does not differ significantly between the Rainier and North-Central zones, but is about 60% higher than in the Northeast zone across scenarios. Figure 6.1.2.11 shows the per-acre TNPV of each timber management zone in relation to the area of canopy openings created by root rot under all five alternative scenarios. The differences in wood biomass harvested per ha across zones are exclusively driven by the input on per-ha harvest rate.

The total net present value (TNPV) and total biomass for three large timber management zones and for the entire installation are shown in Figure 6.1.2.10. Variation in TNPV across scenarios and across zones is similar to variation in per-ha TNPV. Total TNPV at JBLM is about 75 million dollars during 2010-2030 under the BAU, HBDT and LBDT scenarios, and it declines by 15% in the two scenarios with increased training intensity (LBIT and HBIT). The total biomass harvested also decreases in the two scenarios with increased training, but at a smaller rate. TNPV in the Rainier and North-Central zones is about 50% higher than in the Northeast zone[4], and the total biomass is about 40% higher.

The results imply that training intensity has a much larger impact on timber production and revenue than budget. In the case of an inevitable increase in training intensity, careful planning of training activities to avoid spreading root rot among commercial forest is important to keep constant timber value. The difference in per-acre timber value among three zones suggests that competing land uses with timber production, such as clear-cut for facility building, are likely to lead to less revenue loss if they take place in the northeast zone, rather than the other two zones.

[4] The Total Net Present Value (TNPV) for JBLM is greater than TNPV summed across the three zones because timber zone-level results were calculated using parameters generalized from all small timber parcels within each zone, but total TNPV was calculated using parameters based on harvest practice on the entire installation. There is a deviation between these two sets of parameters.

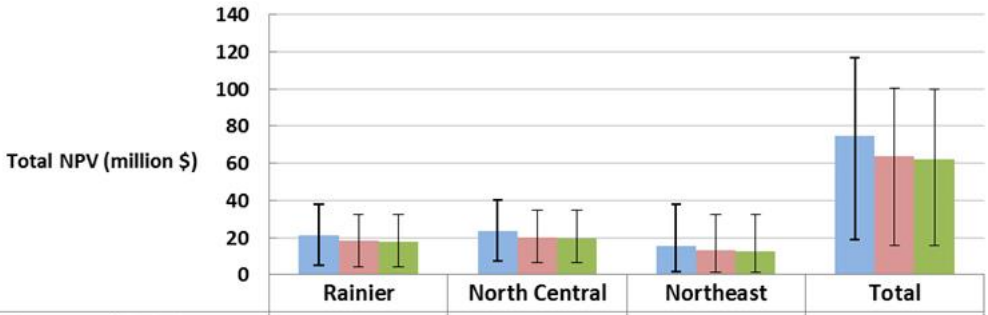


	Rainier	North Central	Northeast	Total
BAU & Decreased Training (1000$)	76	76	47	69
High-Budget Increased-Training (1000$)	65	65	40	59
Low-Budget Increased-Training (1000$)	65	65	40	59

Total Biomass (ton/ha)

BAU & Decreased Training (ton)	35	28	20	33
High Budget-Increased Training (ton)	36	29	21	34
Low Budget- Increased Training (ton)	35	28	21	34

or three timber management zones and the entire base at Joint Base Lewis-McChord, WA, 2010-2030. Error bars indicate 90% confidence intervals based on Monte Carlo simulation. Scenarios include Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).



	Rainier	North Central	Northeast	Total
BAU & Decreased Training (million $)	21	23	15	75
High Budget- Increased Training (million $)	18	20	13	64
Low Budget- Increased Training (million $)	18	19	13	62

Total Biomass (1,000 ton)

BAU & Decreased Training (1,000 ton)	175	208	136	634
High Budget-Increased Training (1,000 ton)	181	217	141	659
Low Budget- Increased Training (1,000 ton)	177	211	138	643

Figure 6.1.2.10. Total Net Present Value (NPV) and total wood biomass (ton) for three timber management zones and the entire base at Joint Base Lewis-McChord, WA, 2010-2030. Error bars indicate 90% confidence intervals based on Monte Carlo simulation. Scenarios include Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

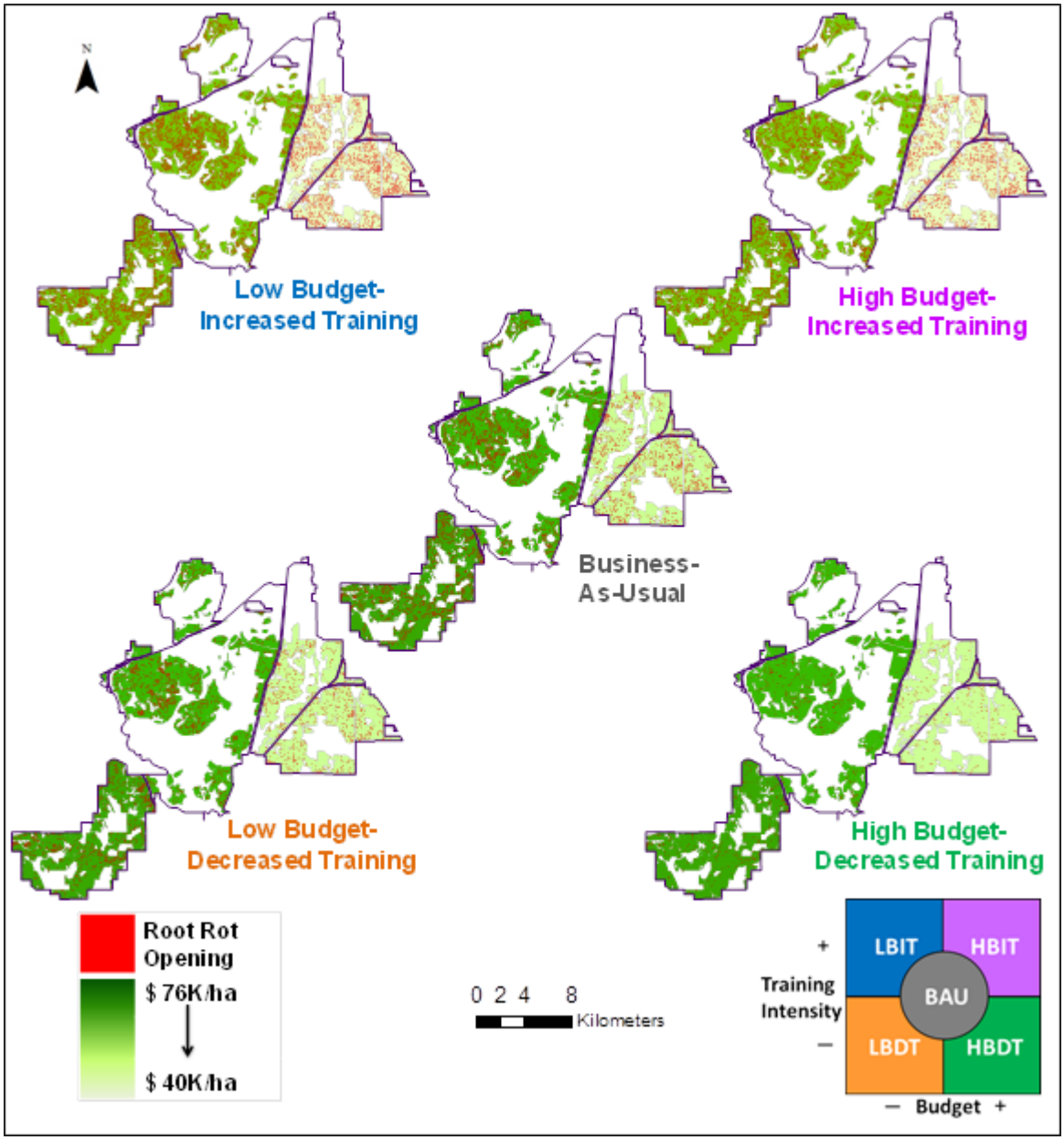


Figure 6.1.2.11. Per-acre timber Total Net Present Value/ha (NPV/ha) and canopy opening area created by root rot infestation at Joint Base Lewis-McChord, WA, 2010-2030. Scenarios include Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

- **Training capacity**

✓ Objective 1: Quantify provision of ecosystem services using existing GIS data
✓ Objective 3: Provide spatially-explicit rendering of service provision
✓ Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

To meet Objectives 1, 3, and 8, we used the new training capacity model to assess suitable area for infantry and vehicle training at JBLM under current conditions, a Business-As-Usual (BAU) scenario, and four alternative scenarios (High Budget-Decreased Training [HBDT], High Budget-Increased Training [HBIT], Low Budget-Increased Training [LBIT], and Low Budget-Decreased Training [LBDT]) at training area level.

Model inputs and assumptions

We applied the training capacity model to calculate area of usable land cover for infantry and vehicle training in 29 training areas (45-2,397 ha) and four impact areas (172-2,397 ha) at JBLM. For each training/impact area at JBLM, we calculated training capacity by multiplying suitable land cover for infantry or vehicle training, adjusted for accessibility and training restrictions, by frequency of training use.

Infantry and vehicle training activities have different land requirements. As infantry is highly mobile, it occurs in most land covers, excepting areas with large surface water and dense shrubs, such as Scotch broom. Suitable infantry land cover thus includes forest, grassland, woodland, and savanna at JBLM. We obtained the total area of each type of suitable land cover by overlaying the LULC map with a training area map provided by JBLM. We then identified infantry-accessible areas by eliminating suitable but isolated land patches not connected to other suitable land cover by roads. Vehicle maneuvering typically occurs on large open areas, including grassland, savanna, and low shrubland. We assumed that one third of Scotch broom habitat is covered by tall shrubs preventing vehicle movement, and hence is unsuitable. Some grassland areas are protected from off-road vehicle maneuvering year-round to protect candidate species (e.g., Mazama pocket gopher and Taylor's checkerspot butterfly) and were excluded from the suitable vehicle training area. In contrast, seasonal restrictions for vehicle training are imposed in certain areas during the nesting and breeding seasons of sensitive bird species, such as bald eagle and streaked horned lark. Thus, we assume seasonally-restricted areas are unavailable for half the year for bald eagle or one-third of the year for lark. We included the area of roads in both infantry and vehicle training capacities because they are extensively used by troops to access training areas.

We calculated frequency of training use for each training area as the percentage of a year the area is used for training. We categorized frequencies in all training areas into four levels (100%,

70%, 40%, and 10%), based on discussion with JBLM personnel (Inger Gruhn, personal communication, September 6, 2012). Training areas are more frequently used for both infantry and vehicle training if they are closer to barracks, have more open space, and are free of natural barriers such as rivers. We derived most changes in inputs under alternative scenarios from alternative LULC maps.

Results

Objective 1: Quantify provision of ecosystem services using existing GIS data
Objective 3: Provide spatially-explicit rendering of service provision
Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

We assessed these objectives together in the section below as they are closely related.
In general, area-weighted infantry training capacity varies only slightly across scenarios, as it is highly mobile and not refined by training restrictions for habitat conservation. The capacity is highest in the HBDT scenario at 91%, decreases to 85%-86% in three intermediate scenarios (HBIT, BAU, and LBDT) and further declines to 81% in the LBDT scenario. Scotch broom expansion, which is jointly influenced by training intensity (via open area created by training-facilitated root rot infestation) and budget (due to less invasive species control effort), is the main cause of declines in infantry training capacity.

The area-weighted vehicle training capacity has a larger variation across scenarios, which is largely driven by budget change; it drops slightly from 24% for the two High Budget scenarios (HBIT and HBDT) to 23% under BAU, and declines to 18% in the two Low Budget scenarios (LBIT and LBDT). Budget cuts would lead to less habitat restoration effort on and off base and result in more restrictions for vehicle movement within sensitive species habitat.

For individual TAs shown in Figure 6.1.2.13, infantry training capacity measured in percentage of suitable area ranges from 8% in TA 17 (HBIT and LBIT) to 97% in TA A East (HBIT). As TA 17 is isolated by a river from the rest area, training activities only take place in 10% of time available, which thus dramatically reduces its capacity. Across the base, training areas closer to the cantonment in the north-central and northeast regions have higher capacity, while the infantry capacity on TAs 19-23 are mostly lower than 50% because they are further from the cantonment and less frequently used. TA 14, which carries 75% to 90% capacity across scenarios, stands out in the northeast region. This prairie-dominated area is restricted species habitat and requires intensive scotch broom control even in the LBIT scenario. Considering both the total area of each training zone and the percentage measure, TAs 4, 5, 10, 11, 13 and 15 are top-ranked based on their large suitability for carrying out infantry training.

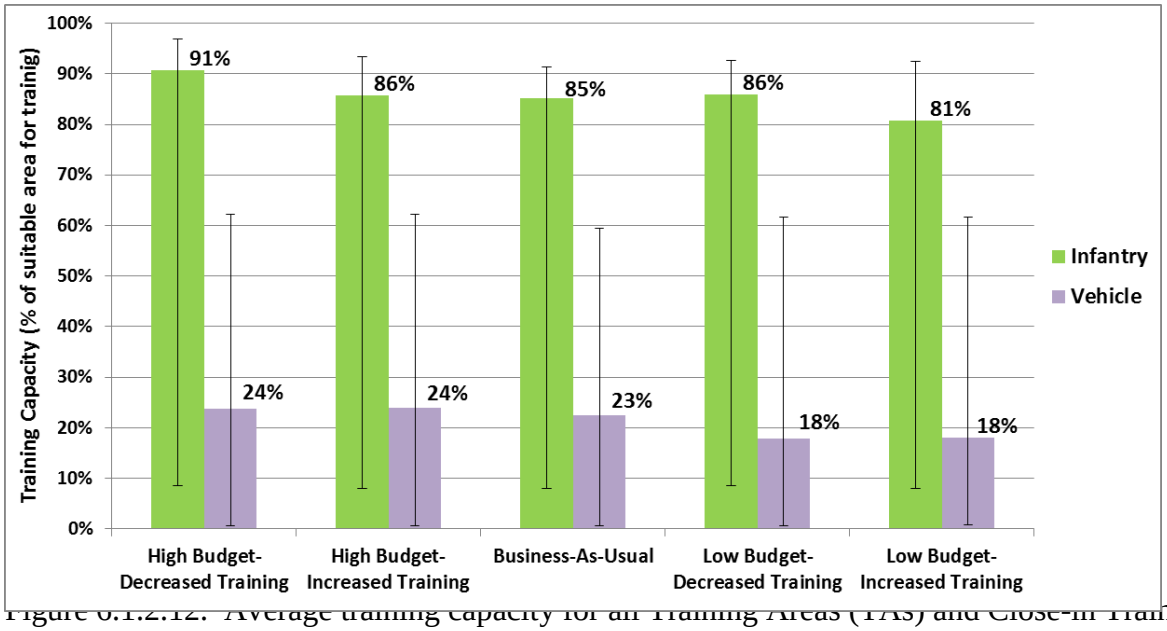


Figure 6.1.2.12. Average training capacity for all Training Areas (TAs) and Close-in Training Areas (CTAs) under five alternative scenarios weighed by area at Joint Base Lewis-McChord, WA. Error bars indicate maximum and minimum capacity among all individual TAs and CTAs. Scenarios include Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

For individual training areas shown in Figure 6.1.2.14, vehicle training capacity measured in percentage of suitable area ranges from 0.6% in TA 17 to 62% in Close-in Training Area (CTA) F (HBIT and HBDT). Similar to infantry capacity, low capacity in TA 17 is a result of its isolation. Training areas closer to the cantonment in the north-central and northeast regions have higher capacity, which is also consistent with infantry training. Vehicle training capacity is primarily affected by the “no off-road vehicle movement” restriction on sensitive species habitat. The restriction is imposed on a larger area when insufficient habitat restoration and maintenance is triggered by low budget. This explains the reduction in vehicle training capacity for TAs with occupied or potential habitats, including TAs 4, 5, and 6 in the north-central region and TAs 11, 12, 13, 14, and 15 in the northeast region. Although TA 14 has extensive prairie habitat for sensitive species, it still has relatively higher vehicle training capacity compared to surrounding zones because it is more frequently used due to its large, open area and because most of its restrictions are half-year (seasonal). Considering both the total area of each training zone and the percentage measure, TAs 4, 5, 6, 10, and 11 are top-ranked based on their large suitability for carrying out vehicle training.

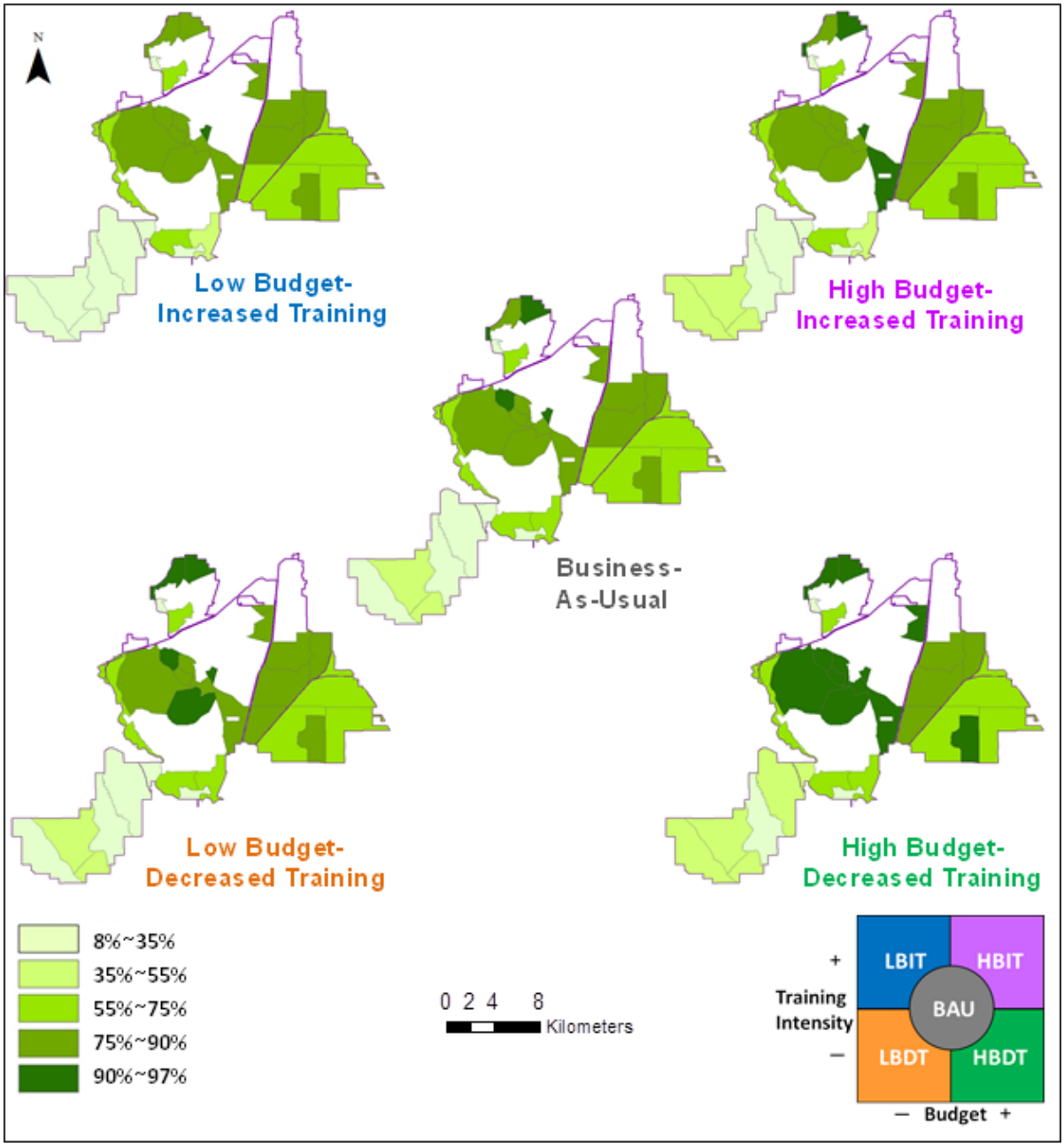


Figure 6.1.2.13. Infantry training capacity (% of suitable area) within each Training Area at Joint Base Lewis-McChord, WA. Scenarios include Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

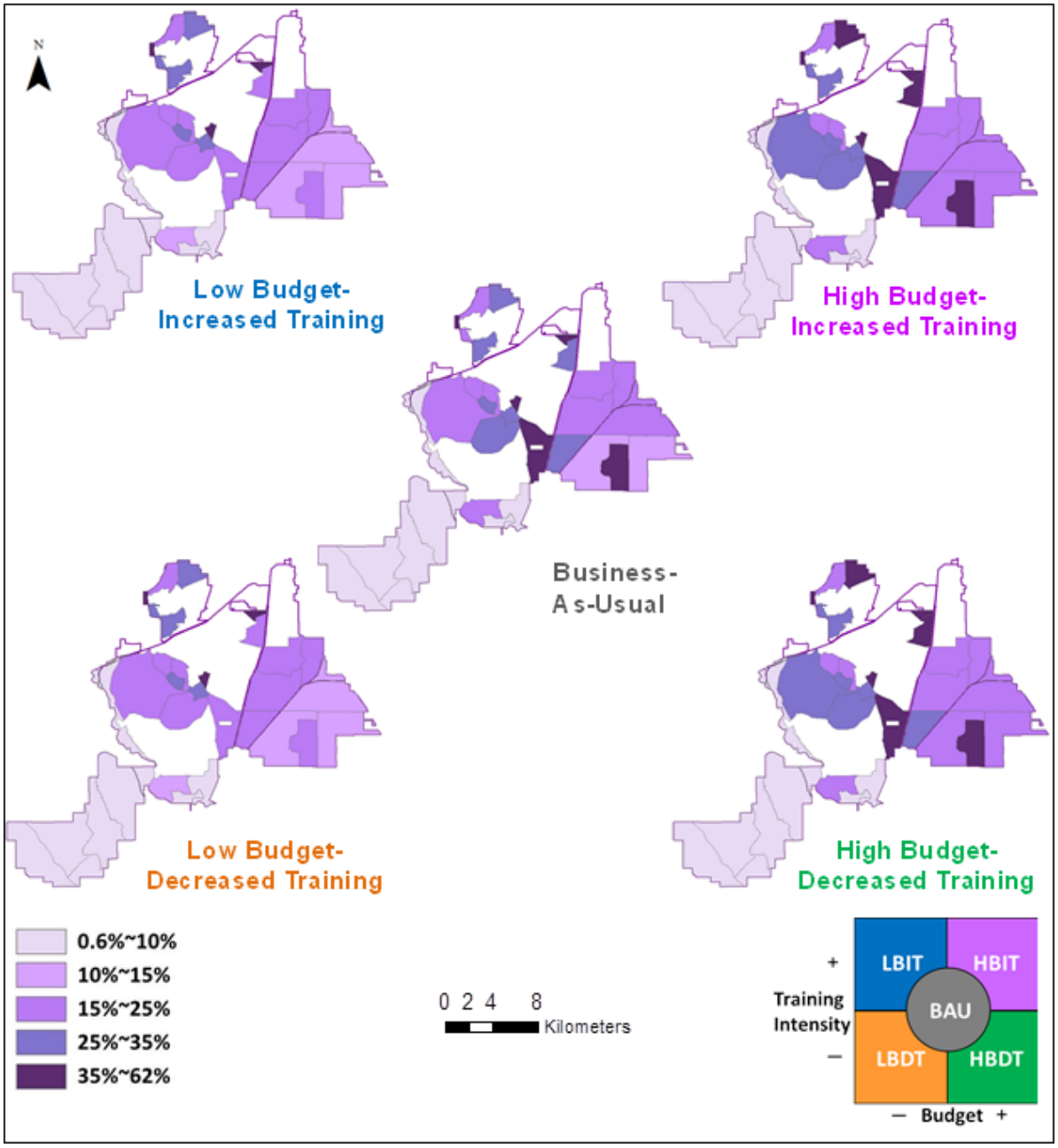


Figure 6.1.2.14. Vehicle training capacity (% of suitable area) within each Training Area at Joint Base Lewis-McChord, WA. Scenarios include Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

6.1.3 Tradeoff and synergy analysis

Objective 9: Use service maps to evaluate multi-service impacts of alternative management options for at least two services

<u>Ecosystem Services Aggregate Analysis</u>

Training intensity and the budget for resource management influence ecosystem service provision in different directions and magnitudes across scenarios (Table 6.1.3.1 and Figure 6.1.3.1). Compared with BAU, the two scenarios with increased training intensity reveal an obvious decline in carbon sequestration and timber production, because vehicle movement associated with training activities increases the proportion of susceptible forest infected with root rot. Whereas the HBIT scenario decreases carbon sequestration by 46% (1.09*105Mg biomass) and the 20-year timber net present value by 15% ($11.3 million), the LBIT scenario results in 62% (1.47*105Mg) and 17% ($12.8 million) reduction in these services, respectively. The decreased training scenarios (HBDT and LBDT) exhibit comparable gain in carbon sequestration (~50%; ~1.2*105Mg), but not in timber production, because timber harvest generally remains at the current scale unless significant decline of timber resources occurs. Budget availability, which determines on- and off-base habitat maintenance and consequent restrictions on vehicle maneuvering, causes a ~20% (~1000 ha suitable training area) decrease in vehicle training capacity for two low-budget scenarios (LBDT and LBIT) relative to BAU. The high-budget scenarios generate a minor increase (~5%; ~1000 ha) in vehicle training capacity. We consider variation in ecosystem services less than 10% as inconsequential.

The area sustaining Puget Sound Prairie is jointly affected by budget-driven habitat maintenance and threats imposed by training activities. It ranges from an increase of 28% (1,300 low-risk ha) in HBDT to a decrease of -12% (530 low-risk ha) in LBIT, relative to BAU. Two intermediate scenarios, HBIT and LBDT, result in a low-risk area similar to BAU. Infantry training is mobile and adaptable to most environments on the installation, and Scotch broom infestation is the primary cause for small variations in infantry training capacity. Scotch broom infestation is primarily driven by decreased budget for invasive species control, but it can also relate to increased training intensity that triggers root rot expansion and subsequent Scotch broom invasion. As a result, infantry training capacity changes little across scenarios; indeed, no difference occurs between the two intermediate scenarios (HBIT and LBDT) in which budget and training intensity offset each other. Across services, the HBDT scenario has the highest provision in all ecosystem services and the LBIT scenario provides the least. When considering only ecosystem services pertaining to the military mission (i.e., infantry and vehicle training capacities) and regulatory training constraints (i.e., candidate species associated with Puget Sound Prairie), both high-budget scenarios result in no service degradation relative to BAU, with considerable gain in area sustaining Puget Sound Prairie (28%) by HBDT.

Table 6.1.3.1. Ecosystem service provision for each scenario (absolute provision and percentage changes relative to Business-As-Usual [BAU]) at Joint Base Lewis-McChord, WA. Scenarios include Business-As-Usual (BAU), High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

Ecosystem Service	Infantry Training Capacity	Vehicle Training Capacity	Puget Sound Prairie Sustainability	Timber Production	Carbon Sequestration
Measure / **Management Scenarios**	Suitable area (1000 ha)	Suitable area (1000 ha)	Low-risk habitat (1000 ha)	Net present value (1M $)	Biomass (1000 Mg)
High Budget-Decreased Training	16.9 (7%)	4.86 (5%)	5.77 (28%)	74.9 (0%)	375 (57%)
High Budget-Increased Training	16.0 (1%)	4.90 (6%)	4.45 (-1%)	63.6 (-15%)	130 (-46%)
Business-As-Usual	15.9 (0%)	4.62 (0%)	4.51 (0%)	74.9 (0%)	239 (0%)
Low Budget-Decreased Training	16.0 (1%)	3.55 (-23%)	4.52 (0%)	74.9 (0%)	343 (44%)
Low Budget-Increased Training	15.1 (-5%)	3.60 (-22%)	3.98 (-12%)	62.1 (-17%)	92 (-62%)

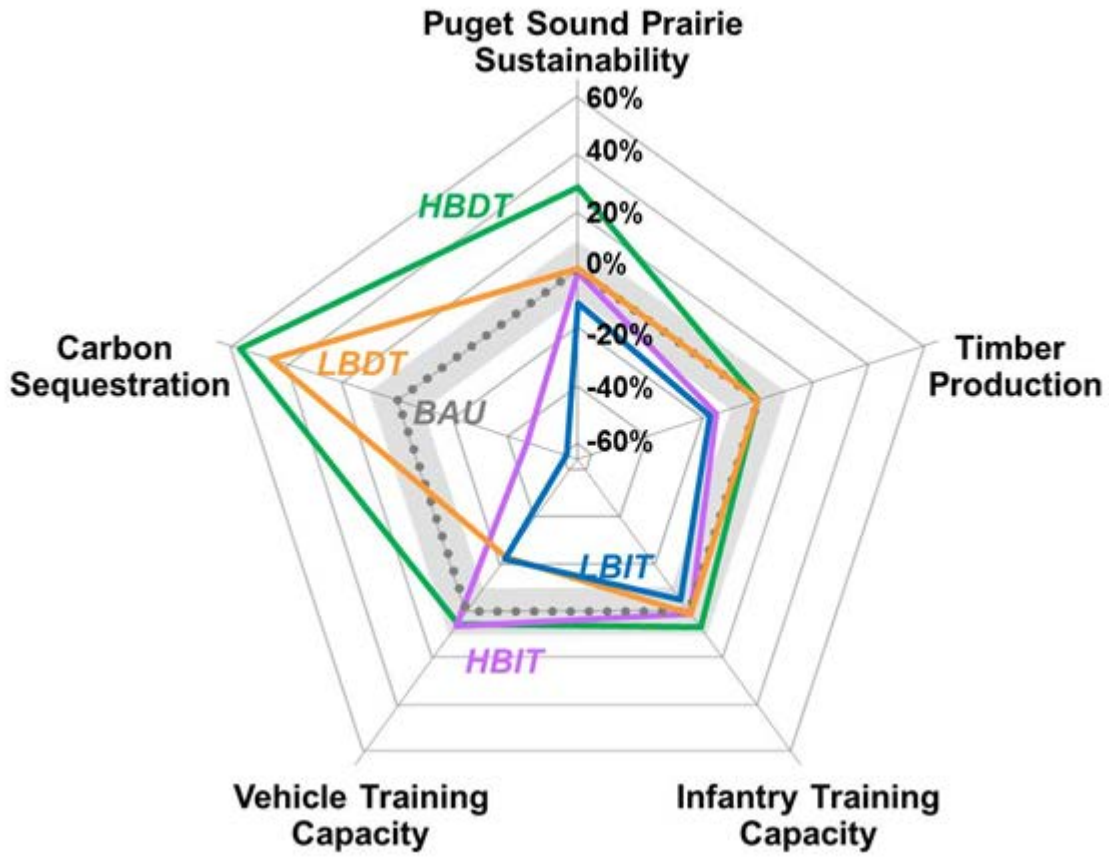


Figure 6.1.3.1. Percentage change of ecosystem service provision in four alternative scenarios relative to the Business-As-Usual (BAU) scenario for: Puget Sound Prairie sustainability (low-risk in ha), vehicle training capacity (applicable habitat in ha), infantry training capacity (suitable landscape in ha), carbon sequestration (Mg), and timber production (net present value in dollars for 2010-2030) at Joint Base Lewis-McChord, WA. Alternative scenarios include LBIT (Low Budget-Increased Training), HBIT (High Budget-Increased Training), HBDT (High Budget-Decreased Training), and LBDT (Low Budget-Decreased Training). Grey shade indicates 10% variation from BAU.

Spatially Explicit Assessment

The spatial distribution of ecosystem services highlights important areas for resource management (Figure 4). We report the relative contribution of training and impact areas to the total provision of each service (Figure 6.1.3.2 for BAU) using a combined measure of absolute provision and efficiency of provision (i.e., service per unit functional area). Areas with high contribution to infantry and vehicle training capacity are located primarily in the central and east regions, where grasslands are abundant. Some areas of dense forest in these regions provide lower capacity for vehicle training than for infantry (Figure 6.1.3.2). The Artillery Impact Area, where Scotch broom cover remains low because of repeated fires triggered during gunnery practices, provides about half of low-risk area sustaining Puget Sound Prairie at JBLM (Figure 6.1.3.2). In contrast, grasslands in Training Area 14 are classified as a high-risk area, due

primarily to pervasive Scotch broom cover and vehicle training disturbance. Relatively higher carbon sequestration and timber returns overlap in several training areas, mostly covered by forest, in the west and central regions (Figure 6.1.3.2). Forest areas in the east region, which show relatively lower timber productivity, still serve as an important carbon sink (Figure 6.1.3.2).

Aggregating across services, Training Areas 4, 5, 6, 8, 11, 13, 19, 22, and 23 play major roles in supporting multiple ecosystem services (Figure 6.1.3.2 B). Most of these areas are dominated by forest with scattered grassland patches that have minimal training restrictions for protecting candidate species. An exception is Training Area 6, which provides more expansive open space desired for infantry and vehicle training, but with ~50% of its area restricted. Despite large variations in aggregate provision of some services across scenarios, the relative contributions of each training area to each service are generally consistent among all scenarios (Figure 6.1.3.3).

Differences in ecosystem service provision between two extreme scenarios, HBDT and LBIT, reveal areas that can potentially produce large gains with improved management conditions, namely higher budget for conservation by reallocating budget among areas, or lower training intensity by shifting training activities to other areas. While HBDT provides favorable management conditions in budget and training intensity, LBIT, the most plausible future for JBLM, does not. We illustrate priority management areas in Figure 4C by 1) calculating the difference in provision of each service between these two scenarios in each training area, and 2) identifying the lowest number of training areas able to fill at least 25% of the total difference for each service. Whereas Training Areas 6 and 11 may be managed to improve one service (i.e., vehicle and infantry training capacity, respectively), Training Area 19 is likely to improve both timber production and carbon sequestration. Training Area 4, however, could achieve an increase in three services: infantry training capacity, timber production, and carbon sequestration. Training Area 14, dominated by grasslands, is classified as a high-risk area and harbors one candidate species. Investment in habitat maintenance could potentially decrease risk to the area and promote colonization by other candidate species. Alternatively, investment in habitat maintenance could improve the suitability, and thus increase provision, of unrestricted open area for vehicle training in Training Area 14.

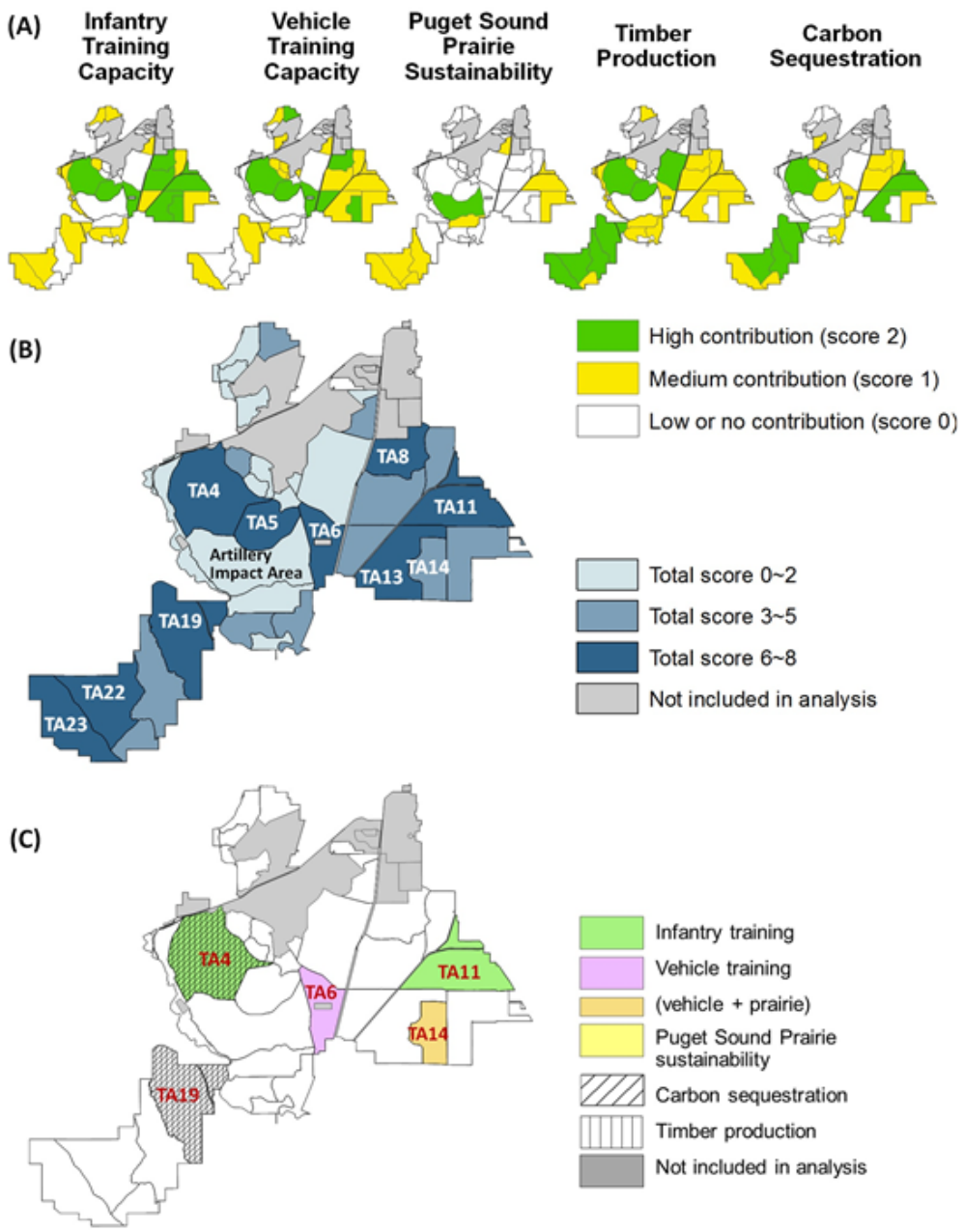


Figure 6.1.3.2. (A) Relative contribution of Training Areas (TA) and Impact Areas to total ecosystem service provision under the Business-As-Usual (BAU) scenario. Green areas support >50% of total ecosystem service provision, yellow areas support an additional 40%, and white areas contribute to the remaining 10%. (B) Relative contribution of Training/Impact Areas to all five ecosystem services based on the sum of scores. (C) Training/Impact Areas with the largest potential ecosystem service improvements from Low Budget-Increased Training scenario to High Budget-Decreased Training scenario. Selected areas contribute to at least 25% of the improvement for each service.

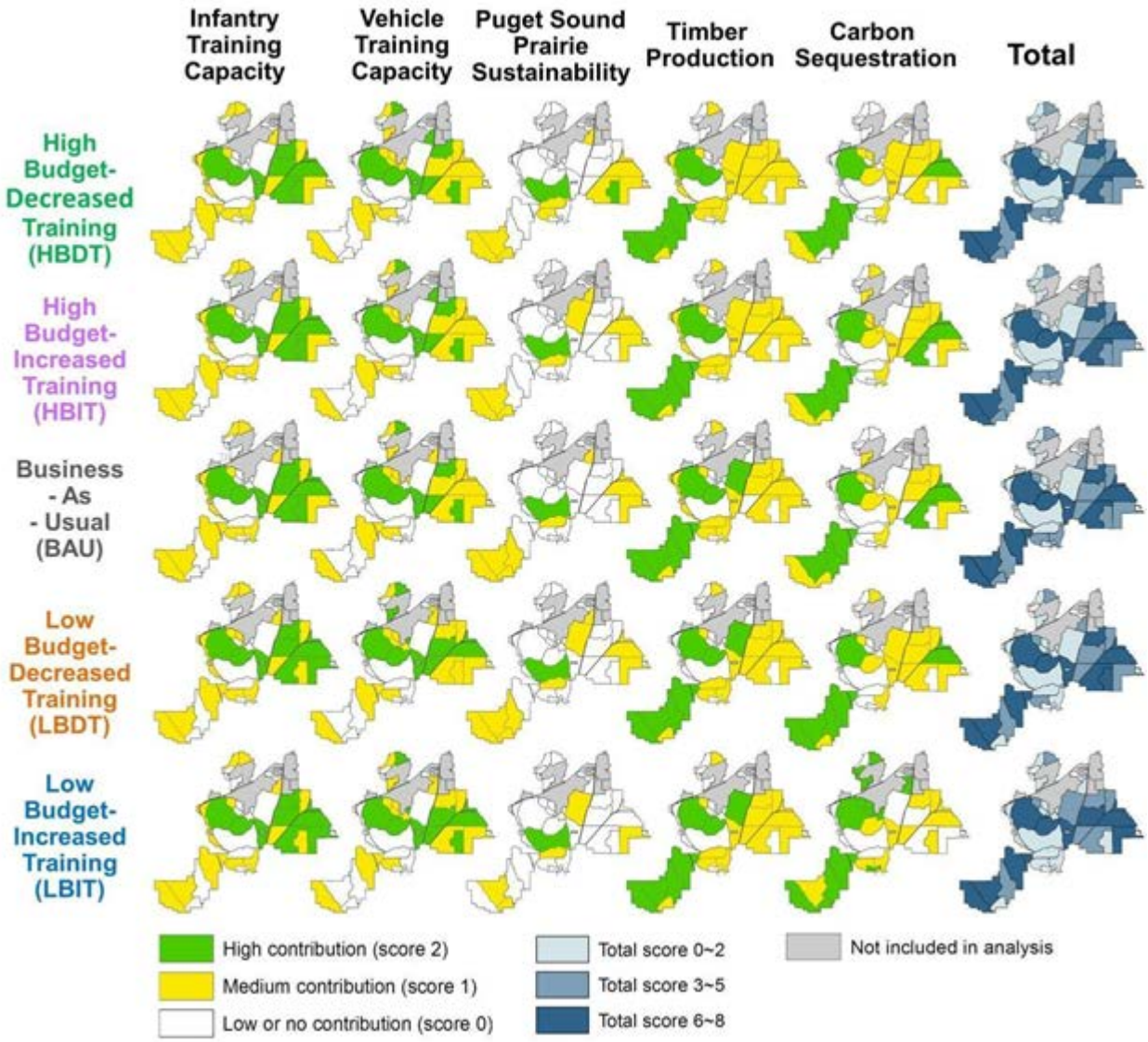


Figure 6.1.3.3. Relative contribution of each Training/Impact Area to ecosystem service provision under the Business-As-Usual (BAU) scenario and four alternative scenarios at Joint Base Lewis-McChord, WA. Alternative scenarios include High Budget-Decreased Training (HBDT), High Budget-Increased Training (HBIT), Low Budget-Decreased Training (LBDT), and Low Budget-Increased Training (LBIT).

6.1.4 Qualitative analysis

This section summarizes the results of our three qualitative objectives (10-12) and deems two of them fully successful. We suggest several opportunities for InVEST models to inform and improve natural resource decisions at JBLM (Objective 10), and we also identify where Army protocol already incorporates ecosystem service information into their environmental management (Objective 11). Due to lack of GIS capacity in the JBLM Environmental Division, we were unable to gather feedback on the independent use of InVEST (Objective 12). However, we received positive feedback on the value of our analytical approach and the scenario generation process by base personnel during the final workshop and in interviews.

Objective 10. Identify opportunities for InVEST to inform decision-making process.

InVEST and its outputs have potential to contribute broadly to three activities: conducting environmental evaluation and proactive impact analyses, sharing results among installation personnel and DoD partnering agencies, and preparing documentation for project proposals and regulatory compliance. Based on a literature review of army regulation and JBLM planning documents, CEQ and USAEC guidance on environmental regulation compliance, and four 30-45 minute interviews conducted with base personnel (Appendix B), we conclude the application of InVEST models is compatible to the Army's existing decision-making practices on installations. The flow-chart below (Figure 6.1.4) delineates the chain of command and the processes and practices surrounding natural resource decision-making at JBLM based on information collected during the interviews. Opportunities to use InVEST in the process are indicated with red text. The universal requirements for INRMP driven decision-making and the general process of land use deconfliction make the following chart applicable, with minor amendments, to most military installations.

As reflected in Figure 6.1.4, InVEST can add value in day-to-day management of natural resources and in long-term planning. We briefly review three of its primary uses below: impact analysis, communication of results and planning, and documentation for regulatory compliance.

Impact analysis

GIS software is currently used on JBLM to survey wildlife and archaeology, create land use layers for mapping topography, site areas for construction activities, and keep records of past actions and impacts. It has not been used in official capacity to model future conditions or compare ecosystem impacts across scenarios. Interview participants indicated an interest in using the InVEST models for this purpose. InVEST enables users to approximate the supply and value of ecosystem services and estimate changes to them under realistic management scenarios. Both the ED and ITAM might use these impact analyses to assess projects across future scenarios, identify conflicts with other programs, and formulate plans to sustain ecosystem benefits.

IMCOM and senior personnel can review these analyses in the revision of INRMPs and the evaluation of long-term projects.

Communication of results and planning

InVEST outputs may be shared among agencies involved in the management of resources at army installations (e.g., USFWS, State fish and wildlife agencies, partnering conservation organizations) and help mediate among competing objectives. InVEST may also improve the existing Land-Use Deconfliction Process (LUDP) at JBLM by providing a single-point software solution to produce the impact analyses in a spatially- explicit manner. A scenario- based approach using InVEST can cut the costs of ignored conflicts and identify ways to minimize impacts to the greatest number of resources.

InVEST outputs may also be useful in communications with the public. For example, army regulation requires the public's involvement in the preparation of Environmental Impact Statements (EISs) and strongly encourages it in more routine Environmental Assessments (EAs) (32 CFR § 651.47), necessitating the engagement of surrounding communities in the review of major projects. InVEST outputs can enhance the process of public review by providing clear, meaningful metrics of comparison among the resources that are expected to be impacted by an action. They can also facilitate communication among the army proponent preparing NEPA documentation and subject-area experts who review proposals.

Finally, InVEST outputs can be shown to the Sustainable Range Program, which may incorporate results into their budget proposal to Congress. InVEST can produce quantified measures of ecosystem services that may enhance the evaluation of budget priorities and support installation requests for budget modifications.

Regulatory Compliance

InVEST has potential to support defensible documentation justifying that adequate environmental analysis has been undertaken for regulation compliance. For example, NEPA requires agencies to document the direct, indirect, and cumulative impacts of a proposed major action (40CFR § 1508.8). Consistency in level of analysis and documentation is needed across resource areas, and InVEST models can provide a credible, science-based approach to achieve this standardization.

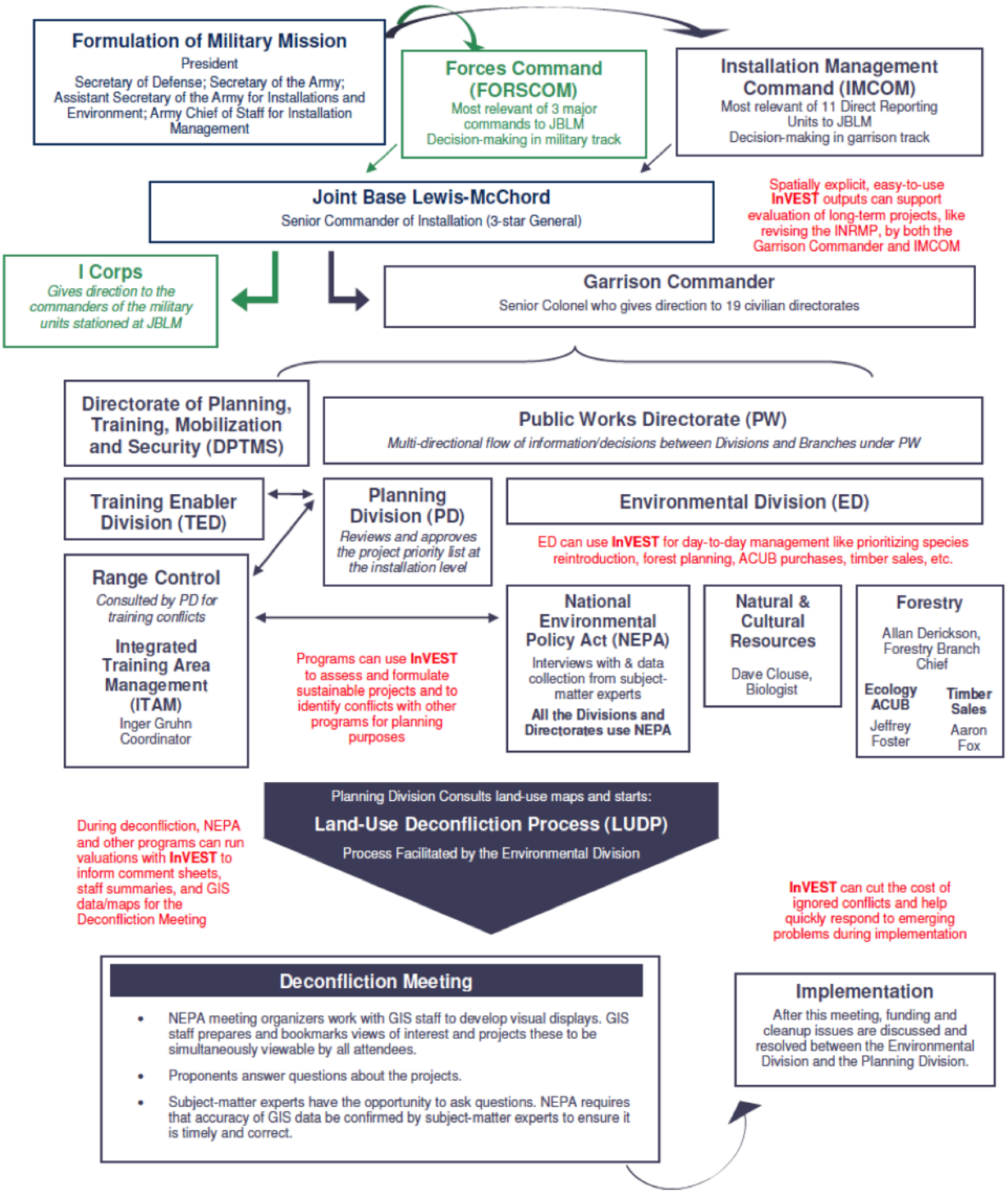


Figure 6.1.4. Joint Base Lewis-McChord Garrison Environmental Decision-Making and Potential Uses of InVEST. Green text indicates the military decision-making track. Dark purple text indicates the garrison decision-making track. Red text indicates potential use of InVEST. (Source: information collected from Joint Base Lewis-McChord personnel interviews)

In its guidance manual for Army NEPA practitioners, the CEQ published guidelines for enhancing cumulative impact analysis with the concept of Valued Environmental Components (VECs). The USAEC defines seven VECs applicable to cumulative impacts on Army ranges: air quality, air space, cultural resources, noise, soil erosion, threatened and endangered species, and wetlands (USAEC 2007). InVEST has the potential to be used in analyzing several of these VECs for NEPA documentation. For example, InVEST hydrology models including those analyzing sediment retention, water quality, and water yield, can be useful in modeling processes related to soil erosion, wetland resources, and water resources VECs. The InVEST Habitat Risk Assessment Model can assess the condition of the threatened and endangered species VEC within installations and in surrounding ACUB lands.

Finally, a scenario-based approach using InVEST can help fulfill NEPA's requirement to present alternatives for a proposed action, including comparison with an alternative of no action (i.e., a "Business As Usual" case). Running InVEST under different management conditions can help identify quantifiable target levels of ecosystem service provision and Draft an appropriate plan to maintain them.

Objective 11. Inclusion of ecosystem-services language in decision-making process.

While JBLM-specific documents do not explicitly refer to "ecosystem services", the term is employed in both army policy and DoD-wide instructions. Additionally, we explain below that the ecosystem-based management approach adopted by the DoD and employed at JBLM is highly compatible with the InVEST framework of ecosystem services.

DoD Instruction 4715.3 of 1996 first called for the integrated management of natural and cultural resources on DoD lands. In 2011, an update to this instruction (DoDI 4715.03) states it is DoD policy to "sustain the long-term ecological integrity of the resource base and the ecosystem services they provide" (DoD 2011). Additionally, a 2011 Army Environmental Policy Institute's (AEPI) Foresight Report concluded that the concept of ecosystem services and emerging valuation tools could help improve the implementation of the Integrated Natural Resource Management Plan (INRMP), the Range and Training Land Program, and the Compatible Use Buffer Program (AEPI 2011). Finally, some DoD environmental guidance documents are using the language of ecosystem services. A recent DoD manual on biodiversity conservation explicitly mentions the concept as a helpful emerging framework for management (Benton et al. 2012).

Considerations for ecosystem services (e.g., habitat, water provision and erosion control), while not explicitly termed as such, are reflected in installation INRMPs. INRMPs require installations to assess natural resources in context of the whole ecosystem; management objectives in each chapter are presented with cognizance of their impact to other aspects of the landscape and to military mission. InVEST models can facilitate the efficient planning and oversight of INRMP

projects when grouped within existing thematic management areas on installations, as proposed in the following table:

Table 6.1.4. Linking ecosystem services and InVEST models with DoD natural resource management themes

Management Theme*	**Ecosystem Service**	**InVEST models**
Forestry	Habitat provision for species at risk, Carbon Sequestration, Timber revenue	Management Timber Production, Carbon Storage and Sequestration, Habitat Risk Assessment (HRA)
Land Deconfliction	Habitat provision for training, Habitat provision for species at risk	Training Capacity Model, HRA
Soil Conservation	Erosion Control	Water Yield, Sediment Retention,
Freshwater Management	Clean Water Provision	Water Purification, Water Yield
Threatened & Endangered Species	Habitat provision for species at risk	HRA, Biodiversity
Prescribed Burning Management	Habitat provision for training, Habitat provision for species at risk	HRA, Biodiversity, Training Capacity Model

*drawn from demonstration-site installations' INRMPs (Fort Benning 2001, JBLM 2007, Fort Pickett 2007)

InVEST models offer an opportunity to consider multiple services within a management area, and analyze the overlap of services among existing thematically-defined or ecosystem-based management themes. For example, the ecosystem services of habitat provision for forest species, carbon sequestration, and revenue from timber yields could all be considered to inform an installation's forestry management objectives and planning. In addition, it is likely some of these services are also relevant to other installation management themes (e.g., the provision of habitat for the management of threatened and endangered species and fish and wildlife, or for distributing land uses among training and restoration areas). Managers can integrate an ecosystem services approach into existing installation management schemes as defined in the installation INRMPs (e.g., Fort Benning 2001, JBLM 2007, Fort Pickett 2007)

We can imagine a tiered application of InVEST models according to level of risk associated with a management decision. A model may be run according to the amount and quality of data needed, and the expertise required to calibrate the model. For example, a low-risk decision might be one related to anticipated regulation, or in a preliminary assessment of environmental impact (e.g., an EA under NEPA) when coarse-scale results are adequate for informing a report or a management action. High-risk decisions may be those for which immediate management of service tradeoffs is required to comply with current regulation, and those which require fine-

scale results and high-quality data (e.g. providing quantitative estimates of sediment loading to comply with TMDLs if implemented, or informing an expert's biological opinion on the state of a listed species' habitat). InVEST models are well-suited to accommodate these diverse applications.

Objective 12. Positive comments about ability of independent InVEST application.

Although we initially hoped JBLM personnel would be able to adopt the InVEST software by the end of the project, they were unable to apply InVEST independently and provide direct evaluation due to lack of GIS capacity in the JBLM Environmental Division and time constraints (see discussion of cost drivers, implementation issues, and technical requirements in Sections 7.2, 8.1, and 8.3). However, participants in the final workshop (August 22, 2012) offered positive feedback from base personnel on the collaborative process of scenario development and the spatial analysis of ecosystem service tradeoffs. The functionality of InVEST and the scenario-development approach seems novel and useful to JBLM staff. ITAM representatives suggested that InVEST would be helpful to Range Control in planning sustainable training practices. In interviews with JBLM personnel, a respondent suggested that InVEST outputs would likely be useful to the NEPA process. Another respondent discussed the value in our approach to early scenario development planning, which involved identifying the resources of importance at JBLM. Preliminary strategic thinking was perceived as useful to tailoring projects to explore only those scenarios most relevant to the decision context. Finally, respondents indicated the spatially-explicit visualization of ecosystem service changes over time as a helpful method to compare and discuss management options.

6.1.5 Summary and discussion

We tailored an ecosystem service approach to management of DoD lands and demonstrated its use at JBLM by evaluating five ecosystem services (i.e., infantry training capacity, vehicle training capacity, Puget Sound Prairie sustainability, timber production, and carbon sequestration) and their interrelationships under alternative future scenarios.
Our aggregate ecosystem service analysis illustrates potential consequences of training and budgetary variations, and can aid installation commanders in evaluating training and budget priorities and justifying requests for modification. Information describing varied sets of ecosystem services may lead to different decisions. Based on our analysis, if we consider only those ecosystem benefits directly supporting the military mission and compliance with environmental regulation, budget increase for resource management has a greater effect than changes in training intensity for maintaining current levels of ecosystem services. However, if indirect links of ecosystem service changes to mission are considered (e.g., potential regulation of greenhouse gas emissions, emerging carbon markets, and revenues from timber production), both training activities and budget for resource management could be advantageously used to

maintain current levels of ecosystem benefits.

In addition, spatially-explicit representations of ecosystem services could support details of resource management on the ground. At JBLM, our analysis identifies priority areas for sustaining current levels of ecosystem services and areas that might be targeted to improve service provision by shifting management funds to those areas and/or shifting some training activities to other areas. For example, three centrally located training/impact areas with a mixed cover of forest and grassland are likely to maintain supply of multiple services if they are consistently monitored and managed over time (Figure 6.1.3.2 B). The large grassland area in the east region is a reasonable target for improvement, as it can provide a higher proportional increase in both area sustaining Puget Sound Prairie and training capacity with increased resource management budget and decreased training intensity (Figure 6.1.3.2 C). This scenario-based approach can potentially support development of reasonable alternatives for proposed actions under the National Environmental Policy Act, in negotiating shared objectives with community partners for buffer zone management, and in facilitating communication among different base divisions when discussing conflicting land uses.

There are clear tradeoffs between training intensity and forest-related services, and a strong correlation between a reduced budget and decreased vehicle training capacity. Thus, management plans can be developed proactively to safeguard priority services when facing budget changes or shifts in military training goals. Our results also indicate weak tradeoffs between policy drivers and provision of Puget Sound Prairie sustainability. Impacts imposed by one policy driver (e.g., increased training intensity) can be mostly offset with complementary change in the other driver (e.g., higher budget). The spatial distribution of low-risk area sustaining Puget Sound Prairie indicates a synergy between artillery training and this rare ecosystem. Similar synergies between training activities and fire-dependent ecosystems have been described on other military installations as well (Warren et al. 2007, Stein et al. 2008). Together, spatial overlap of ecosystem services in their provision and improvement potential suggest multiple services can be secured or improved with efficiency.

6.2 FORT PICKETT

This section presents the assessment results for our demonstration at Fort Pickett.

6.2.1 Summary of scenarios

Objective 7: Convert alternative management scenarios into realistic alternative LULC maps

ESTCP expressed interest in applying NatCap's ecosystem service approach and InVEST at multiple scales to demonstrate the flexibility of the InVEST models and approach. Thus, we designed the demonstration at Fort Pickett to highlight a simpler application, and focused on the management question of how to site new training ranges within the installation. In consultation with base personnel and the Headquarter Integrated Training Area Management (ITAM) manager, we identified siting a potential new firing range as a focal question, and used the 35-acre FCC 17809 Qualification Training Range as a prototype in our analysis (HQDA 2010). A standard DoD qualification range measures approximately 480 meters in width and 500 meters in length (Figure 6.2.1.1), and new ranges could be located and oriented around the Non-Dudded Impact Area.

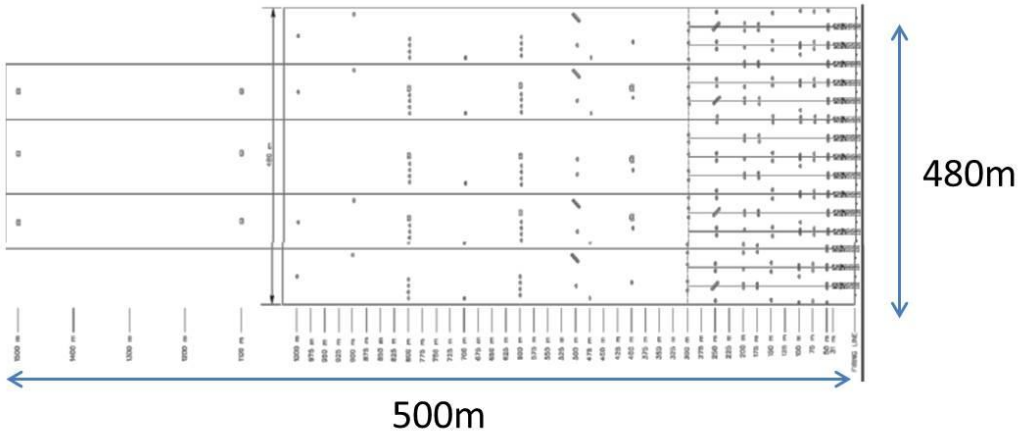


Figure 6.2.1.1. FCC 17809 Qualification Training Range dimensions and footprint (HQDA 2010).

We originally sited 28 potential areas for new training ranges using the training range footprint and guidelines for orienting potential ranges towards the impact area (Figure 6.2.1.2). Following consultation with Fort Pickett personnel regarding the feasibility of the placement for the 28 potential locations, we then narrowed potential locations to 9 to avoid proximity to the Dudded Impact Area or waterways (Figure 6.2.1.3). Each of the 9 potential training range areas were then treated as separate siting scenarios, and we converted the land use/land cover (with the exception of water or wetland areas) within the training range footprint to grassland to mimic the

land conditions of the training range for each scenario. We compared the tradeoffs in provision of carbon sequestration, biodiversity, and sediment retention to inform siting of a new training range.

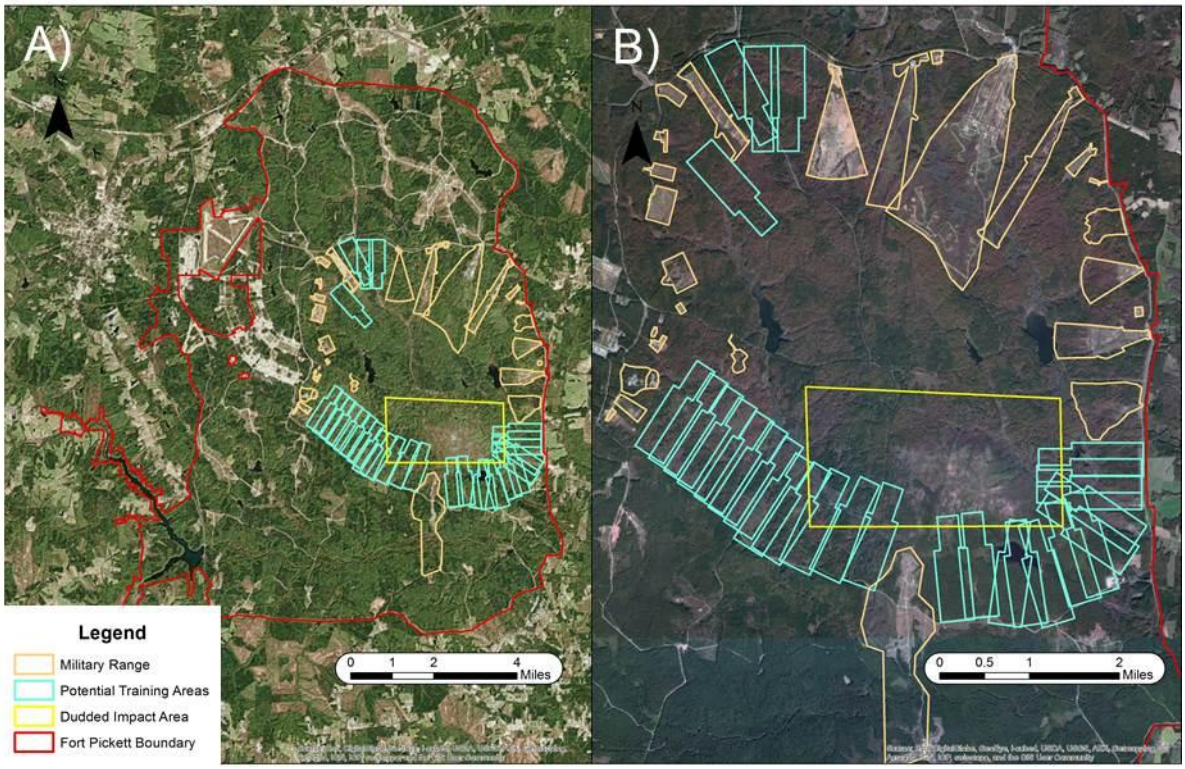


Figure 6.2.1.2. A) Preliminary siting locations of 28 potential training ranges at Fort Pickett, VA and B) Inset map of Impact Area showing preliminary siting of 28 potential training ranges relative to the Dudded Impact Area (within yellow box).

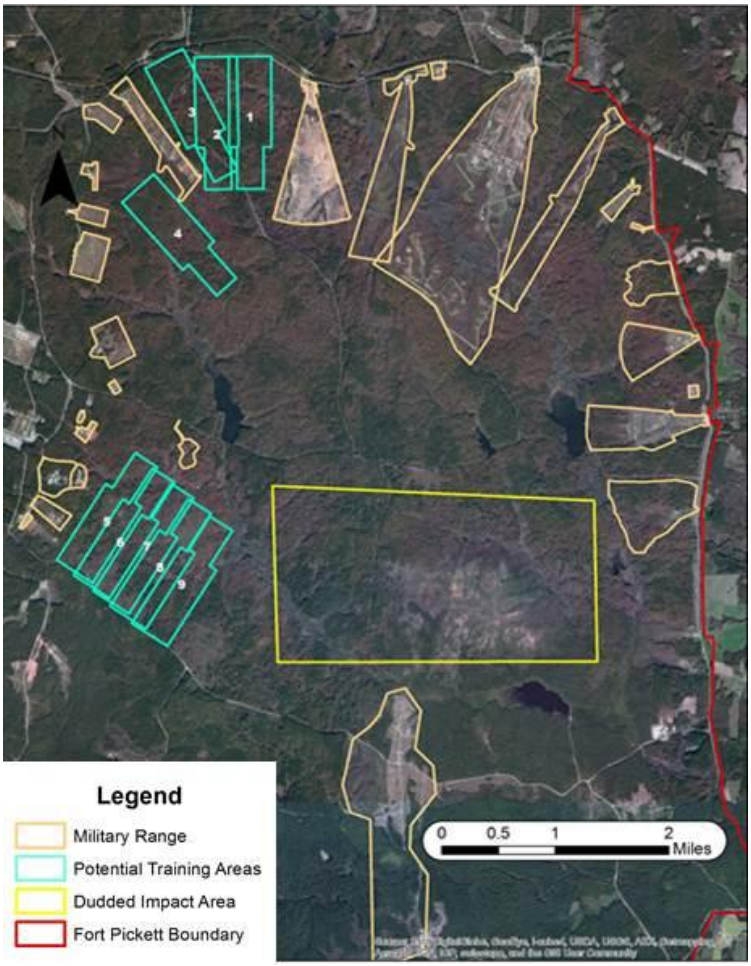


Figure 6.2.1.3. Final siting locations of 9 potential training ranges at Fort Pickett, VA.

6.2.2 Quantification, valuation and mapping of individual ecosystem services

This section presents our assessments of the following objectives:

Objective 1: Quantify provision of ecosystem services using existing GIS data
Objective 3: Provide spatially-explicit rendering of service provision
Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

These objectives are assessed together for each ecosystem service as they are closely related. In each of the sub-sections below, we first describe the model inputs and assumptions supporting data analyses for these objectives, and then provide the analysis results for baseline and alternative siting scenarios. Because our demonstration at Fort Pickett is a simpler application at reduced scale, we did not assess Objectives 2, 4, 5, and 6 due to insufficient data.

We modeled three services identified as priorities for Fort Pickett: carbon sequestration, biodiversity, and sediment retention. Potential regulation of carbon sequestration on public lands drives DoD to consider how their management affects carbon dynamics. Conservation of biodiversity is also an important component of the DoD's ecological forestry initiative, which emphasizes managing forests for services in addition to timber production. Fort Pickett has a number of species at risk (e.g., Michaux's sumac, bald eagle, Bachman's sparrow, and Roanoke logperch) that require additional attention in impact assessments for new projects. Sedimentation resulting from training activities is the primary water quality problem at Fort Pickett. The installation is challenged to effectively control soil disturbance from maneuver training and reduce sediment entering the Nottoway River watershed, which supports diverse and unique biological and cultural resources. Carbon sequestration, biodiversity, and sediment retention are interconnected via their dependence on LULC, providing an opportunity to observe tradeoffs and synergies among services and biodiversity that can inform management decisions.

- **Carbon storage and sequestration**

<u>Model inputs and assumptions</u>

We applied the InVEST Carbon Storage and Sequestration model to map, quantify, and value aboveground and belowground carbon biomass stored within Fort Pickett for siting alternative training ranges. We did not assess carbon stored in soil, dead organic matter, or harvested wood products because site-specific data are lacking. We calculated carbon sequestration for each of the 9 alternative training range scenarios using 2013 land use/land cover (LULC) for Fort Pickett as the baseline for comparison. For scenarios, we assume the LULC (with the exception of water or wetland areas) within the training range footprint will be converted to grassland to mimic the

land conditions of the training range.

For Fort Pickett, we derived carbon values for LULC classes using the National Biomass and Carbon Dataset (NBCD; Kellndorfer et al. 2000). The NBCD is a 30-m resolution raster that depicts aboveground biomass (Mg/ha) for tree species within the contiguous U.S. for the year 2000. We calculated aboveground biomass by aggregating vegetation types from the 2013 Fort Pickett LULC into structural classes and averaging the NBCD biomass values for each structural class. We converted mean values to carbon (Mg/ha) for LULC classes (Table 6.2.2.1). Since the NBCD only provides values for tree and some shrub species, we used an aboveground biomass value of 2.7 Mg/ha for grassland (warm temperate grassland) based on available scientific literature (IPCC 2006). We converted mean aboveground biomass to carbon storage (Mg/ha) by multiplying the aboveground biomass value by 0.5 (IPCC 2006). We calculated belowground carbon storage by multiplying aboveground carbon by a root to shoot ratio of 0.3 for temperate forest species and 4.0 for grassland species (IPCC 2006).

Table 6.2.2.1. Mean values for Land Use and Land Cover (LULC) structural classes and types at Fort Pickett, VA, derived from the National Biomass and Carbon Dataset (NBCD) and Intergovernmental Panel on Climate Change (IPCC) root-to-shoot ratios.

LULC Type	Aboveground C (Mg/ha)	Belowground C (Mg/ha)
Agricultural Field Planted Herbaceous Alliance	1.4	5.6
Bottomland Mixed Hardwood Temporarily Flooded Forest Complex	66.2	19.9
Bottomland Mixed Hardwood Temporarily Flooded Woodland Complex	57.0	17.1
Broomsedge Bluestem Herbaceous Alliance	1.4	5.6
Common Buttonbush Seasonally Flooded Shrubland Alliance	47.3	14.2
Common Buttonbush Semipermanently Flooded Shrubland Alliance	51.2	15.4
Flooded Herbaceous Alliance	0.0	0.0
Loblolly Pine - (White Oak, Southern Red Oak, Post Oak) Forest Alliance	67.3	20.2
Loblolly Pine - (White Oak, Southern Red Oak, Post Oak) Woodland Alliance	45.0	13.5
Loblolly Pine - Tuliptree Temporarily Flooded Forest Alliance	68.7	20.6
Loblolly Pine Forest Alliance	67.9	20.4
Loblolly Pine Planted Forest Alliance	63.3	19.0
Loblolly Pine Woodland Alliance	53.4	16.0
Non-Agriculture Disturbed Areas Sparsely Vegetated Alliance	0.0	0.0
Non-Vegetated Land	0.0	0.0
Paved Roads or Buildings	0.0	0.0
Sweetgum - (Tuliptree, Red Maple) Temporarily Flooded Shrubland Alliance	72.0	21.6
Sweetgum Shrubland Alliance	58.0	17.4
Unpaved Roads	0.0	0.0
Upland Mixed Hardwood Forest Complex	68.4	20.5
Upland Mixed Hardwood Woodland Complex	47.7	14.3
Urban	0.0	0.0
Water	0.0	0.0

Results

Carbon stock for the baseline scenario ranges from 0.0 Mg for bare ground in the Dudded Impact Area to 0.96 Mg per 100m^2 pixel for forested areas (Figure 6.2.2.1). All nine training locations resulted in a loss of carbon, ranging from a loss of 3,070 to 5,110 Mg carbon (Table 6.2.2.2). Potential training ranges 1, 2, 3, 4, and 9 resulted in the greatest loss of C (>0.40% carbon loss across Fort Pickett) because these ranges initially had higher forest cover that was converted to grassland under the training range scenarios. We classified the ranges into low, medium, and high tiers based on the change in their C ecosystem service values, and produced a map showing the provision of carbon sequestration resulting from siting a new range in each location (Figure 6.2.2.2). Results suggest that potential training ranges 6, 7, and 8 may be best for siting to minimize carbon loss. Although percent carbon loss from the baseline seems relatively small (ranging from 0.26%-0.46%), the 35 acre footprint of a new training range only accounts for 0.08% of the total area of Fort Pickett (45,148 acres). The cumulative effects of changing land management decisions on Ft. Pickett could add up to significant overall changes in carbon storage and sequestration services.

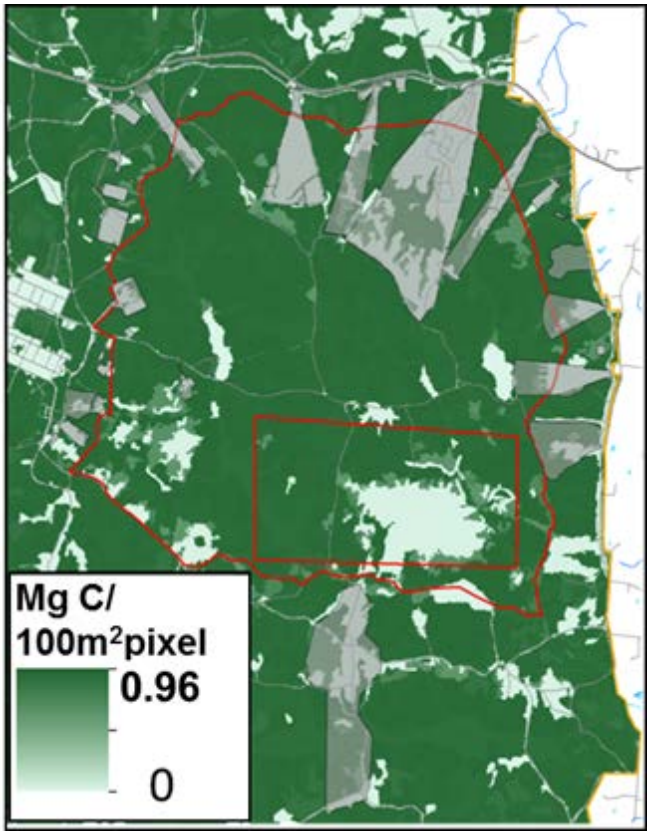


Figure 6.2.2.1. Carbon storage (Mg) for Impact Areas under the baseline scenario at Fort Pickett, VA. The area enclosed in the outer red polygon represents the Non-Dudded Impact Area, and the inner red rectangle represents the Dudded Impact Area.

Table 6.2.2.2. Summary of carbon metrics from the InVEST Carbon Storage and Sequestration Model for nine training range siting scenarios at Fort Pickett, VA.

Scenario	Carbon storage-installation total (Mg)	Carbon loss from baseline (Mg)	Carbon loss from baseline (%)	Rank (carbon loss)
baseline	1,180,480	-	-	-
1	1,175,380	5,100	0.43%	7
2	1,175,370	5,110	0.43%	8
3	1,175,470	5,010	0.42%	6
4	1,175,010	5,470	0.46%	9
5	1,176,590	3,890	0.33%	4
6	1,176,810	3,670	0.31%	3
7	1,176,880	3,600	0.30%	2
8	1,177,410	3,070	0.26%	1
9	1,175,810	4,670	0.40%	5

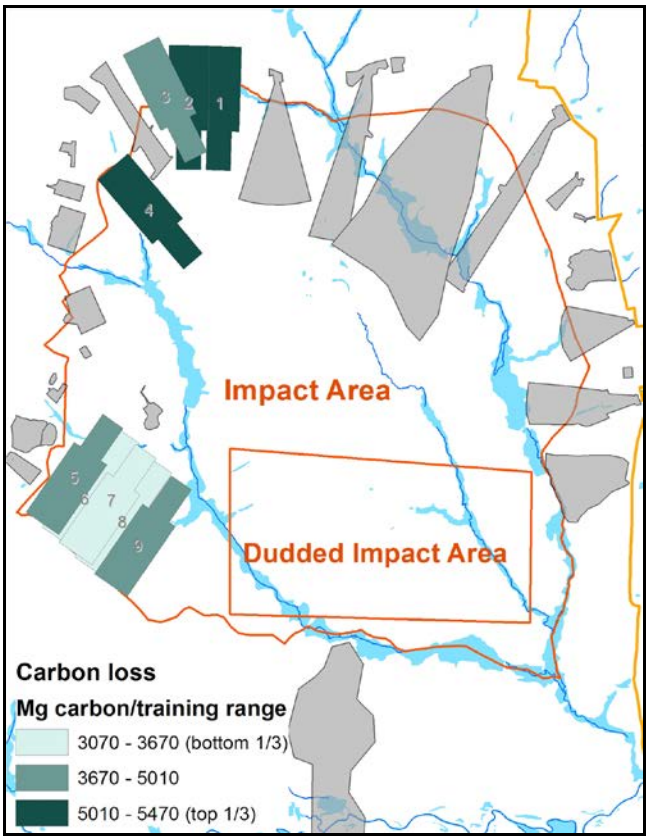


Figure 6.2.2.2. Categorical loss in carbon sequestration from baseline conditions for nine training range scenarios at Fort Pickett, VA. Light green indicates lower 1/3 of carbon loss; dark green indicates highest grouping of carbon loss.

- **Biodiversity**

<u>Model inputs and assumptions</u>

We applied the GLOBIO3 model (Alkamade et al. 2009) to map, quantify, and value biodiversity changes within Fort Pickett under alternative siting scenarios for training ranges. GLOBIO3 provides a proxy for biodiversity by calculating mean species abundance (MSA; see section 5.3.7.2 above for model details), and ESTCP expressed interest in integrating models outside of InVEST into our ecosystem service approach to demonstrate its flexibility. For this application, we ignore the nitrogen deposition and climate change terms in GLOBIO3, since both would not vary much at this scale and therefore show no change in ecosystem service among scenarios. We used the coefficients from Table 6.2.2.3 to calculate the MSA scores. The land use/land cover (LULC) term ($MSA_{(LULC)}$) is based on the LULC maps for each scenario and represents MSA by accounting for age and structural class of the LULC habitat. For this term, we assume all forests are categorized as lightly used natural forest, shrublands as primary vegetation, and training range grasslands as man-made pastures. GLOBIO's infrastructure term ($MSA_{(I)}$) term accounts for edge effects from man-made structures and indicates that biodiversity will decrease with proximity to such structures. We calculated distance to road and urban areas in GIS for woody and grassland cover types and apply the mean species coefficients for infrastructure ($MSA_{(I)}$). Finally, we aggregated all anthropogenic LULC types and all vegetated cover types using ArcGIS to calculate the area of the continuous vegetated patches. From this area, we applied GLOBIO's fragmentation term ($MSA_{(F)}$), which indicates that larger patches of continuous vegetation will support more species. We then use GIS to multiply the $MSA_{(LULC)}$, $MSA_{(I)}$, and $MSA_{(F)}$ together to derive a final value for MSA.

<u>Results</u>

Mean species abundance for each of the 9 alternative training range scenarios was calculated using the 2013 as the baseline for comparison (Figure 6.2.2.3). Mean Species Abundance (MSA) across the base ranged from 0.0 (urban/built up areas) to 0.54 (fragmented forested areas). The values are largely affected by the roads and training ranges throughout the base, which contribute to the distance to infrastructure and fragmentation factors in the MSA calculation.

Results suggest that MSA is not largely affected by siting training ranges, most likely due to the small area required for conversion. All nine training locations resulted in a very small loss of MSA, ranging from a loss of 0.009 to 0.0012 (Table 6.2.2.4).We divided the ranges into low, medium, and high classes based on the change in MSA values, and Fig. 6.2.2.4 shows the resulting provision of biodiversity for each potential range site. Potential training ranges 3, 5, and

8 resulted in the lowest percent loss from the baseline (<0.40% loss in MSA), and training areas 1, 4, and 9 resulted in the highest percent loss of species. Although forest conversion to grassland decreases the $MSA_{(LULC)}$ from 0.7 to 0.1; decreases in patch size due to fragmentation also substantially decrease overall MSA. These results suggest that orientation and location of potential training ranges across the landscape are important factors to consider in minimizing edge effects and reducing loss of biodiversity.

Table 6.2.2.3. GLOBIO3 model coefficients used for Fort Pickett, VA.

Land Use Land Cover	$MSA_{(LULC)}$
Artifical areas	0.05
Forest (lightly used)	0.70
Man-made grasslands	0.10
Shrubland	1.00
Distance to roads/urban (km)	$MSA_{(I)}$
0.0-0.25 (Woody)	0.40
0.25-1.25 (Woody)	0.80
1.25-4.0 (Woody)	0.90
>4.0 (Woody)	1.00
0.0-0.5 (Grassland)	0.40
0.5-2.0 (Grassland)	0.80
2.0-7.0 (Grassland)	0.90
>7.0 (Grassland)	1.00
Area (km^2)	$MSA_{(F)}$
<1	0.30
<10	0.60
<100	0.70
<1,000	0.90
<10,000	0.95
>10,000	1.00

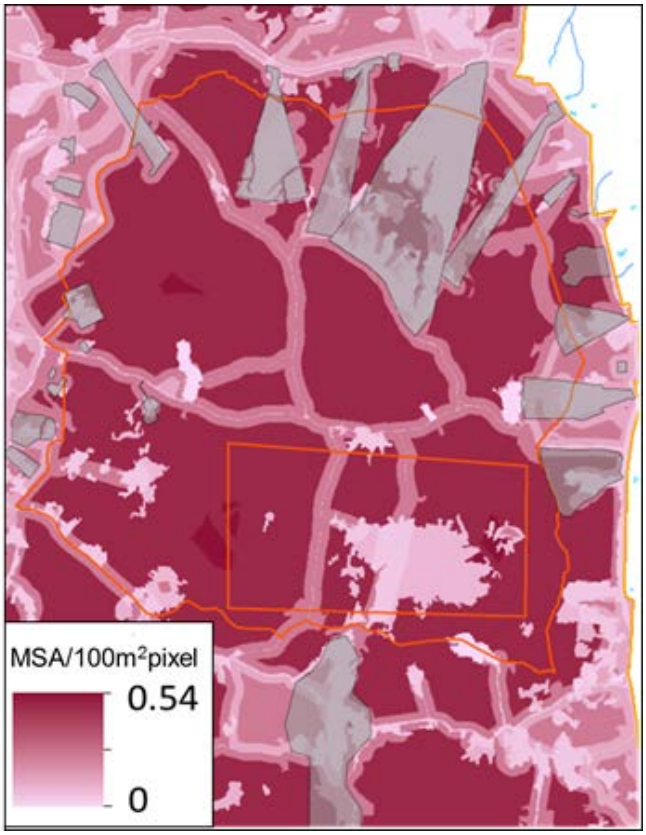


Figure 6.2.2.3. Biodiversity metrics (MSA; mean species abundance) for Impact Areas under the baseline scenario at Fort Pickett, VA. The area enclosed in the outer red polygon represents the non- Dudded Impact Area, and the inner red rectangle represents the Dudded Impact Area.

Table 6.2.2.4. Summary of biodiversity metrics (MSA; mean species abundance) for nine training range scenarios at Fort Pickett, VA.

Scenario	Biodiversity score-installtion total (mean species abundance/MSA)	Biodiversity loss from baseline (MSA)	Biodiversity loss from baseline (%)	Rank (biodiversity loss)
baseline	0.2734	-	-	-
1	0.2721	0.0013	0.48%	8
2	0.2721	0.0012	0.45%	6
3	0.2725	0.0009	0.33%	2
4	0.2720	0.0014	0.52%	9
5	0.2723	0.0011	0.40%	4
6	0.2722	0.0012	0.45%	5
7	0.2723	0.0010	0.38%	3
8	0.2725	0.0009	0.33%	1
9	0.2721	0.0013	0.46%	7

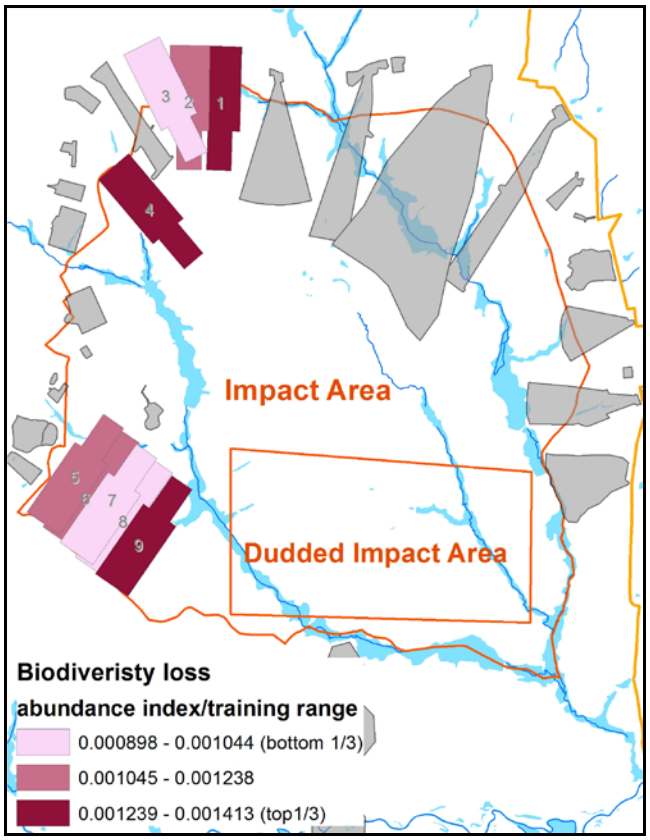


Figure 6.2.2.4. Impact on biodiversity (MSA; mean species abundance) for nine training range scenarios at Fort Pickett, VA. Light pink indicates lower 1/3 of biodiversity loss; dark red indicates highest grouping of biodiversity loss.

- **Sediment retention**

<u>Model inputs and assumptions</u>

Sediment retention by natural vegetation was the third vital ecosystem service examined for evaluating the potential impacts of military training at Fort Pickett. Disturbance caused by military training is not randomly distributed and is often concentrated in areas based on the type of training being conducted (Fort Pickett 2011). Because of the varied nature of military training, some military activities (e.g., scape and evasion, infiltration, reconnaissance) may cause less damage to the soil and vegetation cover, while other activities such as vehicle maneuver, demolition trainings, and field fortification may have a massive impact on the landscape, leading to greater loss of soil erosion, especially as training frequency and intensity increase. For sediment export, however, the overall degree of military impacts is determined not only by training type, frequency, and intensity, but also by numerous factors that control connectivity of sediment pathways to a river, including climate, proximity to river and/or water bodies, soil type,

topography, vegetation type, and density. To effectively evaluate the impacts of military activities, it is important to understand and explicitly quantify the pathways and sinks associated with sediment transport. As is briefly described in Section 5.3, InVEST calculates the average annual soil loss from each parcel of land using the USLE and then based on LULC retention efficiencies, it quantifies how much of that soil arrive to the nearest stream segment and how much is retained along the flow path by the landscape.

First, this study analyzes how naturally occurring and military influences, such as vehicle maneuver, road construction, and vegetation/soil disturbance on steep slopes, are reflected in the amount of soil erosion and sediment export and retention within the watershed of Fort Pickett. The spatial distribution of these processes is presented in Figure 6.2.2.5. The model was not calibrated due to lack of measured data in vicinity of the installation. However, to ensure that the model captures the impacts of military activities (e.g., vehicle maneuver, demolition training, artillery firing, roads, etc.), model parameters related to vegetation and soils are adjusted with values recommended by other researchers (e.g., Fort Pickett 2006). Qualitatively, the degree of impacts caused by military training and land use activities are generally categorized into *low* and *high* in Fort Pickett's final INRMP report. As is the case for all modeling exercise, we used simplifying assumptions based on expert opinion to incorporate these qualitative measures into our model. Initially, a 20% reduction in vegetation cover (i.e., crop factor) was assumed for low impact (e.g., firing range) and up to 60% loss of vegetation cover was considered for high impact activities (e.g., vehicle maneuver area). The soil erodibility factor was also assumed to increase by 30% for the high impact activities (Table 6.2.2.5). These assumptions were adjusted by comparing the simulated soil erosion with recommended soil erosion rates for various land use types (Donigian 2013).

Table 6.2.2.5. Military training types and their estimated impact on soil erosion and sediment export at Fort Pickett, VA.

	Military training type	**Impacts**
Low Impact area	Existing firing ranges	-20% crop factor, -20% retention capacity
High Impact area	TA 15 MPRC, TA 16 IPBC, maneuver corridors, open grasslands, and grasslands in High Hazard Impact Area	-60% crop factor, -60% retention capacity, +30% erodibility
Forest maneuver area	Forest stands thinned for vehicle maneuver training	-60% crop factor, -60% retention capacity, +30% erodibility

Results

For the baseline condition at watershed scale, the mean erosion rate was estimated at 0.3 tons/ac/year (Figure 6.2.2.5). However, there exists a large variation in erosion rates among various land use units across the landscape. The impact zone and the off-installation agricultural areas, not surprisingly, are hot spots for erosion. Apparently, clearance/replacement of natural vegetation compounded with increased soil disturbance is the major cause for high range soil loss in these areas. Because of riparian buffers and dense vegetation cover along streams, most eroded soils were intercepted by different types of ecosystems in the process of sediment delivery along flow paths within the watershed. Basin wide average sediment export is estimated at 0.12 tons/ac/year and this attributed to the high retention efficiency of natural vegetation to control sediments exported from uplands. Only 9% of the total eroded soils are estimated to arrive into the streams, and the watershed can be regarded as sink for sediment. Most of the large sediment exports are coming from areas that are directly connected to receiving rivers with sparse vegetation cover (Figure 6.2.2.5).

It is important to note that InVEST has the tendency to under-estimate sediment export due to inability to fully account for sediment transport processes. Although our analysis indicates that the sediment export in the base was relatively small when viewed and analyzed at the overall watershed scale, there might be more significant impacts at finer scales.

Next, we applied the InVEST sediment model to investigate the expected footprint of the 9 alternative locations of a new training range and to identify locations that would need more attention to prevent deleterious environmental impacts. To demonstrate the usefulness of InVEST for such assessment, the contributions to soil erosion and sediment export from each location were tracked and for ease of comparison, the outputs are classified into thirds: dark brown or dark blue (top 1/3), orange or sky blue (middle 1/3) and yellow or light blue (bottom 1/3) in decreasing order as shown in Figure 6.2.2.6. The increase in soil erosion due to conversion of each of these 9 locations to a firing range, relative to the baseline, generally ranges from 0.5-5% tons/ac/year. The large increase in soil erosion for some locations is attributed to the replacement of natural dense vegetation with bare soil (Table 6.2.2.6, ranges 1, 2, and 3). Our analysis emphasizes the relative increase of sediment export to receiving water bodies due to creation of a training range. For soil erosion, locations 1, 2, and 3 displayed the highest soil erosion, ranging between 134-169 tons/year, while locations 2, 3, and 5 are found to be critical areas that export between 44-76 tons/year to receiving water bodies. Soil erosion from location 5 was the lowest (72 tons/year), but its exporting rate to the nearest river was the second highest (68 tons/year), indicating 95% of its erosion was transported into the river system. Range 4 produced less soil erosion (80 tons/year) and exhibited the lowest sediment export (only 4%). There are multiple factors that explain the occurrence of high soil erosion but low sediment export for the same range. The primary factors include the relatively long flow path to a

receiving river and the high retention by riparian vegetation that removes some fraction of sediment that may otherwise be transported to receiving rivers.

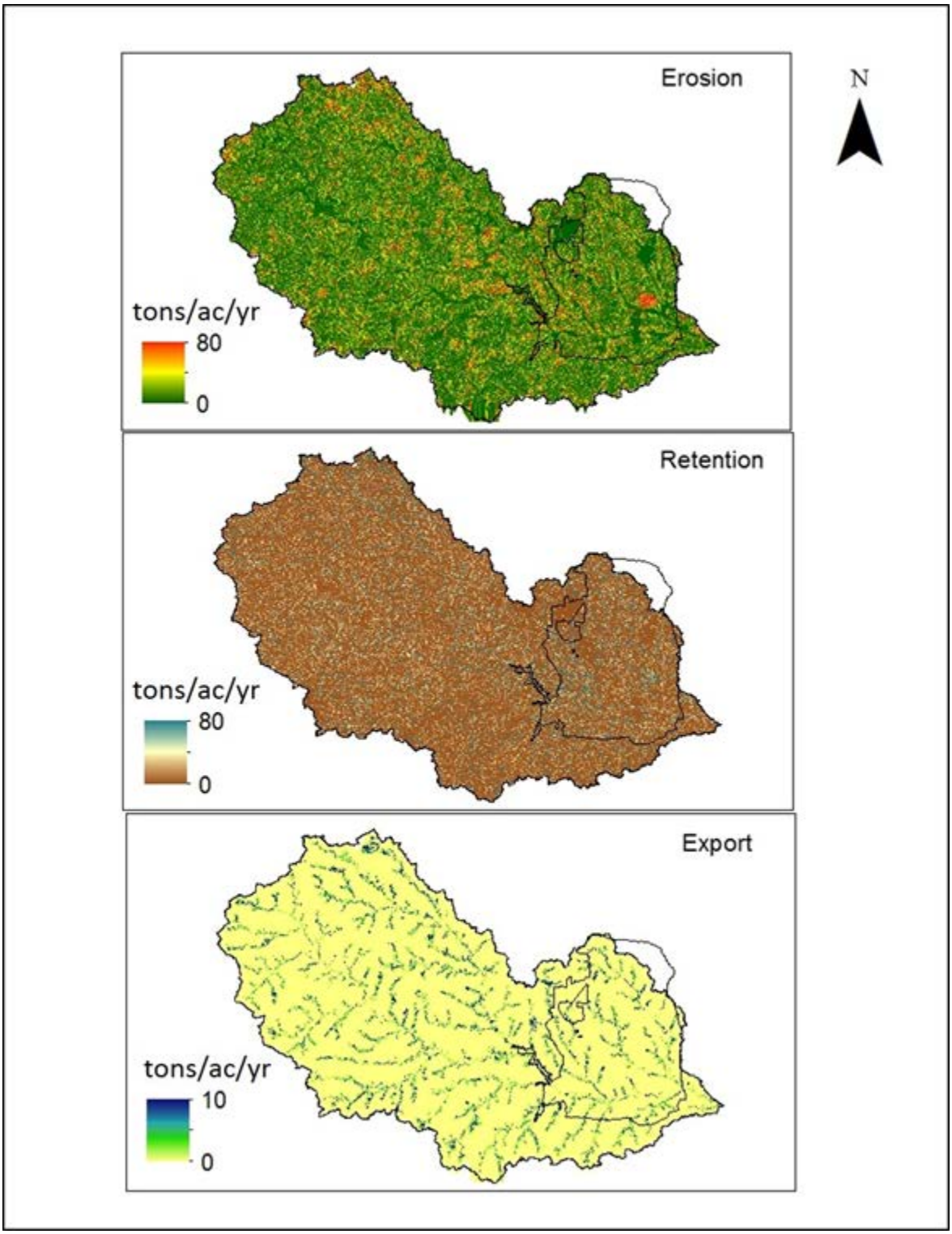


Figure 6.2.2.5. Soil erosion, sediment retention and export simulated by the INVEST Sediment Retention Model on the watershed in Fort Pickett, VA.

Figure 6.2.2.5. Soil erosion, sediment retention and export simulated by the INVEST Sediment Retention Model on the watershed in Fort Pickett, VA.

Scenarios	Soil Erosion-watershed total (ton/year)	Additional soil erosion from baseline (ton/year)	Additional soil erosion from baseline (%)	Normalized soil erosion	Rank
Baseline	412103				
1	412237	134.3	0.03%	0.639	7
2	412256	153.5	0.04%	0.837	8
3	412272	169.4	0.04%	1.000	9
4	412183	80.1	0.02%	0.083	2
5	412175	72.0	0.02%	0.000	1
6	412185	82.2	0.02%	0.104	3
7	412220	117.4	0.03%	0.466	6
8	412205	102.1	0.02%	0.309	5
9	412199	96.8	0.02%	0.254	4
Scenarios	**Sediment Export-watershed total (ton/year)**	**Additional sediment export from baseline (ton/year)**	**Additional sediment export from baseline (%)**	**Normalized sediment export**	**Rank**
Baseline	28743				
1	28779	35.9	0.12%	0.442	5
2	28819	76.1	0.26%	1.000	9
3	28787	44.1	0.15%	0.556	7
4	28747	4.0	0.01%	0.000	1
5	28811	68.4	0.24%	0.893	8
6	28757	13.8	0.05%	0.136	2
7	28764	21.4	0.07%	0.241	4
8	28764	20.8	0.07%	0.233	3
9	28781	38.2	0.13%	0.475	6

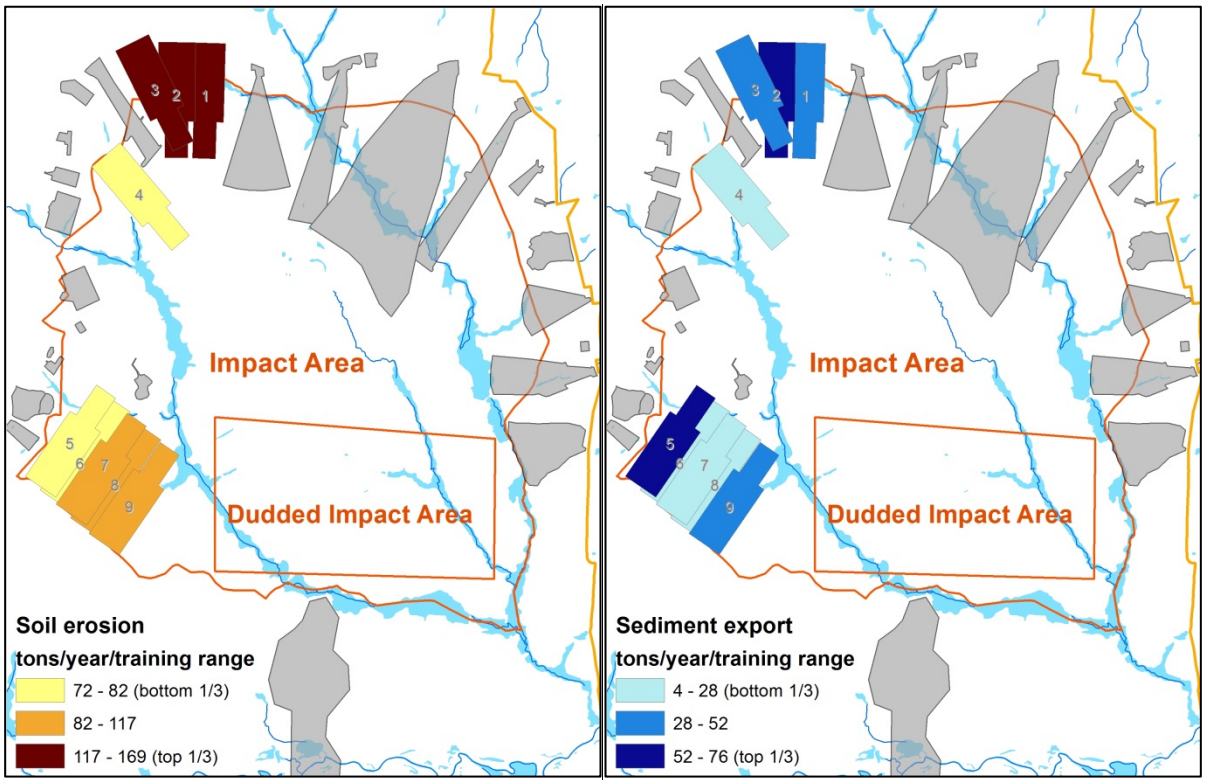


Figure 6.2.2.6. Soil erosion and sediment export simulated by the InVEST Sediment Retention Model for nine alternative range locations at Fort Pickett, VA.

Such simple depictions can easily inform installation managers about the consequences of choices on sustaining natural resources for preventing soil erosion and river sedimentation. The most important feature of using the InVEST sediment model as a decision support tool is not only the ability to identify sources of soil erosion and sediment depositions, but also the ability to provide information vital to managing trade-offs between scenarios, as demonstrated here. One might use these location scenarios to: (1) identify and avoid areas of sediment hot spots (e.g., range 9) that have high footprints to receiving water bodies and other ecosystem services, (2) establish a reasonable balance between the suitability of locations for a firing range and maintaining the underlying ecological functions that support biodiversity and key freshwater ecosystem services, and (3) determine the value lost to society from bringing a firing range to ecologically sensitive areas.

6.2.3 Tradeoff and synergy analysis

Objective 9: Use service maps to evaluate multi-service impacts of alternative management options for at least two services

In previous sections, we evaluated the ecosystem impacts on biodiversity, carbon storage and sediment export under the baseline and nine alternative scenarios, which represent potential siting choices for a new training range. We calculated the losses of ecosystem benefits from creating the new training range as the difference between each alternative scenario and the baseline (Table 6.2.3.1). In this section, we demonstrate how the impacts from alternative locations might be compared and aggregated to inform decisions.

A simple way to compare ecosystem impacts is to categorize the potential siting choices based on the absolute losses from creating the new training range. For each of the three ecosystem impacts, we divided nine potential locations into three categories representing high, medium, and low loss as shown in Figure 6.2.3.1. Darker color indicates higher loss in ecosystem services and thus a less desirable siting choice. As explained in previous sections, carbon storage and biodiversity losses are mostly affected by the baseline land use/land cover within alternative locations. Converting areas covered largely by forestland to open grasslands for training would result in higher loss in carbon biomass and species habitat (e.g., locations #1, #2, #4, and #9). Alternative locations contributing more to sediment export are often close to rivers or streams because of insufficient vegetation buffer to capture the soil erosion (e.g., locations #1, #2, #5, and #9). Some areas with large on-site soil erosion can result in relatively small sediment impacts if they are far from river networks (e.g., locations #7 and #8).

To compare different ecosystem service losses at a consistent scale, we further normalized them into a 0-1 index, where 0 represents the lowest loss among all siting choices and 1 represents the highest (Table 6.2.3.2, Figure 6.2.3.3). Putting all services together, we can readily identify the impacts from potential locations. For example, location #8 leads to low losses in all three services and locations #2 and #9 results in high losses overall (Figure 6.2.3.2). This Figure also shows the high correlation between carbon storage and biodiversity in most locations (#1, #4, #5, #8, and #9), as the baseline land use/land cover primarily affects both services.

To inform site selection decisions, the results of ecosystem service impacts can be aggregated in a way that makes most sense to decision makers. For example, if sediment erosion is the major concern for resource management due to regulation compliance, the best location(s) can be determined by following the sediment export results or by assigning a higher weight on sediment than others. Based on discussion with Fort Pickett personnel, we assigned equal weights to all three services to derive the aggregate results for the demonstration. We ranked the potential locations based on the sum of normalized scores in biodiversity, carbon storage, and sediment export, where higher scores represent higher losses (Table 6.2.3.1). Figure 6.2.3.3 clearly shows

the ecological suitability of alternative locations based on three equal intervals of the aggregate scores. Sites in red (#1, #2, #4, and #9) indicate high ecosystem service loss or low ecological suitability for siting the new training range. Among these four locations, #2 and #9 show high losses in all three services, while #1 and #4 exhibit high losses in two out of three services. Locations most suitable for siting appear to cluster in the southwest region of the impact area (#6, #7, and #8 in green), where the baseline landscape has relatively large patches of grasslands and minimal interaction with the water network.

Table 6.2.3.1. Summary of ecosystem impacts under different scenarios at Fort Pickett, VA.

Scenario (Training range location ID)	Biodiversity		Carbon storage		Sediment export		Aggregate	
	Loss from baseline (Mean Species Abundance)	Normalized loss	Loss from baseline (Mg)	Normalized loss	Increase from baseline (ton)	Normalized increase	Sum of normalized change (equal weights)	Ranking
1	0.00131	0.81	5100	0.85	35.9	0.44	2.10	8
2	0.00124	0.66	5110	0.85	76.1	1.00	2.51	9
3	0.00091	0.02	5010	0.81	44.1	0.56	1.39	4
4	0.00141	1.00	5470	1.00	4.0	0.00	2.00	7
5	0.00108	0.36	3890	0.34	68.4	0.89	1.59	5
6	0.00122	0.63	3670	0.25	13.8	0.14	1.02	3
7	0.00104	0.28	3600	0.22	21.4	0.24	0.75	2
8	0.00090	0.00	3070	0.00	20.8	0.23	0.23	1
9	0.00126	0.71	4670	0.67	38.2	0.47	1.85	6

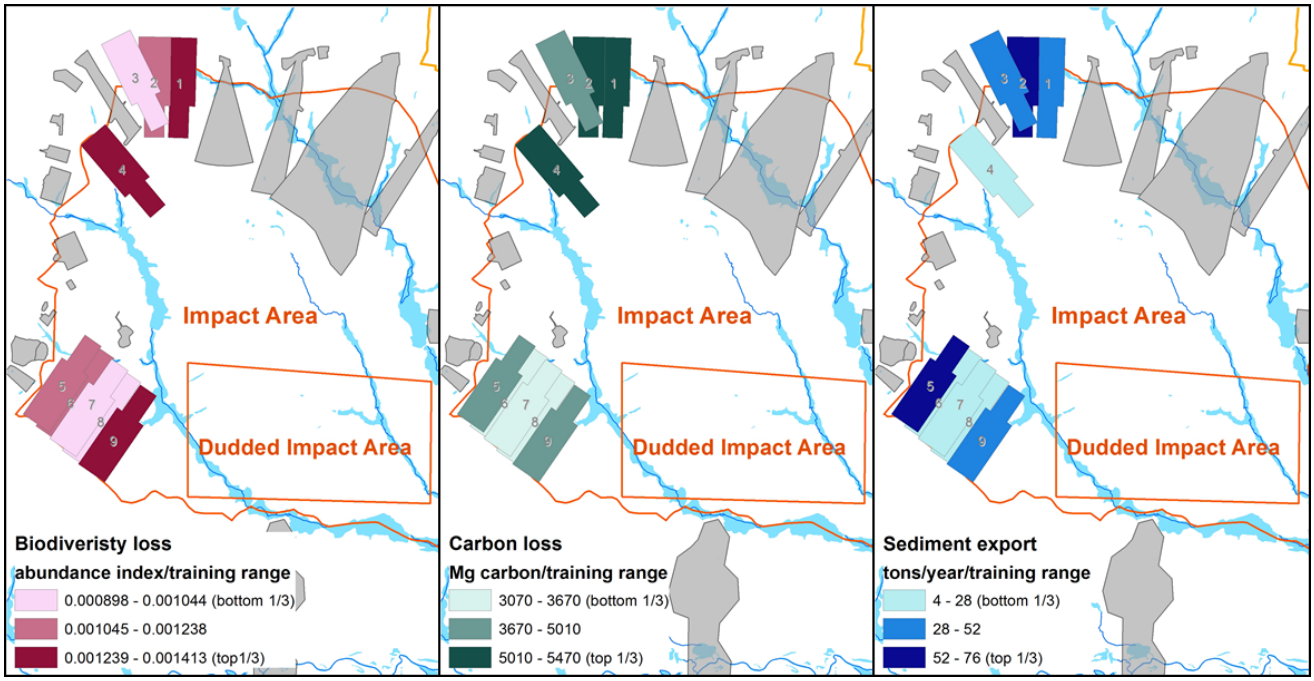


Figure 6.2.3.1. Ecosystem service losses on biodiversity, carbon storage, and sediment export under alternative scenarios at Fort Pickett, VA.

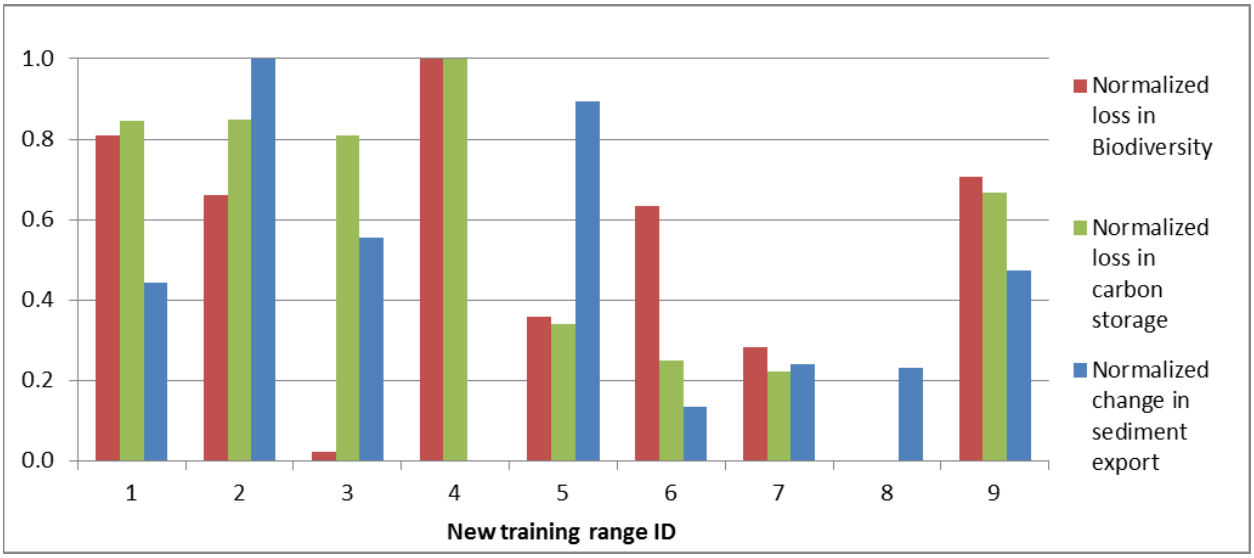


Figure 6.2.3.2. Normalized ecosystem losses on biodiversity, carbon storage and sediment export under alternative scenarios at Fort Pickett, VA.

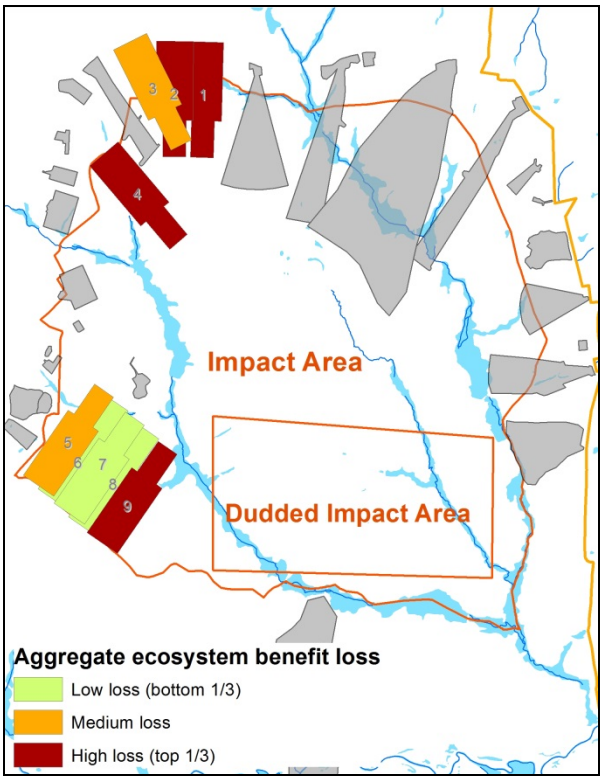


Figure 6.2.3.3. Aggregate ecosystem impacts on biodiversity, carbon storage, and sediment export under alternative scenarios for Fort Pickett, VA.

Virginia Polytech Institute and State University (Virginia Tech) was engaged in a concurrent ESTCP project conducting an ecosystem service-based approach at Fort Pickett and here we compare results for siting alternative training ranges. In their approach, Virginia Tech calculated normalized loss for soil erosion (based on USLE), surface water regulation, and riparian filtration of nutrients for each on the 9 hypothetical training ranges. Due to variations in sample design, we only compare the relative rankings between the two approaches. The only ecosystem service that overlaps between the two projects is soil erosion and there is some agreement between both Virginia Tech and our relative rankings for training ranges (Figure 6.2.3.4.). Differences between the two outcomes are related to different parameters being used for calculating soil loss as well as the area of interest being used for analysis as Virginia Tech uses the Fort Pickett footprint while NatCap uses the entire watershed.

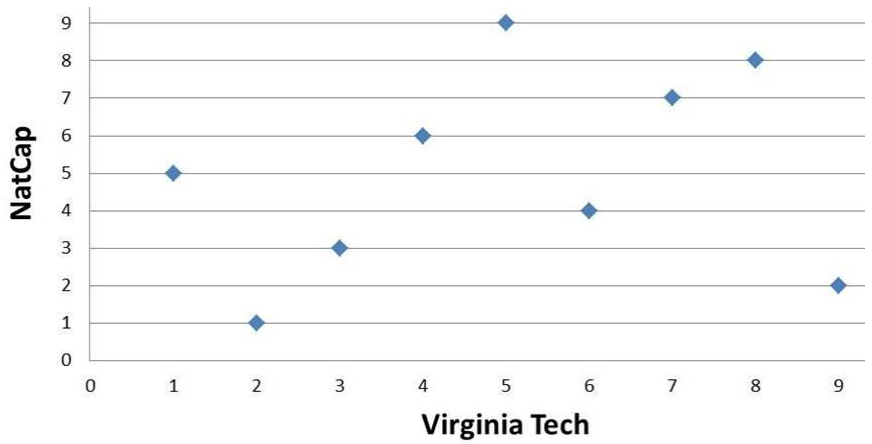


Figure 6.2.3.4. Relative rankings for soil erosion on nine alternative training ranges at Fort Pickett, VA based on Natural Capital Project (NatCap) and Virginia Polytech Institute and State University (Virginia Tech) studies.

Comparison of relative rankings for aggregated ecosystem services between the Virginia Tech and Natural Capital Project approach can lead to a more comprehensive understanding of siting alternative training ranges. It is important to note that both studies value different ecosystem services and, therefore, interpretation among the aggregated services is difficult to compare. However, there seems to be some agreement between the relative rankings for both projects (Figure 6.2.3.5), except for training ranges 3 (NatCap rank 4, Virginia Tech rank 8) and 6 (NatCap rank 3, Virginia Tech rank 7). This is most likely due to the greater influence of water-related services with the Virginia Tech approach.

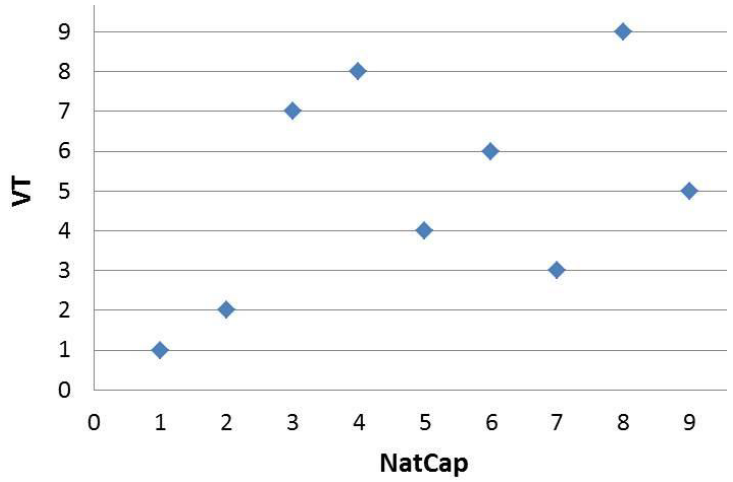


Figure 6.2.3.5. Relative rankings for aggregated ecosystem services on nine alternative training ranges at Fort Pickett, VA based on Natural Capital Project (NatCap) and Virginia Polytech Institute and State University (Virginia Tech) studies.

6.2.4 Qualitative analysis and summary

This section summarizes the results of our three qualitative objectives (10-12) and deems two of them fully successful. We suggest several opportunities for InVEST models to inform and improve impact assessments at Fort Pickett (Objective 10), and we also identify where Army protocol already incorporates ecosystem service information into their environmental management (Objective 11). Due to reduced application scale, we were unable to gather feedback on the independent use of InVEST (Objective 12). However, we received positive feedback on the value of our analytical approach by base personnel through our interaction with them.

Objective 10. Identify opportunities for InVEST to inform decision-making process.

This case study at Fort Pickett demonstrated how the ecosystem service approach and InVEST tools might inform an environmental impact assessment for siting new facilities at military installations. The approach and tools are especially helpful in three ways. First, the approach we implemented provides a channel for incorporating ecosystem services into the existing ecosystem-based management framework. With the convenience of InVEST models, some ecosystem services that are not often considered by military installations, such as carbon storage and sequestration, can be easily evaluated and included into their resource planning and impact assessment. Second, this approach provides spatially explicit, quantitative measures of ecosystem services and impacts to complement field observations and qualitative measures that are more common in current environmental impact assessment. For example, the InVEST sediment model calculates on-site erosion and sediment export in rivers and streams in tons of soil. These measures may better support decisions, as they are more informative than simple description of soil erodibility and soil-disturbing activities in an area. Third, our approach also presents a flexible, modular structure to aggregate various types of information to support a more comprehensive assessment. Installation personnel may not be able to adopt the InVEST models immediately due to limited technical capacity, but they often have alternative decision-supporting information, such as distributions of forest, streams, and species at risk. With the ecosystem service framework, they can start with the existing information for an aggregate assessment and gradually incorporate more services and measures that are more accurate as time and capacity allows. Non-environmental information, such as cultural resources and sensitive military areas, can also be included in the natural capital framework we demonstrate. As an example, we adopted the GLOBIO model to assess impacts on biodiversity and demonstrated how this approach is capable of incorporating methodologies outside the InVEST package. This case study also shows how InVEST is applicable for small-scale assessment in addition to many examples where it is applied for broader scale regional planning (Ruckelshaus et al. 2013).

Objective 11. Inclusion of ecosystem-services language in decision-making process.
See Objective 11 under section 6.1.4.

Objective 12. Positive comments about ability of independent InVEST application.
Although we hoped Fort Pickett personnel would be able to adopt the InVEST software by the end of the project, they were unable to use InVEST independently and provide direct evaluation because of technical capacity constraints and additional software certification requirements (see discussion of cost drivers, implementation issues, and technical requirements in Sections 7.2, 8.1, and 8.3). Similar as JBLM, we were unable to gather feedback on the independent use of InVEST at Fort Pickett as InVEST is not currently adopted. However, Fort Pickett staff offered positive feedback through our email/phone communication during the demonstration and in the final workshop (October 31, 2014). They are especially interested in applying the general ecosystem service framework for selecting sites for potential new training and energy facilities. They also suggested this approach could be useful in evaluating sedimentation at the installation and assessing the cost of BMPs to mitigate soil erosion.

6.3 FORT BENNING

This section presents the assessment results for our demonstration at Fort Benning.

6.3.1 Summary of scenarios

Objective 7: ***Convert alternative management scenarios into realistic alternative LULC maps***

Scenarios for future land use in Fort Benning were developed iteratively in a series of several workshops with base personnel. DoD staff were interviewed to discuss ecosystem services and key drivers that influence management at the base. An initial meeting was held on base in December 2013 to discuss the dynamics of key drivers and targets. Priority targets identified for modeling included the red-cockaded woodpecker, carbon sequestration, soil erosion control, conversion of loblolly pine forests to long-leaf pine, and training capacity, as well as how these factors influence each other throughout the base.

The red-cockaded woodpecker (RCW) is an endangered species that occurs within Fort Benning, and management and training activities are largely based around recovery efforts for the species. The species requires fairly mature pine forest for nesting cavities and food, and ecological forestry and other management efforts are currently employed to create and manage habitat for the species. The Army Compatible Use Buffer (ACUB) program can help recovery efforts for the red-cockaded woodpecker through acquisition of adjacent land that is used to restore woodpecker habitat and serve as areas for reintroduction. RCW habitat also is threatened by a complex of tree diseases and pine beetles that cause declines or mortality in loblolly pine, a dominant tree that occurs across the base. When the loblolly pine trees die, forestry staff replant areas with long-leaf pine, which is important to RCW and is a longer-lived, native tree species that historically dominated the area. In addition to concerns about woodpeckers, resource management at Fort Benning also focuses on soil erosion control from mechanized training activities. Such training is concentrated in three maneuver areas (Northern, Southern, and Good Hope) and there are efforts to mitigate soil erosion using several types of best management practices (BMPs) throughout these areas.

Based on the management and environmental concerns described by Fort Benning personnel, we developed 4 scenarios: Baseline, Short-term Diffuse Training (SDT), Short-Term Concentrated Training (SCT), and Long-term Ecological Forestry (LEF). Scenarios are summarized below and linkages between the scenarios are illustrated in Figure 6.3.1.1.

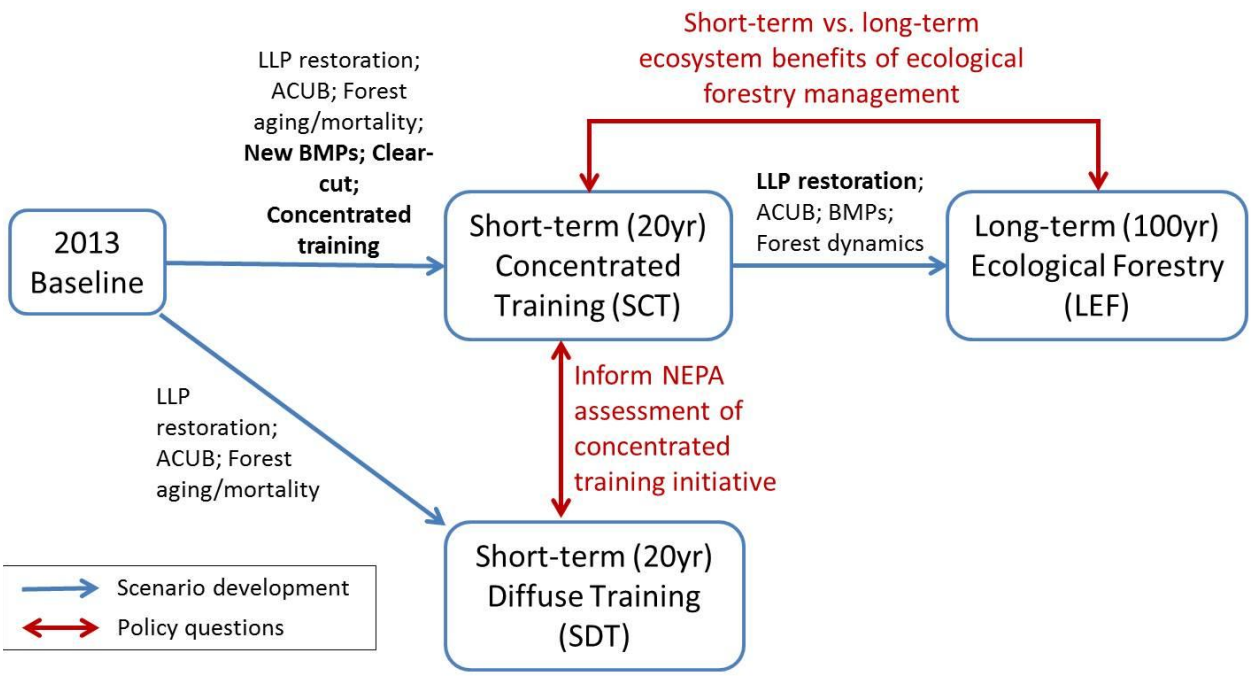


Figure 6.3.1.1. Four scenarios (blue boxes) were developed to depict changes from baseline (blue arrows) to inform management decisions and policy (red arrows) at Fort Benning, GA and adjacent Army Compatible Use Buffer (ACUB) lands. Potential actions affecting Land Use and Land Cover (black text) include clearcutting of loblolly pine, long leaf pine (LLP) restoration, protection/management of land in the ACUB program, enhanced Best Management Practices (BMPs) for soil and water management, and changes in mechanized training distribution.

- **Baseline (2013)**

The 2013 baseline represents current land use, resource management, and training activities after major BRAC/MCoE transformations. New training ranges, tank trails, and three new maneuver training areas have been built to accommodate the new training mission, especially the major increase in mechanized training carried out by the Armor School, which was relocated from Fort Knox to Fort Benning in 2010 under BRAC. This scenario will not be compared with future scenarios for policy discussion because the LULC is similar to that of the SCT scenario. However, the baseline estimates of carbon storage and RCW habitat can be used to derive carbon sequestration estimates and improvement in RCW habitat for future scenarios.

- **Short-term diffuse training (SDT) scenario**

This scenario represents 20-year projection of current land use, resource management, and training activities as planned under BRAC/MCoE. Compared with the 2013 baseline, it encompasses additional longleaf pine restoration and development in ACUB. Mechanized training is distributed on tank trails in all three maneuver areas (Northern, Southern, and Good Hope) and on the ~845-acre off-road maneuver corridors in the Good Hope Maneuver Training

areas (GHMTA). Comparing this scenario with SCT (see description below) reveals the ecosystem impacts from concentrated armor training and helps inform the on-going NEPA assessment of this new initiative.

- **Short-term concentrated training (SCT) scenario**

This scenario represents foreseeable land use, resource management, and training activities (i.e., business-as-usual) over the next 20 years. Compared with SDT, this scenario incorporates a new initiative to concentrate most mechanized training activities by the Armor School to the GHMTA, with limited activities remaining in Southern MTA. The use of tank trails in the northern installation also are reduced in this scenario. Although the environmental impact of this new initiative is being evaluated, installation personnel deemed it as a business-as-usual change. To accommodate this new training alignment, ~700-acres of forest will be clear-cut in GHMTA to create additional off-road corridors, and new BMPs will be installed to mitigate the impact of soil disturbance. Comparing this scenario with the SDT scenario reveals the ecosystem impacts from concentrated armor training and helps inform the on-going impact assessment of this new initiative.

Long-term ecological forestry (LEF) scenario

This scenario represents foreseeable land use and resource management (i.e., business-as-usual) over the next 100 years, especially ecological forestry management. In particular, Fort Benning is planning to gradually replant dead loblolly pine and mixed pine stands as longleaf pine. The 100-year time scale is necessary to capture the transition in forest composition/structure and resulting impacts on RCW reproduction and carbon sequestration. This scenario also assumes that prescribed fire, soil conservation, and expansion in the current ACUB program to create habitat corridors off base are effective. We assume the same level and locations of training activities as in the SCT scenario. Comparing this scenario with the SCT scenario reveals long-term vs. short-term ecosystem benefits (carbon and RCW habitat) of ecological forestry management.

Criteria for building future scenarios are presented in Table 6.3.1.1 and individually explained below:

Training: We incorporated impacts on land uses from all major training activities, including tank trails and heavy maneuver areas, high-impact firing ranges (tank/fighting vehicle stationary gunnery range, tank platoon battle run, mortar ranges), Dudded Impact Areas, other firing ranges, and unpaved roads. Most impacts from training intensity were captured by adjusting parameters in the sediment model based on expert opinion, literature review, Fort Pickett INPRM, and RC-1547 final report (see sediment model assumptions in section 6.3.2 for details). Impacts from training-driven land use changes were reflected in all models.

Forestry Management: Forestry management at Fort Benning focuses on longleaf pine (LLP) restoration and prescribed fire to support forest habitat for RCW and long-term ecological

sustainability. We assumed all forest areas are managed under the current burn regime, which implements prescribed fire on a three-year average cycle. We assumed pine decline is driven by observed mortality rates for loblolly, shortleaf, and mixed pine stands, and that mortality varies across different soil types based on a recent ecological monitoring study at Fort Benning (G. Matusek, personal communication, June 20, 2014) (Table 6.3.1.1) and applied these rates to the 20-year scenarios. To account for uncertainty over a longer period of time, we assume loblolly, shortleaf, and mixed pine stands will decline by 1.7% in basal area annually (the average mortality rate from the ecological monitoring study) across the installation after 20 years. When a stand falls below 30 ft^2/acre in basal area, the scenarios reflect conversion of the entire stand to longleaf pine the following year because forest management works at the stand level. Our simulation of forest transition based on these mortality rates showed no functional loblolly stands will remain at the end of 100 years. Based on discussion with installation personnel (G. Matusek, personal communication, June 20, 2014), we assumed mixed forests that are currently populated by loblolly pine would revert to hardwood forests due to the dominance of hardwood species following loblolly pine mortality, and hardwood species would constantly regenerate and remain a multi-age structure. We assume climate change will not affect forest transition based on the conclusion from SERDP project RC-1541, which examined nine climate change scenarios and found no change in the projections of dominant vegetation for Fort Benning (Lawler et al. 2011).

Table 6.3.1.1. Mortality rates for loblolly pine (% decrease of basal area [BA]/year) across soil types based on a short-term ecological monitoring study.

Soil Texture	Mean annual BA mortality (%)	SD	N	SE
Fine sandy loam	0.89	1.22	5	0.55
Loamy coarse sand	1.14	1.67	9	0.56
Loamy sand	1.30	1.65	55	0.22
Sandy clay loam	2.42	2.27	15	0.59
Sandy loam	1.94	2.31	13	0.64

Soil and Water Management: Soil and water management are important to control soil compaction and vegetation disturbance caused by mechanized training activities. This management became especially after the Armor School relocated to Fort Benning and activities intensified. Soil and water management are mainly implemented through structural BMPs (e.g., sediment basin, ripraps) and non-structural BMPs (e.g., riparian vegetation buffer). For all scenarios, we assume 25 feet regulatory buffers occur along rivers and wetlands in all training areas, and riparian vegetation buffers in all ACUB parcels are well maintained.

ACUB: There are around 23,500 acres of land protected under ACUB in the priority area to the northeast of Fort Benning, and 4,000 acres of potential parcels to be protected under the current budget. In discussion with Fort Benning personnel, additional parcels were selected as candidates for ACUB based on their pine coverage, connectivity and proximity to existing ACUB parcels, potential as RCW habitat, and proximity to rivers/streams upstream to Fort Benning.

Table 6.3.1.2. Criteria for scenario development at Fort Benning, GA.

	Baseline	Short-term Diffuse Training (SDT)	Short-term Concentrated Training (SCT)	Long-term Ecological Forestry (LEF)
Description	Current land use / management (PostBRAC/ MCoE)	Current trend of land use/ management with mechanized training distributed in all three maneuver training areas	Foreseeable land use/ management with most mechanized training concentrated in Good Hope Maneuver Training Area (GHMTA)	Foreseeable land use/ management in long term with ecological forestry management
Year/time scale	2013	20 year from baseline	20 year from baseline	100 year from baseline
Training	New tank trails, training ranges, and three new maneuver training areas built under BRAC/MCoE to accommodate additional mechanized training requirement by the Armor School	Mechanized training distributed on tank trails in all three maneuver areas and ~845 ac offroad maneuver corridors in GHMTA (same as 2013 baseline)	Most mechanized training concentrated on tank trails and ~1500 ac offroad maneuver corridors in GHMTA; reduced use of tank trails in northern installation	Same as SCT
Forestry Management	Longleaf (LLP) pine ~25K ac with active conversion of Loblolly pine to LLP between 20062013	Convert ~ 1500 ac loblolly pine plantation outside RCW partitions to LLP between 20132020	Convert ~1500 ac loblolly pine plantation outside RCW partitions to LLP; clearcut ~700 ac forest in GHMTA to create offroad corridors	Gradually convert dead loblolly/shortleaf pine and mixed pine stands to LLP
Soil and Water Management	Existing watershed management BMPs; additional voluntary buffer in GHMTA; 25feet regulatory buffer	Same as 2013 baseline	Add enhanced BMPs in GHMTA to 2013 baseline (based on Parsons report); 25feet regulatory buffer	Improve retention efficiency of existing BMPs
Army Competitive Use Buffer (ACUB)	23,500 ac protected area with partial prescribed fire and riparian buffer maintenance	27,450 ac protected area with prescribed fire, LLP replantation, and riparian buffer maintenance	Same as SDT	40,000 ac protected area with prescribed fire, LLP replantation, and riparian buffer maintenance

6.3.2 Quantification, valuation and mapping of individual ecosystem services

This section presents our assessments for Performance Objectives 1-6, and 8. For each ecosystem service, we first summarize the assessment results for all relevant objectives. Next, we describe the model inputs and assumptions supporting data analyses for these objectives. Last, we provide the analysis results for individual objectives.

We modeled three services of interest for Fort Benning: risk to nesting habitat for red-cockaded woodpecker (RCW), sediment retention, and carbon sequestration. Maintaining habitat suitable for military training while complying with environmental regulation (e.g., recovery plans for federally endangered RCW) is a priority at Fort Benning. Additionally, potential for future regulation of carbon sequestration on public lands motivates the DoD to consider how management on installations affects carbon dynamics. Management decisions at Fort Benning have recently focused on the placement of additional mechanized training required by the Base Closure and Realignment Commission/Maneuver Center of Excellence (BRAC/MCoE), which necessitate clearcutting of forest for additional off-road corridors, and on the benefits of ecological forestry, which include the conversion of loblolly pine stands and forest gaps to longleaf forest. Risk to RCW nesting habitat, sediment retention, and carbon sequestration are interconnected via their dependence on LULC, particularly through longleaf forest habitat; and examining potential responses of these services to changes in LULC provides an opportunity to observe tradeoffs and synergies that can inform management decisions at Fort Benning.

- **Carbon sequestration**

- ✓ Objective 1: Quantify provision of ecosystem services using existing GIS data
- ✓ Objective 2: Quantify value of ecosystem services for at least two ecosystem services
- ✓ Objective 3: Provide spatially-explicit rendering of service provision
- ✓ Objective 4: Provide spatially-explicit rendering of the social value of at least two key ecosystem services
- ✓ Objective 5: Assess and report degree to which model results depict reality
- ✓ Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest
- ✓ Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

To meet Objectives 1, 2, 3, 4, and 8, we used the InVEST carbon model to assess carbon biomass and its economic value (i.e., social cost of carbon) at Fort Benning and adjacent ACUB lands under three alternative scenarios (Short-term Concentrated Training [SCT], Short-term Diffuse Training [SDT], and Long-term Ecological Forestry [LEF]) at a 10-m resolution. To meet Objective 5c, we compared the generalized aboveground carbon biomass estimates with site-estimates under the 2013 baseline. To meet Objective 6, we quantified and mapped

confident carbon sequestration using Monte Carlo simulation.

Model inputs and assumptions

We applied the InVEST Carbon Storage and Sequestration model to map, quantify, and value aboveground and belowground carbon biomass stored within Fort Benning and its ACUB areas[5].

We derived the carbon pool values for aboveground biomass primarily from the National Biomass and Carbon Dataset (NBCD; Kellndorfer et al. 2000). NBCD provides radar-derived, 30m-resolution, aboveground carbon biomass estimates within the contiguous United States for the year 2000. We calculated the average carbon biomass for more than 200 LULC classes categorized by vegetation types and 5-year age intervals for the 2013 baseline using NBCD (section 6.3.1).

Objective 5: Assess and report degree to which model results depict reality

To examine the applicability of this generalized dataset for Fort Benning, we compared the aboveground carbon values from NBCD with estimates from 216 longleaf pine sampling plots at Fort Benning (M. Hurteau, Penn State University, unpublished data) at the level of both stands (Figure 6.3.2.1-A) and vegetation class (Figure 6.3.2.1-B). For most cases, the mean estimates from NBCD are reasonably close to those from field sampling. The largest divergence occurs with the stand involving longleaf pine understory, which is likely because the satellite imagery used in NBCD does not well capture carbon biomass stored in mid-story and under-story. This comparison suggests NBCD provides valid data for estimating carbon biomass stored in longleaf pine stands and it may be used for other vegetation types as well. Estimates from other Fort Benning studies cannot be applied with InVEST as they either focus on limited vegetation types and age classes (M. Hurteau, Penn State University, unpublished data) or require additional field data, such as tree height and diameter at breast height, to generalize carbon value from their site-specific regression equations (Samuelson et al. 2014).

[5] We did not assess carbon stored in soil, dead organic matter, or harvested wood products because site-specific data are lacking.

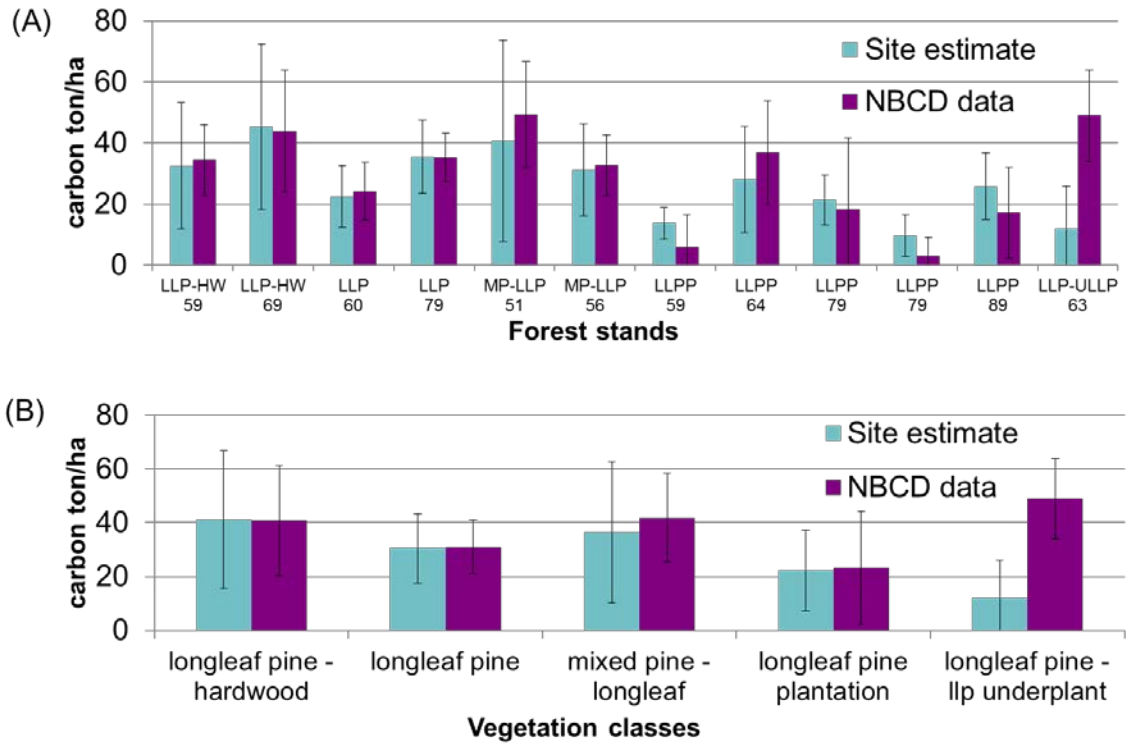


Figure 6.3.2.1. Mean carbon storage estimates from a site sampling dataset and National Biomass and Carbon Dataset (NBCD) data at (A) forest stand level and (B) vegetation class level. X-axis in Figure A represents the stand composition (LLP-longleaf pine, HW-hardwood, MP-mixed pine, LLPP-longleaf pine plantation, ULLP-longleaf pine underplant) and age. Error bars represent the standard deviation from mean carbon storage.

To quantify carbon sequestration, we need to derive the carbon biomass estimates for additional LULC classes emerging under the alternative scenarios due to forest aging. We developed regression equations between aboveground carbon biomass and tree age for eight major vegetation types (Table 6.3.2.1) to predict carbon values for those new LULC classes. We tested a number of functional forms based on the biomass estimates derived from NBCD for the 2013 baseline and found the log-log form, i.e., $ln(biomass)=\beta_0+\beta_1 ln(age)$, showed the best fit for seven out of eight vegetation types. Age data were adjusted for the difference between the NBCD base year 2000 and our LULC baseline year 2013. However, as NBCD data do not provide good carbon estimates for early ages from satellite images, we further calibrated the regression equations shown in Table 6.3.2.1 with the regional carbon estimates provided by the United States Forest Service (Smith et al. 2006). The Forest Service data provide useful yield curves between aboveground carbon estimates and tree age for a few major vegetation types in the southeast U.S., but they appear to overestimate the absolute carbon value for Fort Benning when compared with site-specific estimates (Samuelson et al. 2014, M. Hurteau, Penn State University, Unpublished Data). Thus, we adopted regressions derived from NBCD for age greater than 30 years, but re-calibrated the regression using the Forest Service yield curve for

early ages (<30), i.e., assuming a linear functional form from zero to the 30-year NBCD value. Figure 6.3.2.2 illustrates how we combined the two data sources using the longleaf pine classes as an example. For other LULC classes with limited age data, we simply used the mean NBCD estimates for the 2013 baseline for aboveground carbon values (Table 6.3.2.1).

Table 6.3.2.1. Mean values or equations derived from National Biomass and Carbon Dataset (NBCD) data for Land Use and Land Cover (LULC) classes at Fort Benning, GA and adjacent Army Compatible Use Buffer (ACUB) lands.

Fort Benning LULC classes	Aboveground C (Mg/ha)
Loblolly Pine Forest/Plantation (classified by 5-year interval)	exp(0.12*ln(age)+3.31)
Loblolly Pine-Hardwood (classified by 5-year interval)	exp(0.16*ln(age)+3.33)
Longleaf Pine Forest/Plantation (classified by 5-year interval)	exp(0.33*ln(age)+2.26)
Mixed Pine Forest (classified by 5-year interval)	exp(0.13*ln(age)+3.19)
Mixed Pine-Longleaf (classified by 5-year interval)	exp(0.21*ln(age)+2.78)
Riparian Hardwood Forest (classified by 5-year interval)	exp(0.81*age)
Riparian Mixed Forest (classified by 5-year interval)	exp(0.06*ln(age)+4.02)
Upland Mixed Forest (classified by 5-year interval)	exp(0.18*ln(age)+3.36)
Pasture/Hay	5.1
Cultivated Crops	3.8
Shrubland (scrub oak)	39.0
Sparsely Vegetated	5.9
Shortleaf Pine	34.2
Longleaf Pine-Hardwood	42.1
Slash Pine Plantation	32.8
Upland Hardwood Forest	49.7
ACUB LULC classes	Aboveground C (Mg/ha)
Hardwood	57.0
Longleaf Pine Plantation	31.2
Pine	31.2
Conifer Forest	31.2
Cropland	32.8
Deciduous Forest	43.8
Forested Wetland	85.3
Herbaceous Wetland	11.8
Mixed Forest	44.1
Open	7.6
Shrubland	28.8
Sparsely Vegetated	5.9

We represented the LULC classes for the ACUB area only by vegetation types because the age information is not reliable. We derived the aboveground carbon biomass value for each class by averaging the NBCD estimates for the 2013 baseline (Table 6.3.2.1).

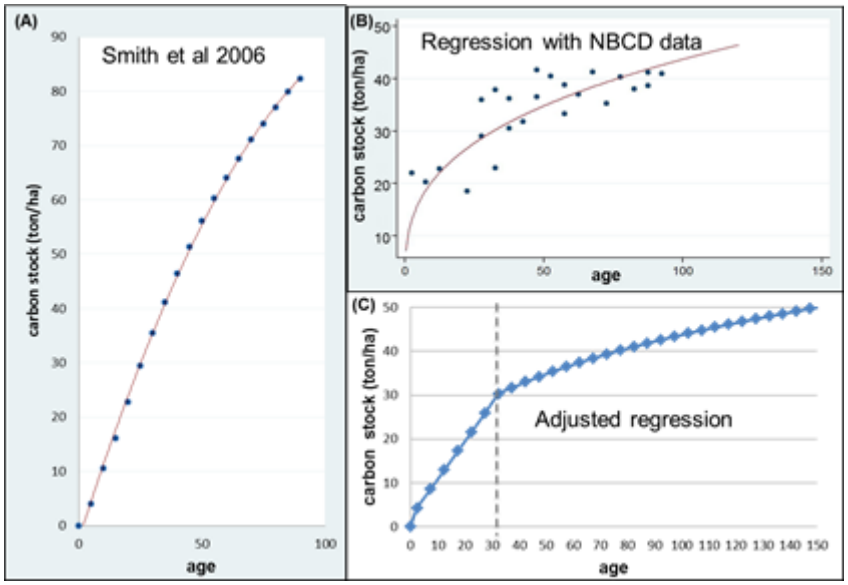


Figure 6.3.2.2. Illustration of aboveground carbon value derivation for Land Use and Land Cover (LULC) classes. (A) U.S. Forest Service carbon yield curve for longleaf pine in the southeastern U.S. (Smith et al. 2006); (B) Log-log regression between mean National Biomass and Carbon Dataset (NBCD) carbon value and stand age for longleaf pine classes; (C) Regression adjusted by combining Forest Service data and NBCD estimates.

We calculated the belowground biomass for LULC classes using either a root biomass equation or a simple root-to-shoot ratio. For most woody LULC classes categorized by vegetation type and age, we predicted the belowground carbon storage based on the aboveground carbon and age following the well-accepted root biomass equation (Cairns et al. 1997). While the root to shoot ratio derived from this equation varies across our LULC classes, the average value is 0.27, which is comparable with the site estimates from five longleaf pine stands by Samuelson et al. (2014). We applied this average ratio to other LULC classes lacking age information to calculate the belowground carbon storage for both Fort Benning and ACUB area. For grassland species, we adopted the root to shoot ratio of 4.0 from IPCC (2006).

We assessed the economic value of carbon sequestration in the form of social cost of carbon, which represents the social damage (health, property value, agriculture, ecosystems, etc.) avoided by not releasing one additional ton of carbon into the atmosphere. Compared with the carbon market price, the social cost of carbon is more suitable for government decision contexts as it reflects more of the true economic impacts of climate change. The United States Interagency Working Group on the Social Cost of Carbon (USIWGSCC) provides guidance for the appropriate carbon cost through time for regulatory cost-benefit analyses by synthesizing three integrated assessment models with commonly agreed climate sensitivity, socio-economic

trajectory, and discount rates (USIWGSCC 2010, 2013). For the InVEST carbon model, we used the interpolated 2013 carbon value−$40.6 per metric ton of CO_2 in 2013 dollar−from the USIWGSCC carbon value table, the average annual rate of change 1.93% calculated from the table, and a 3% discount rate—the middle rate among all three provided by USIWGSCC. The InVEST model calculates net present value of carbon for each year and sums them up for the 20- and 100-year scenario.

Results

Objective 1: ***Quantify provision of ecosystem services using existing GIS data***
Objective 3: ***Provide spatially-explicit rendering of service provision***
Objective 8: ***Estimate absolute and relative changes in each ecosystem service that will result from alternative management options***

We assessed these objectives together in the section below as they are closely related.

We first estimated the total carbon storage (million metric ton) under the 2013 baseline and three alternative scenarios (Short-term Concentrated Training [SCT], Short-term Diffuse Training [SDT], and Long-term Ecological Forestry [LEF]) for Fort Benning and its ACUB areas (Table 6.3.2.2). Carbon sequestration was then estimated as the carbon storage accumulated between the 2013 baseline and each alternative scenario. For Fort Benning, carbon storage increases by 149 and 162 thousand metric tons in the SCT and SDT scenarios, and 681 thousand tons in the LEF scenario, primarily due to forest aging and silvicultural management for longleaf pine restoration ACUB areas (Table 6.3.2.2).

Figure 6.3.2.3 illustrates the spatial distribution of carbon sequestration across the installation[6]. Comparing the two 20-year scenarios, concentrated maneuver training creates more carbon loss in the GHMTA under SCT than SDT. Active longleaf pine conversion carried out by clear-cutting loblolly pine yields sharp loss of carbon across the installation in these two scenarios (red in Figure 6.3.2.3). The LEF scenario shows apparent carbon gains over 100 years resulting from longleaf restoration and tree growth. The mild loss of carbon in some areas is because of the gradual conversion of loblolly pine stands to young longleaf pine plantations in later years of the LEF scenario (orange in Figure 6.3.2.3).

[6] We cannot show the carbon sequestration distribution in ACUB parcels because the locations of potential land acquisition are confidential.

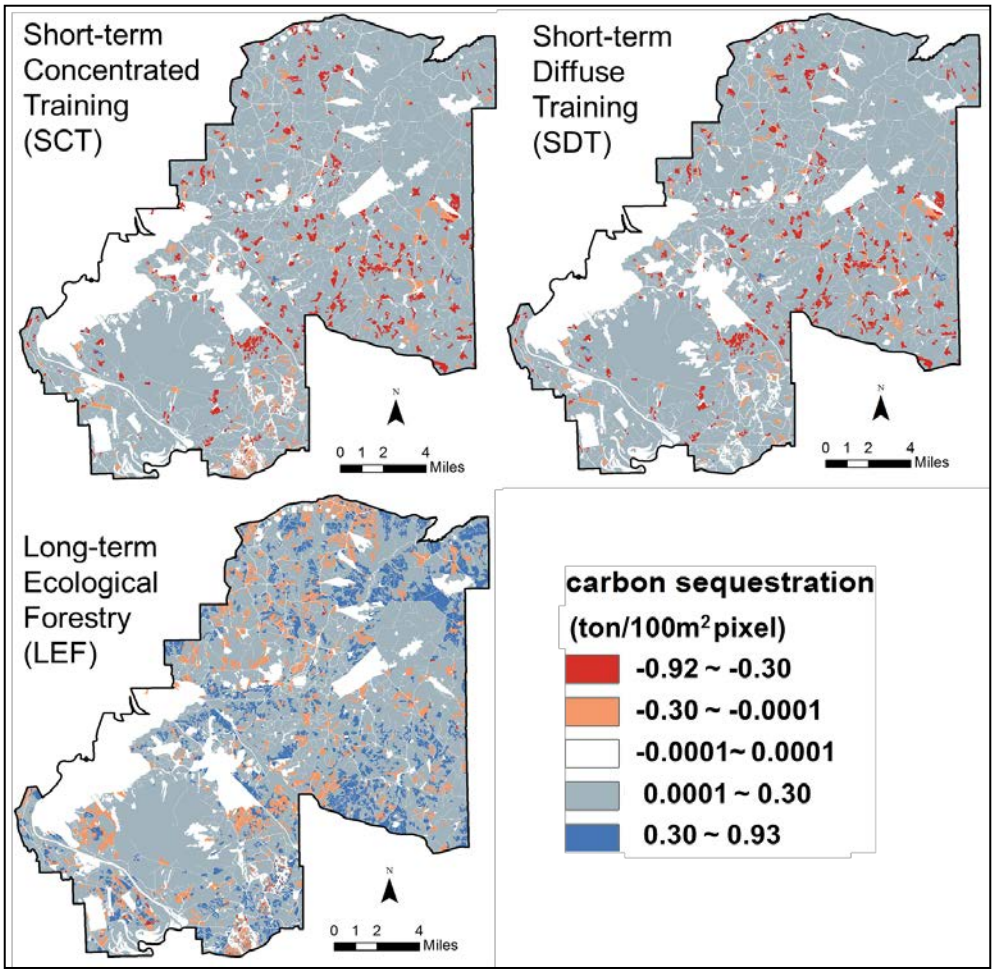


Figure 6.3.2.3. Spatial distribution of carbon sequestration within Fort Benning, GA, under three alternative scenarios relative to the 2013 baseline.

Objective 2: Quantify value of ecosystem services for at least two ecosystem services
Objective 4: Provide spatially-explicit rendering of the DoD-relevant values of two key ecosystem services

We assessed these objectives together in the section below as they are closely related.

Economic analysis shows the social cost of carbon is 14~15 million USD in the two 20-year scenarios and ~21 million USD in LEF scenario. The cost exhibits a less proportional increase than carbon biomass due to discounting (Table 6.3.2.2). For the ACUB areas, land acquisition is the major cause of the significant gains in carbon sequestration from the 20-year scenarios to the 100-year scenario, as we did not incorporate forest aging for ACUB.

Table 6.3.2.2. Carbon storage and sequestration under 2013 baseline and alternative scenarios for Fort Benning and the Army Compatible Use Buffer (ACUB) areas, GA. Alternative scenarios include Short-term Concentrated Training (SCT), Short-term Diffuse Training (SDT), and Long-term Ecological Forestry (LEF).

	2013 Baseline	Short-term Concentrate Training (SCT)	Short-term Diffuse Training (SDT)	Long-term Ecological Forestry (LEF)
Fort Benning				
carbon storage (million metric ton)	3.80	3.94	3.96	4.48
carbon sequestration (million metric ton)		0.149	0.162	0.681
% change from SCT		*100%*	*9%*	*358%*
Social cost of carbon (million $)		14.5	15.7	21.2
% change from SCT		*100%*	*9%*	*46%*
ACUB				
carbon storage (million metric ton)	0.312	0.348	0.348	0.508
carbon sequestration (million metric ton)		0.0361	0.0361	0.196
% change from SCT		*100%*	*0%*	*442%*
Social cost of carbon (million $)		3.52	3.52	6.08
% change from SCT		*100%*	*0%*	*73%*

Figure 6.3.2.4 illustrates the spatial distribution of the social cost of carbon sequestration across the installation. The results reveal the impact of concentrated maneuver training between the two 20-year scenarios around the GHMTA. Similar to the biophysical mapping in Figure 6.3.2.3, these two scenarios also exhibit sharp loss of carbon across due to active longleaf pine conversion (red in Figure 6.3.2.4). The increase of carbon value in the LEF scenario are mostly in the clear-cut areas for active longleaf restoration (from red to orange in Figure 6.3.2.4), which is not as pervasive as the biophysical estimates in Figure 6.3.2.3 due to discounting. Some areas also show mild loss of carbon value because of the gradual conversion of loblolly pine stands to young longleaf pine plantations (from light blue to orange or from dark blue to light blue in Figure 6.3.2.4).

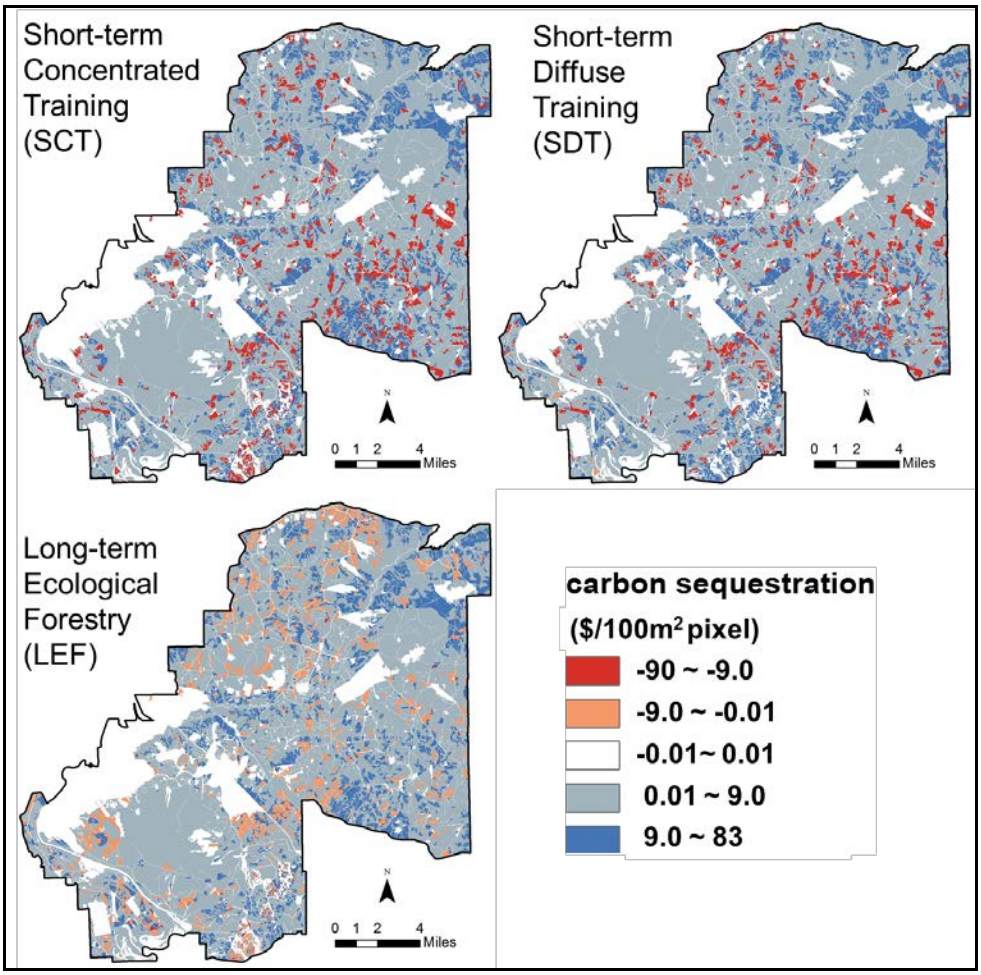


Figure 6.3.2.4. Spatial distribution of carbon sequestration within Fort Benning, GA, under three alternative scenarios relative to the 2013 baseline.

Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest

To analyze the uncertainty of carbon estimates with the build-in Monte Carlo simulation feature of InVEST carbon model, we derived the standard deviation of carbon pool values in addition to the mean. For LULC classes with carbon value generated from regressions, we calculated the standard error of the predicted mean as the deviation. For other LULC classes without the age component, we used the standard deviations associated with the NBCD mean estimates.

Applying the InVEST carbon model, we found the long-term forest aging and restoration largely reduce the uncertainty in carbon estimates. For a 90% confidence interval, model results suggest 82%~83% carbon sequestration would be realized under the two 20-year scenarios (SCT and SDT), and carbon sequestration under the LEF scenario is 99.94% likely (Table 6.3.2.3, Figure 6.3.2.5). Interestingly, the annualized carbon sequestration (i.e., total sequestration divided by

the number of years) in the LEF scenario changes from the lowest among all three scenarios to the highest when considering uncertainty in carbon estimates, which demonstrates the long-term benefit of ecological forest management.

Table 6.3.2.3. Carbon sequestration estimates under three scenarios at Fort Benning, GA, with and without considering uncertainty. Scenarios include Short-term Concentrated Training (SCT), Short-term Diffuse Training (SDT), and Long-term Ecological Forestry (LEF).

	Short-term Concentrate Training (SCT)	Short-term Diffuse Training (SDT)	Long-term Ecological Forestry (LEF)
Carbon sequestration (thousand metric ton)	149	162	681
Annualized sequestration (thousand metric ton)	7.44	8.08	6.81
Carbon sequestration with 90% confidence (thousand metric ton)	122	135	681
Percentage of all sequestration	82.2%	83.6%	99.94%
Annualized confident sequestration (thousand metric ton)	6.12	6.75	6.81

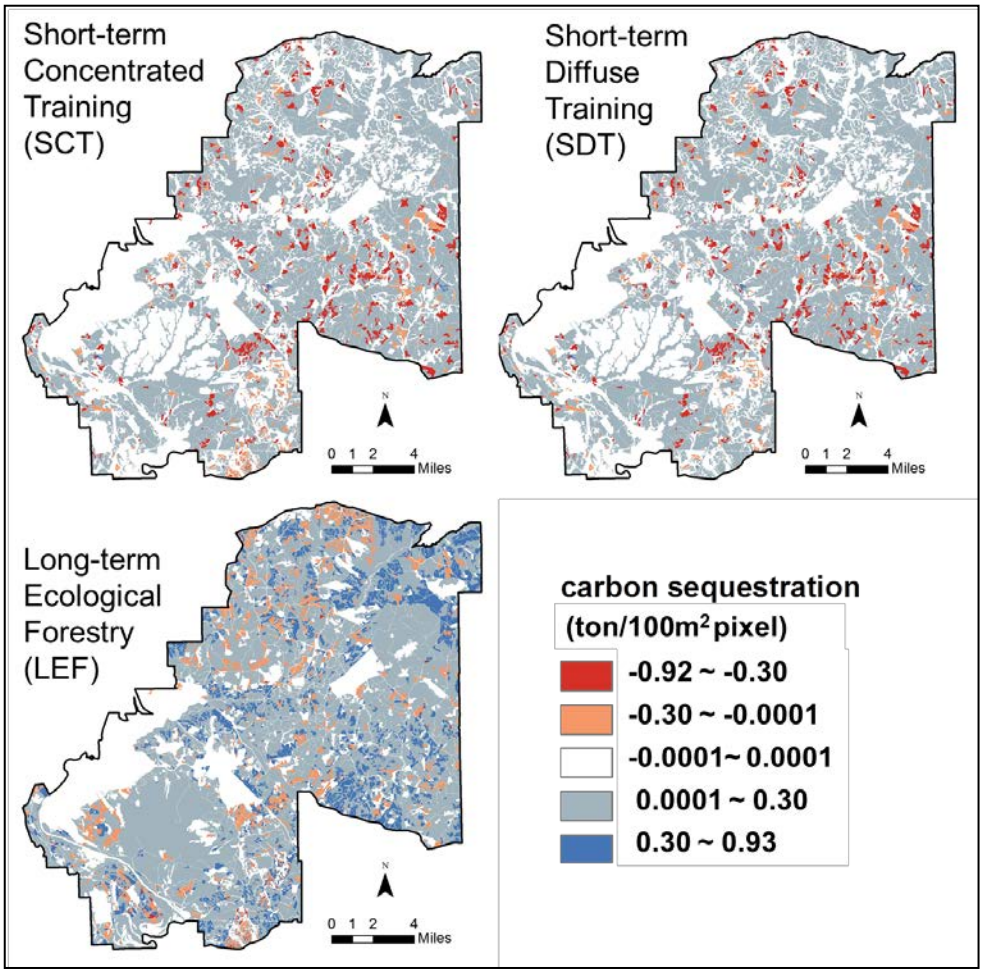


Figure 6.3.2.5. Spatial distribution of confident carbon sequestration (assuming a 90% threshold) within Fort Benning, GA, under three alternative scenarios relative to the 2013 baseline.

In sum, we applied the InVEST carbon model as a quick and simple tool to assess the approximate carbon footprint from all types of vegetation within Fort Benning and its ACUB areas. High quality forest inventory data provided by Fort Benning allowed us to incorporate forest aging and structural forest changes in the modeling process, thus producing more informative outcomes. Our model results clearly show carbon loss due to concentrated training and the long-term benefit of longleaf pine restoration. These findings are useful for comparing changes in carbon sequestration across scenarios to inform environmental impact assessments or spatial planning of forestry management.

- **Habitat risk assessment of red-cockaded woodpecker nesting habitat**

✓ Objective 1: Quantify provision of ecosystem services using existing GIS data
✓ Objective 3: Provide spatially-explicit rendering of service provision

- ✓ Objective 5: Assess degree to which model results depict reality and compare Tier 1 vs. Tier 2 performances against observations
- ✓ Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management options

To meet Objectives 1, 3, 8a, and 8b, we used the HRA model to assess risk posed by stressors to the nesting habitat of red cockaded woodpeckers (RCW) at Fort Benning and adjacent ACUB lands for the 2013 baseline and three alternative scenarios (Short-term Concentrated Training [SCT], Short-term Diffuse Training [SDT], and Long-term Ecological Forestry [LEF]) at a 30-m resolution. To meet Objective 5, we tested the performance of the HRA model in predicting presence-absence of RCW clusters across Fort Benning during the baseline year (2013). Additionally, we compared Tier 2 (HexSim) outputs resulting from a model run using HRA risk values as inputs to Tier 2 (HexSim) outputs resulting from a model run using habitat quality values estimated by Lawler et al. (2011).

Model inputs and assumptions

Model inputs include maps of stressors which express spatial overlap between stressors and habitat, as well as a table defining temporal overlap between stressors and habitat, stressor intensity, effectiveness of management strategies mitigating stressor impacts, change in vegetation area and structure, natural disturbance frequency, and habitat resilience (based on natural rates of mortality, recruitment, maturity, and dispersal). Below, we describe each of these inputs and assumptions associated with their use.

Fort Benning personnel provided spatial data designating the extent of each training activity across the installation, as well as tree composition and age for all forest stands on Fort Benning. Additional tree composition and age information for the ACUB lands adjacent to Fort Benning was provided by The Nature Conservancy. Low-resistance open area at Fort Benning consisted of all open habitat (i.e., low statured vegetation such as grass, roads, open water) within 150m of forest habitat. High-resistance open area consisted of all open habitat at distances greater than 150m from forest habitat, as RCW have been found to avoid crossing open gaps greater than 150m in extent (Kesler et al. 2010, Trainor et al. 2013, Bruggeman et al. 2014). Scenarios represented differences in the spatial extent of stressors with changes in land cover under each scenario. Neither temporal overlap of stressors with habitat nor the intensity of stressors varied among scenarios (Table 6.3.2.4). Temporal overlap and intensity were classified as 1 (Low), 2 (Medium), or 3 (High) based on a review literature describing RCW (Hovis and Labisky 1985, Kelly et al. 1993, Conner et al. 1999, Walters et al. 2002, Trainor et al. 2013, Bruggeman et al. 2014).

Table 6.3.2.4. Stressor scores for temporal overlap with red-cockaded woodpecker nesting habitat and intensity at Fort Benning, GA, and adjacent Army Compatible Use Buffer (ACUB) lands. Each stressor is scored from 1-3 (low to high).

Stressor	Temporal overlap	Intensity
Low-intensity ranges	2	1
High-intensity ranges	2	2
Tank trails	2	2
Heavy maneuvering	2	2
0-25% pine	3	1
1-30 year-old trees	3	2
31-60 year-old trees	3	1
Low-resistance open	3	1
High-resistance open	3	3

We scored change in vegetation area and structure caused by each stressor based on a literature review and discussion with biologists at Fort Benning (Hayden 1999; Doresky et al. 2001; Delaney et al. 2002, 2011; Driver et al. 2002; Table 6.3.2.5). Following standard criteria in the model, for each stressor we scored loss in both area and structure from 0-20% as "low", 20-50% as "medium", and greater than 50% as "high" (Table 6.3.2.5; Sharp et al. 2014). We also reviewed literature to determine sources and frequency of historic disturbance in long leaf pine forest (James et al. 1997, Dale et al. 2002, Van Lear et al. 2005, Eckhardt et al. 2010,). We classified the effect of a stressor as "high" when analogous historical disturbances (e.g., foot traffic, forest gaps) occurred much less frequently than stressor disturbance, "medium" when historic disturbances occurred slightly less frequently, and "low" when disturbance frequencies were similar (Table 6.3.2.5).

Table 6.3.2.5. Stressor scores for change in area, change in structure, and impact of frequency, given natural disturbance regimes, at Fort Benning, GA, and adjacent Army Compatible Use Buffer (ACUB) lands. Each stressor is scored from 1-3 (low to high)

Stressor	Change in area	Change in structure	Frequency
Low-intensity ranges	1	1	1
High-intensity ranges	1	1	2
Tank trails	2	2	3
Heavy maneuvering	2	2	3
0-25% pine	1	1	1
1-30 year-old trees	1	1	1
31-60 year-old trees	1	1	1
Low-resistance open	2	2	2
High-resistance open	3	3	3

Lastly, we reviewed the literature to assess the resilience of RCW to changes in nesting habitat based on natural rates of mortality, recruitment, maturity, and dispersal. We assigned resilience scores of "high", "medium", or "low" to classify the impact of stressors, given likelihood of recovery, assuming a habitat with rapid lifecycles (i.e., high mortality and recruitment rates and short times until maturity) and high connectivity (i.e., frequent dispersal between populations) should be those most resilient to the effects of stressors (Arkema et al. 2014, Sharp et al. 2014). Habitats least impacted by stressors have annual mortality rates > 80%, annual recruitment, maturity rates < one year, and dispersal distances > 100 km; and habitats highly impacted by stressors have annual mortality rates < 20%, recruitment rates > two years, maturity rates > 10 years, and dispersal distances < 10 km (Arkema et al. 2014, Sharp et al. 2014). Resilience values are based on biological attributes inherent to a species or habitat and did not vary among scenarios (Table 6.3.2.6).

Table 6.3.2.6. Resilience attributes for the red-cockaded woodpecker at Fort Benning, GA, scored from 1-3 (low to high).

Attribute	Score
Recruitment	2
Natural mortality	3
Connectivity	3
Recovery	2

Objective 5c: Assess degree to which model results depict reality and compare Tier 1 vs. Tier 2 performances against observations

We used a logistic regression to test the performance of the HRA model in predicting presence-absence of RCW clusters across Fort Benning during the baseline year (2013). To create a presence-absence data set, we used the centroids of 2013 RCW clusters to indicate presence of RCW nests and added a 109-ha buffer around each nest to represent the average size of a RCW foraging area at Fort Benning (Lawler et al. 2011). To generate absences, we created 800 random points with 109-ha buffers within the boundaries of Fort Benning. We then eliminated random points with buffers that overlapped buffers surrounding RCW clusters (presences), resulting in 361 "true absences". The predictive performance of the HRA model was significant (N = 736, df = 1, $P < 0.001$, Nagelkerke's $R^2 = 0.33$). We therefore included the same model parameters while running the HRA model on the three alternative management scenarios.

To classify model output into low- and high-risk areas, we used our presence-absence data to

plot rates of true positives (sensitivity) and true negatives (specificity) against risk predicted by the HRA model (Figure 6.3.2.6). Based on this plot, we selected a threshold value of 1.7 to separate low- and high-risk habitat, as this value maximized specificity while maintaining sensitivity greater than 90%.

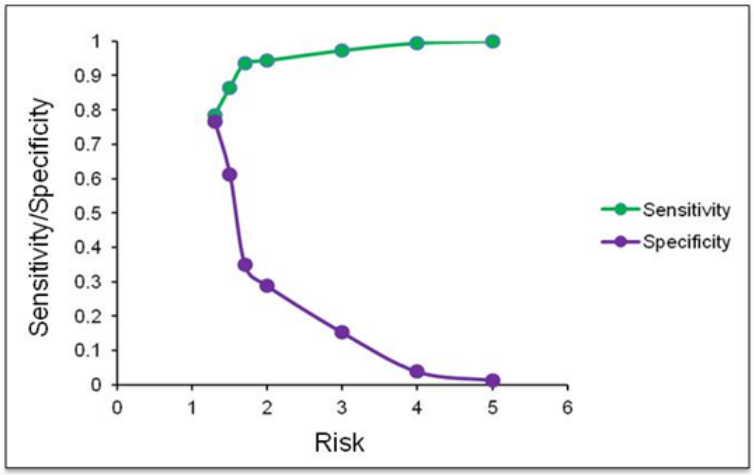


Figure 6.3.2.6. Sensitivity (true positives) and specificity (true negatives) plotted against risk to red-cockaded woodpecker nesting habitat at Fort Benning, GA, predicted by the InVEST Habitat Risk Assessment Model for the baseline year 2013.

Results:

Objective 1: ***Quantify provision of ecosystem services using existing GIS data***
Objective 3: ***Provide spatially-explicit rendering of service provision***
Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management options

We assessed these objectives together in the section below as they are closely related.
Based on HRA model output describing risk to habitat at baseline conditions in 2013, 48% of the total area found within Fort Benning and adjacent Army Compatible Use Buffer (ACUB) lands (110,970 ha) is classified as posing a high risk to nesting success of RCW, and 52% is classified as low risk habitat (Table 6.3.2.7; Figure 6.3.2.7). Under the Short-term Training scenarios, the amount of land predicted to present high risk to RCW nesting decreases. High-risk habitat decreases to 33% when mechanized training is concentrated on tank trails and ~1,500 ac of off-road maneuver corridors in the GHMTA and drops to 30% when mechanized training is distributed across tank trails in all three maneuver areas and on ~845 ac off-road maneuver corridors in the GHMTA (Table 6.3.2.7). Most of the decrease in high-risk habitat occurs in the ACUB lands, as recently burned and replanted long leaf pine forest ages over the 20-yr period

and trees grow to larger sizes favored by RCW for nesting (Hovis and Labisky 1985, Kelly et al. 1993, Conner et al. 1999, Walters et al. 2002; Figure 6.3.2.7; Figure 6.3.2.8). Under the 100-year Ecological Forestry scenario, the amount of habitat posing high levels of risk to RCW nesting drops to 12%, reflecting additional increases in the amount of replanted long leaf forest providing old, large trees over the 100-yr time period (Table 6.3.2.7; Figure 6.3.2.8). Together, the scenarios suggest any negative impacts of the additional mechanized training required by the Base Closure and Realignment Commission/Maneuver Center of Excellence (BRAC/MCoE) on RCW nesting become negligible when considering the much larger positive effects of converting loblolly pine plantations to longleaf forest across Fort Benning and adjacent ACUB lands.

Table 6.3.2.7. Percent of total land (110,970 ha) occurring within Fort Benning, GA, and adjacent Army Compatible Use Buffer (ACUB) lands classified into low- and high-risk areas based on model predictions for risk under Baseline (2013) conditions and alternative management scenarios. Scenarios include Short-term Concentrated Training (SCT), Short-term Diffuse Training (SDT), and Long-term Ecological Forestry (LEF).

	Scenario			
Risk	Baseline	SCT	SDT	LEF
Low	0.090	0.115	0.115	0.146
High	0.910	0.885	0.885	0.854

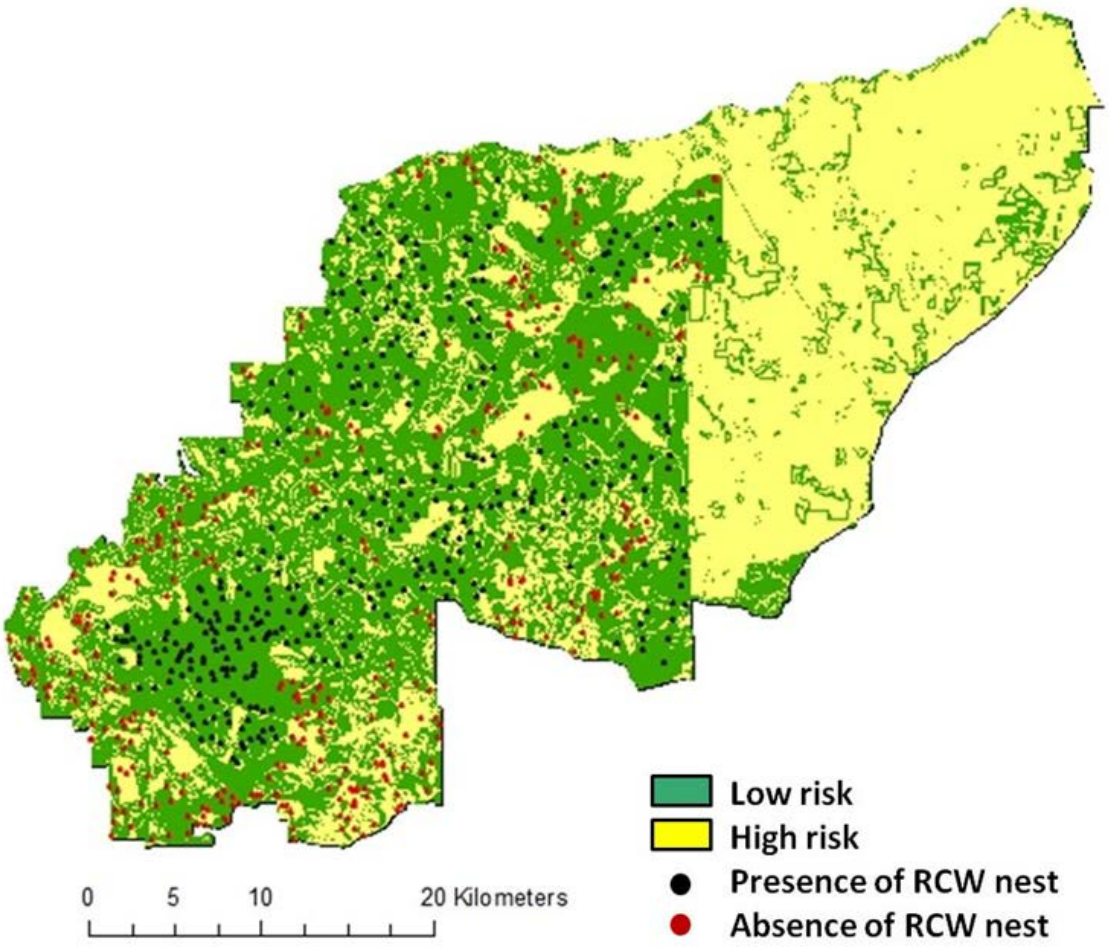


Figure 6.3.2.7. The distribution of habitat into low- and high-risk areas across Fort Benning, GA, and adjacent Army Compatible Use Buffer (ACUB) lands under baseline conditions (2013). Black dots indicate presence of RCW nests (cluster centroids based on 2013 field data) and red dots indicate absence of RCW nests (based on generated random points- see text for description of methods).

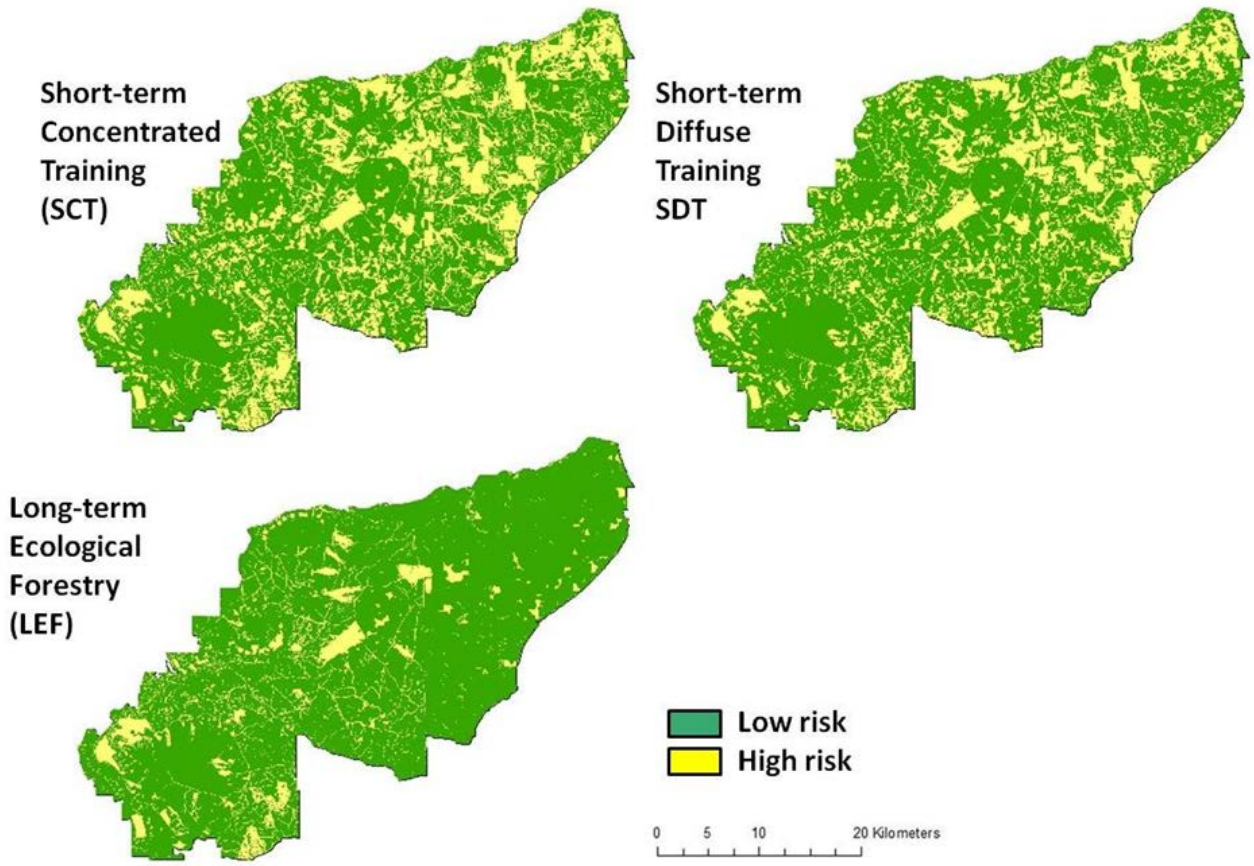


Figure 6.3.2.8. The distribution of habitat into low- and high-risk areas across Fort Benning, GA, and adjacent Army Compatible Use Buffer (ACUB) lands under three alternative management scenarios. Scenarios include Short-term Concentrated Training (20-yr SCT), Short-term Diffuse training (20-yr SDT), and Long-term Ecological Forestry (100-yr LEF).

- **Assessment of red-cockaded woodpecker nesting (Tier 2)**

Objective 5: Assess and report degree to which model results depict reality

To meet Objective 5, we tested the performance of the HRA model in predicting presence-absence of RCW clusters across Fort Benning during the baseline year (2013) (described above). Additionally, we compared Tier 2 (HexSim) outputs resulting from a model run using HRA risk values as inputs to Tier 2 (HexSim) outputs resulting from a model run using habitat quality values estimated by Lawler et al. (2011).

<u>Model inputs and assumptions</u>

Model inputs include hexagonal maps of either risk to habitat or habitat quality, and tables defining demographic parameters for the species of interest (i.e., RCW). Below, we describe

each of these inputs and assumptions associated with their use.

For this demonstration, we developed input maps for HexSim from maps output by the HRA model illustrating risk to habitat at Fort Benning under each alternative management scenario. Because HexSim simulates populations through time, we developed input maps for ten-year intervals covering the 20-year period from 2013 to 2033 for the short-term training scenarios (SCT and SDT) and covering the 100-year period from 2013 to 2113 for the LEF scenario.

In an effort to match the range of habitat quality scores used by Lawler et al. (0-100 with 100 being considered the highest habitat quality, mean = 39, SD = 33.55), we re-ran the HRA models used to meet objectives 1, 3, and 8, but altered the classification of stressor intensity (Table 6.3.2.4). Whereas stressor intensity remained the same for the four training stressors and both low- and high-resistance open habitat, the scale of stressor intensity for forest stand tree age was extended from 1-3 (Table 6.3.2.4) to 1-15. Stands with an average pine age greater than 140 years received an intensity score of 1, 121-140 years an intensity score of 2, 101-120 years an intensity score of 3, 81-100 years an intensity score of 4, 61-80 years an intensity score of 5, 31-60 years an intensity score of 10, and pine stands with an average pine age less than 30 years received an intensity score of 15. We also standardized the HRA output maps by dividing the inverse of each risk score by the highest risk value for all scenarios (risk = 9.4) and adding 100 (range = 25-100, mean = 86, SD = 13.44). Whereas we were able to match the range of HRA risk output scores to that of habitat quality scores used by Lawler et al. (2011), a comparison across 207 randomly sampled points using a Kolmogorov–Smirnov test indicated a significant difference in distribution shape ($P < 0.0001$; Figure 6.3.2.9). Last, we excluded areas considered incompatible for RCW nesting habitat (conifer cover less than 50%) and simulated population growth and dispersal through 10 iterations of HexSim.

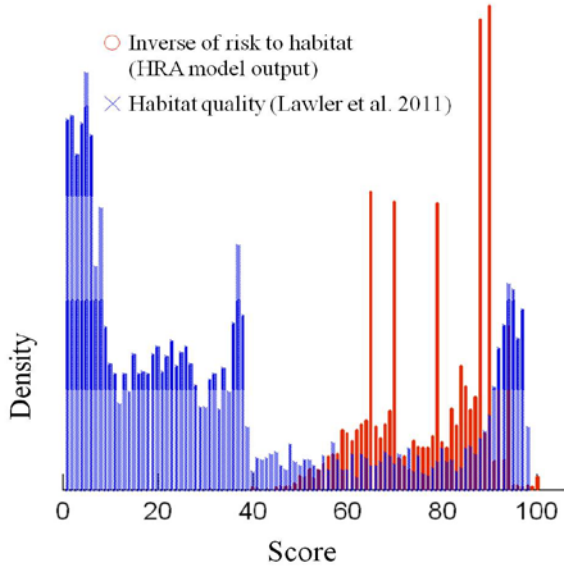


Figure 6.3.2.9. Distributions of Habitat Risk Assessment Model risk scores (red circles) and habitat quality scores (blue x's) from Lawler et al. (2011).

We used species- and population-specific parameters developed by Lawler et al. during a previous application of HexSim to the modeling of RCW populations at Fort Benning (Lawler et al. 2011). Parameter values developed by Lawler et al. (2011) were based on published literature (Walters et al. 1988, Walters 1990, DeLotelle and Epting 1992, LaBranche and Walters 1994, Engstrom and Sanders 1997, Conner et al. 1999, Daniels and Walters 2000, Doresky et al. 2001, Leonard. et al. 2003, Conner et al. 2004) and baseline population trajectories were targeted to match the current number of potential breeding pairs at Fort Benning (N = 240) under current conditions. Since transformed HRA values differ in distribution from habitat quality used by Lawler et al. (2011), we selected a minimum range resource value of 5,184, which was the mean sum of transformed HRA scores within a 79-ha buffer (Epting et al. 1995) around known presence points for RCW (N = 325).

Results:

Objective 5c: Assess and report degree to which model results depict reality

When conditions assumed under the Short-term Concentrated Training scenario are continued from 2013 to 2113, HexSim model output suggests the number of RCW breeding pairs would increase from ~220 pairs in 2013 to ~320 pairs in 2023 and average ~350 pairs between 2043 and 2113 (Figure 6.3.2.10). Whereas habitat maps input into the HexSim model by Lawler et al. (2011) and in this study were both significant predictors of the presence-absence of active RCW nests under current conditions, our results suggest model performance in predicting presence-absence of active RCW nests under current conditions does not directly relate to model performance in predicting RCW population growth through time (Figure 6.3.2.10). More specifically, despite similar performance in predicting presence-absence of active RCW nests under current conditions, risk values output by the Habitat Risk Assessment (HRA) model do not relate directly to habitat quality values as modeled by Lawler et al. (2011). Differences between risk and habitat quality values lead to divergent estimates of RCW breeding pairs through time, although they appear to converge around 2103 (Figure 6.3.2.10). The distribution of risk values output by the HRA model could perhaps be manipulated to establish a direct relationship with habitat quality, but doing so might complicate interpretation of risk values across the study area. Alternatively, additional investigation might find different stressors used as input in the HRA model that result in risk values directly related to habitat quality. We conclude that the HRA model may be best suited to comparing tradeoffs among alternative management scenarios, and that risk output may not act as a reliable predictor for precise estimates of breeding pairs/population size of RCW at a particular place or time.

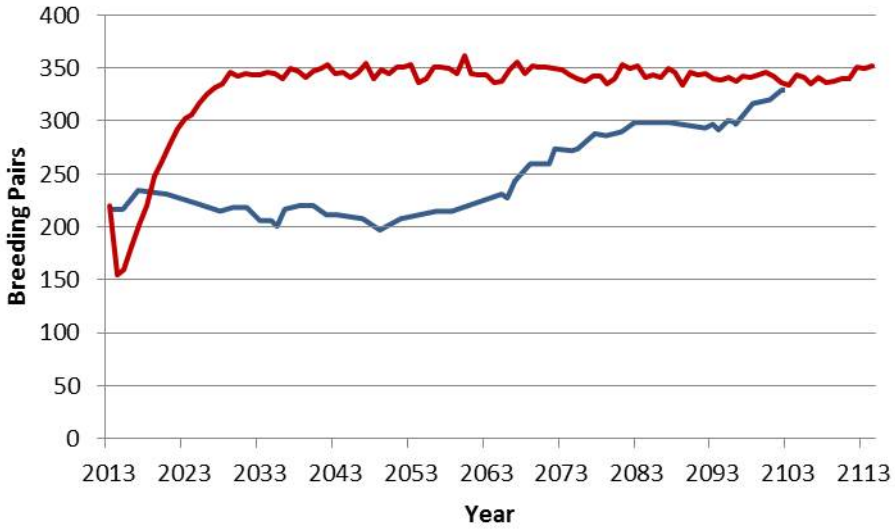


Figure 6.3.2.10. Mean number of red-cockaded woodpecker breeding pairs predicted at Fort Benning, GA, from 10 iterations of HexSim over a 100-year time period. The red line indicates HexSim results using inverse HRA risk value outputs and the blue line indicates previous HexSim results from Lawler et al. (2011) using habitat quality values.

- **Water yield and sediment retention**
  - ✓ Objective 1: Quantify provision of ecosystem services using existing GIS data
  - ✓ Objective 2: Quantify value of ecosystem services for at least two ecosystem services
  - ✓ Objective 3: Provide spatially-explicit rendering of service provision
  - ✓ Objective 4: Provide spatially-explicit rendering of the social value of at least two key ecosystem services
  - ✓ Objective 5: Assess degree to which model results depict reality and compare Tier 1 vs. Tier 2 performances against observations
  - ✓ Objective 6: Incorporate uncertainty into service-provision estimates for at least two key services of interest
  - ✓ Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management option

To meet Objectives 1, 3, and 8, we used the InVEST sediment model to assess soil erosion, sediment export, and sediment retention at Fort Benning watershed for a baseline and two alternative scenarios (Short-term Concentrated Training [SCT] and Short-term Diffuse Training [SDT])[7] at a 10-m resolution. To meet Objective 5, we compared the performance of InVEST

[7] We did not assess the sediment model for the LEF scenario because of the substantial uncertainty associated with hydrological parameters for 100-year predictions. Without considering long-term variation in climate and training activities, our sediment assessment for the SCT scenario remains valid for the LEF scenario as the transition among different forest types has a minor influence on hydrological models.

models with SWAT, a tier-2 alternative, with observed streamflow and suspended sediment concentration data at a sub-watershed of Fort Benning. To meet Objective 6, we conducted a sensitivity analysis to identify influential parameters and their relative contributions to output uncertainty. To meet objectives 2 and 4, we estimated the marginal cost of sediment retention as the avoided cost on structural erosion controls. However, as the total value of sediment retention only applies to additional sediment removal above a threshold defined by water quality regulations, we were not able to assess and map the total economic value of this service due to lack of threshold information.

The landscape of Fort Benning has been re-shaped by military transformation initiatives of the BRAC and MCOE (USACE 2009, Fort Benning 2001). Given the scale and intensity of those transformation activities, soil erosion and sedimentation could potentially be the greatest risk to surface waters in Fort Benning (Fort Benning 2001). Most of the surface soils on Fort Benning are identified as highly erodible due to dominance of sandy and sandy clay loam in uplands, the climate, and the rolling steep slopes along the Fall Line that allows storm water to easily dislodge and transport sand particles into streams and rivers (Fort Benning 2001, 2006). Frequent training with military vehicles on and off roads is anticipated to bring massive vegetation disturbance and soil physical degradation. Subsequently, changes in vegetation and soil structure are expected to exacerbate soil erosion and elevate sediment depositions in streams, rivers, and reservoirs. If appropriate mitigation measures are not taken in advance, elevated suspended sediments could degrade water quality and reduce aquatic and wildlife habitat (Sharif and Balbach 2008, USACE 2009). Therefore, identification and quantification of sources and sinks of soil erosion potential related to military missions and characterization of their impacts is the focus of this study to provide decision-makers with the best scientific information and help them to ensure mission sustainability and prevent adverse environmental impacts on ecosystem functions. On-site assessment of erosion potential is often not practical for an entire watershed or military facility. Often, the most practical and effective means of identifying sources of soil erosion is with the use of models (USACE 2009).

Model inputs and assumptions

This project employed SWAT, a daily semi-distributed model that simulates both erosion and deposition on daily basis, and InVEST, a much simpler model capable of simulating the spatial distribution of mean annual erosion and depositions explicitly at grid scale, to quantify water yield and sediment retention.

InVEST and SWAT require inputs about local climate, land use, and pedology. More on the model structures and required inputs can be found in sections 5.3.6 (InVEST) and 5.3.7.1 (SWAT). Climatic data used for this study were obtained from National Climatic Data Center (NCDC). In addition, static inputs viz. DEM, land use characteristics (e.g., root depth, crop evaporation coefficient, leaf area index), and soil characteristics (e.g., soil water holding

capacity, soil depth texture, soil erodibility) were obtained from databases of USGS, USDA, NOAA, and Fort Benning. Crop evaporation coefficients were obtained from various sources (e.g., Sharif and Balbach 2008, Lui et al. 2010, Donigian 2013). For the base scenario, the 2006 National Land Cover Database (NLCD 2006) land use map was used to represent the pre-BRAC and MCOE conditions and 15 land use classes were identified. For the SCT and SDT scenarios, land use changes are made to include roads, tank trails, and cantonment based upon recent land use land cover (LULC) obtained from installation personnel. In addition, changes in training intensity, soil and water management, forest management, and Army Competitive Use Buffer (ACUB) were considered in the model to realistically simulate soil erosion and sediment retention potential across the installation. For SCT, in addition to existing BMPs, new enhanced BMPs (Parson 2012) were incorporated into the land use layer. Retention efficiencies for different BMPs were estimated based on various sources (e.g., EPA 2006; USACE 2009).

Although both models have been widely used in a number of watersheds to estimate the response of watersheds to land use change scenarios, as well as the effects of scenarios on ecosystem services (e.g., Gassman et al. 2007, Izquierdo et al. 2012, Ziv et al. 2012, Logsdon and Chaubey 2013), the models have not been tested for conditions that exist on military training facilities. One of the most challenging aspects in modeling military installations is the accurate representation of land surface disturbances (e.g., roads, tank trials) and training intensities into model parameters. The Construction Engineering Research Laboratory (CERL) has developed an approach to estimate training intensity and related watershed parameters. However, we found the approach to be incompatible with our models and four of the twelve inputs also require expert opinion, which adds more uncertainty to the parameters. Based on the information provided by the base managers and previous studies conducted on Fort Picket (e.g., FortBenning 2006, 2011) and Fort Benning (Sharif and Balbach 2008, Donigian 2013), impacts generally are categorized into low and high classes as shown in Table 6.3.2.8. These factors were explicitly represented by the parameters for crop factor (C) and practice factor (P) in the USLE equation and by the parameter retention efficiency in the sediment delivery method (Table 6.3.2.8). The differences between SCT and SDT in terms of training and soil and water management is provided in Table 6.3.2.9.

Unpaved roads and tank trails are major erosion contributors in Fort Benning and their accurate representation in the process of modeling is considered critical in order to accurately assess their hydrological consequences (Donigian 2013). Most of the runoff generated on roads and tank trails does not follows the natural hydrological paths when it flows; rather it flows into drainage conduits which are connected to rivers. A new algorithm is developed within InVEST that routes the soil erosion generated from roads and tank/trials to a river and calculates the sediment entering the river based on the retention efficiency of the riparian zone where the river is buffered. InVEST cannot distinguish between road types (e.g., outsloping and insloping), but it distinguishes between unpaved and paved types. SWAT is, in essence, a lumped or semi-distributed model in which the catchment is subdivided into a limited a number of hydrological

units (HRUs). Each HRU is assumed to represent a relatively homogenous land use, even though more than one land cover may still exist within HRU. Nevertheless, the watershed is discretized into smaller HRUs to represent roads and tank trials well within HRUs.

Table 6.3.2.8. Land Use and Land Cover (LULC) classes and their estimated parameters for the InVEST Sediment Retention Model under the Short-term Concentrated Training (SCT) scenario at Fort Benning, GA.

LULC for SCT	Practice factor	Retention	Crop factor
Clearcut	1.00	0.00	0.32
Open Water	1.00	0.90	0.00
Developed, Open Space	1.00	0.00	0.06
Developed, Low Intensity	1.00	0.00	0.06
Developed, Medium Intensity	1.00	0.00	0.09
Developed, High Intensity	1.00	0.00	0.09
Bare Ground	1.00	0.00	0.32
Deciduous Forest	1.00	0.50	0.02
Evergreen Forest	1.00	0.53	0.01
Mixed Forest	1.00	0.52	0.01
Shrubland	1.00	0.37	0.01
Grassland	1.00	0.45	0.05
Sparsely Vegetated	0.70	0.18	0.15
Pasture/Hay	1.00	0.45	0.05
Cultivated Crops	0.60	0.09	0.18
Woody Wetlands	1.00	0.53	0.00
Emergent Herbaceous Wetlands	1.00	0.53	0.00
Paved Roads	1.00	0.00	0.15
Unpaved Roads	1.00	0.00	0.70
Paved Tank Trails	1.00	0.00	0.15
Unpaved Tank Trails	1.00	0.00	0.70
Low Impact Bare Ground	1.00	0.00	0.31
Low Impact Grassland	1.00	0.30	0.01
High Impact Clearcut	1.00	0.00	0.34
High Impact Bare Ground	1.00	0.00	0.43
High Impact Deciduous Forest	1.00	0.30	0.03
High Impact Evergreen Forest	1.00	0.32	0.01
High Impact Mixed Forest	1.00	0.31	0.01
High Impact Grassland	1.00	0.27	0.07
High Impact Sparsely Vegetated	1.00	0.00	0.26
High Impact Woody Wetlands	1.00	0.32	0.00
Berm	1.00	0.34	0.00
Grass Planting	1.00	0.39	0.00
Riser	1.00	0.34	0.00
Rock Dam	1.00	0.21	0.00
Rock Dam (needs maintenance)	1.00	0.48	0.00
Sediment Basin	1.00	0.45	0.00
Water Bar	1.00	0.36	0.00
Voluntary Buffer Deciduous Forest	0.10	0.52	0.02
Voluntary Buffer Evergreen Forest	0.10	0.55	0.01
Voluntary Buffer Mixed Forest	0.10	0.54	0.01
Voluntary Buffer Woody Wetlands	0.10	0.51	0.05
Dudded Deciduous Forest	1.00	0.30	0.03
Dudded Evergreen Forest	1.00	0.52	0.03

Table 6.3.2.9. Differences in Training Area, intensity, and Best Management Practices (BMPs) between Short-term Concentrated Training (SCT) and Short-term Diffuse Training (SDT) scenarios

Differences	**SCT**	**SDT**	**Impact on model parameters**
Off-road maneuver roads in Good Hope Maneuver Training Area	1500ac	845 ac	-60% crop factor (C), -60% retention capacity, +30% soil erodibility (K)
BMPs in Good Hope Maneuver Training Area	Existing + planned	Existing only	More sediment retention for SCT
Mechanized training in Northern Installation	Low intensity	High intensity	-60% crop factor (C), -60% retention capacity, +20% soil erodibility (K) for SCT -60% crop factor, -60% retention capacity, +30% soil erodibility (K) for SDT

Results

Objective 5: ***Assess degree to which model results depict reality and compare Tier 1 vs. Tier 2 performances against observations***

The degree of model calibration and validation is typically dictated by the availability of measured data. The best and most complete streamflow and SSC record available in Fort Benning is at McBride Bridge in the Upatoi creek. InVEST runs on a pixel scale, but the results are reliable only at the sub-basin scale. SWAT runs at scale of HRUs and aggregates outputs at the sub-basin level. For fair comparison, we isolated the differences in model structure to determine both the models' accuracy and the value of the model results for making ecosystem service decisions, rather than allowing variations in model inputs to create differences. To do so, we used inputs to the InVEST model which are equivalent to those in the SWAT model and comparisons were conducted at sub-basin scale.

We first compared the water yield results from both models. The SWAT model was calibrated and validated for streamflow at McBride Bridge during 2008-2011 and 2004-2007, respectively. This calibration required significant effort to reasonably estimate accurate streamflow. A plot of simulated versus observed monthly flows for the calibration period of 2008-2011 and validation period of 2004-2007 is shown in Figure 6.3.2.11. The coefficient of determination (R^2) was computed in order to assess the accuracy of simulated flows against the corresponding observed flows. Figure 6.3.2.11 (a) shows a very high performance of the SWAT model (R^2 = 0.91), revealing that the model is well calibrated against observed flows. The high and low flows are simulated well, except with more scatter at medium flows for the calibration period. SWAT

performance for the validation period is good except with one inlier point that negatively affected the association result (Figure 6.3.2.11 b). Nevertheless, the correlation between model flows and observations (R^2 = 0.73) is above the 0.65 tolerance threshold we set as a success criteria in our performance objectives.

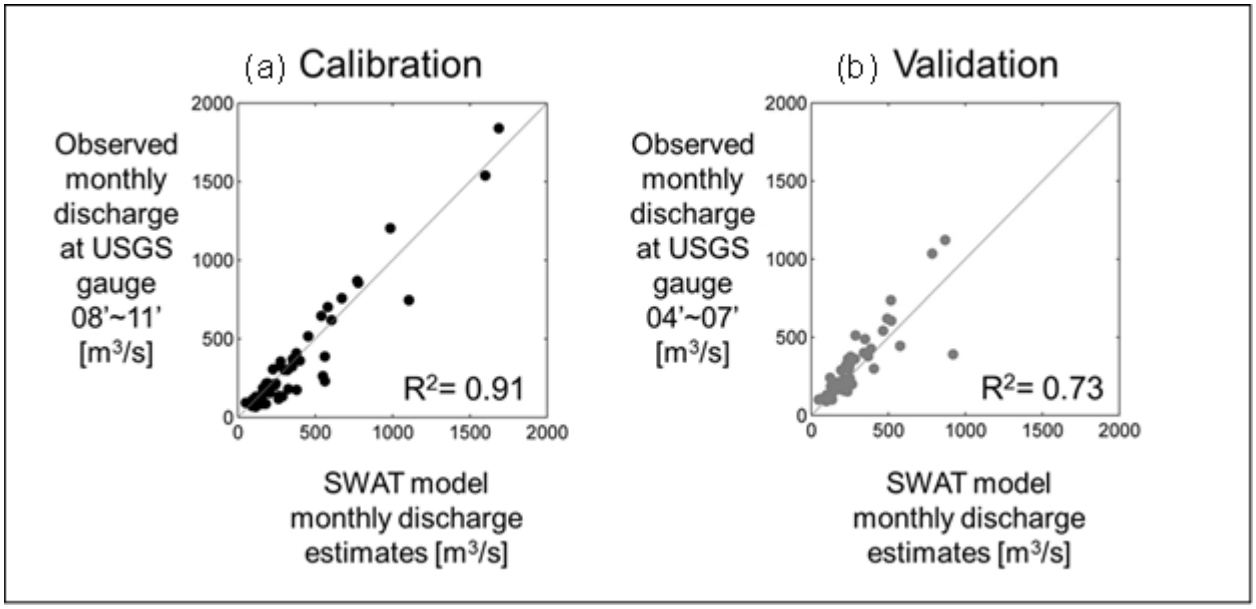


Figure 6.3.2.11. Scatter plots illustrating Soil Water Assessment Tools (SWAT) simulations versus observed flows for (a) the calibration period of 2008-2011 and (b) validation period of 2004 -2007.

InVEST was calibrated for water yield against the mean annual observed stream flows for the period of 2004-2011 at the McBride Bridge station, and the error statistics between InVEST simulations and observations is brought to 1.5%. Since no adequate observed data is available at each sub-basin, true water yield for each subabasin is unknown. SWAT is well calibrated and proven to mimic both the high peakflows and baseflows observed in the basin during the validation period and it is used as a reference to evaluate InVEST performances across the 35 subasins that make up the Upatoi basin at the McBride Bridge gauge. Sub-basin water yields and ranks are depicted in Figure 6.3.2.12.

SWAT and InVEST estimates of water yield diverge significantly in the Upper Upatoi Watershed. SWAT estimates of water yield vary relatively little across the Upper Upatoi Creek Watershed (Figure 6.3.2.12), probably due to its largely baseflow-supported hydrograph. InVEST water yield estimates have a significantly larger range, although most of the estimates are within 15% of the SWAT estimates (Figure 6.3.2.12c). The average annual water yield estimates from the two models also have strong spatial differences. InVEST water model estimates that the northwestern part of the watershed provides a large water yield, while SWAT estimates the water yield from that area will be average. The northwestern part of the watershed

consists of some low-density urban zones interspersed with significant areas of forest and wetlands. While the urban zones could provide a higher water yield than the forests in much of the rest of the watershed, SWAT calibration suggests that these low-density urban zones supply quick runoff after a storm but the well-drained sandy soils elsewhere in the watershed support a great deal of long-term baseflow that provide similar total water yields on a long-term basis. In addition, SWAT suggests that the wetlands in the southern part of the watershed should have an above-average water yield, while InVEST estimates them as only about average.

The mismatch between SWAT and InVEST water yield estimates in the Upper Upatoi Creek watershed is mainly due to the simpler InVEST model's inability to capture baseflow-supported stream dynamics. Because of InVEST's greater simplicity, we used a 20% percent error as an acceptable threshold to evaluate model accuracy. Only 5 out of 35 sub-basins have a greater than 20% error in water yield as seen in Figure 6.3.2.12c. As discussed previously, the InVEST annual water yield model is more suited to estimating relative ranks of sub-basins in water yield than in suggesting absolute values.

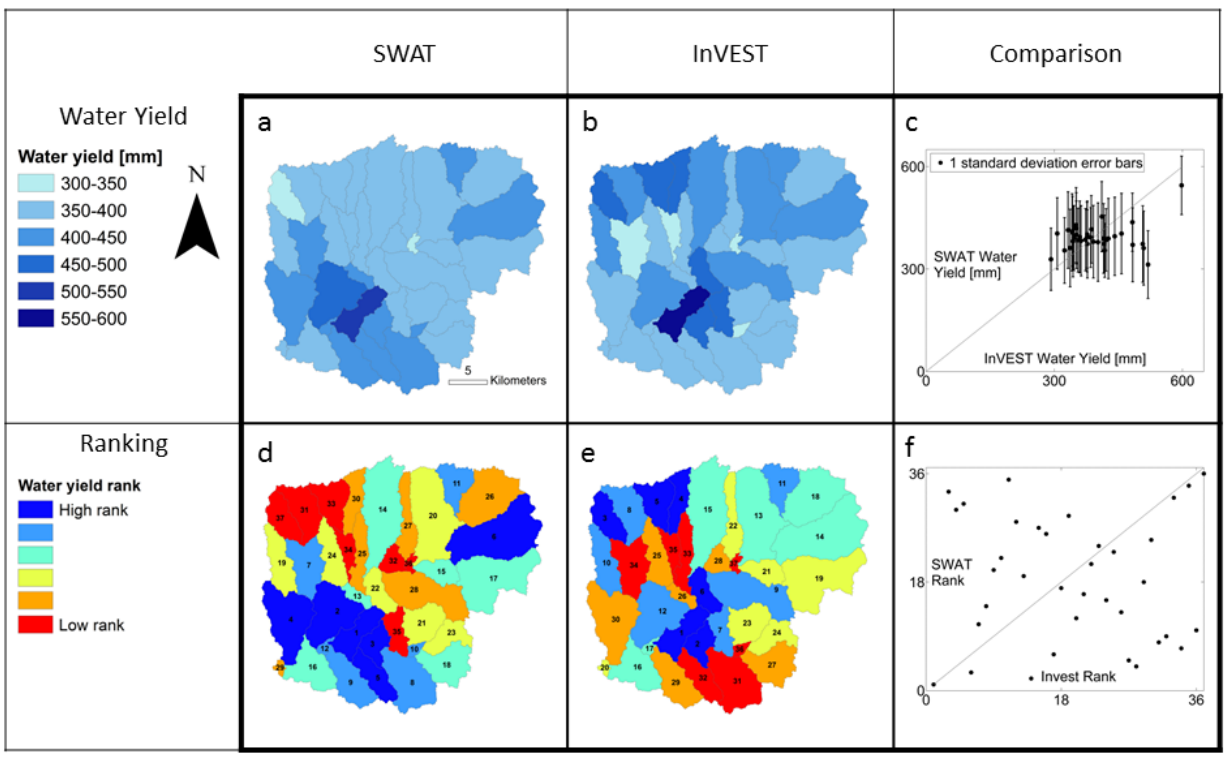


Figure 6.3.2.12. Sub-basin water yields and rank comparison between Soil Water Assessment Tools (SWAT) and InVEST.

Next, we compare SWAT and InVEST sediment yield outputs. SWAT is driven by streamflow and peakflow to estimate erosion and sediment depositions along the flow paths while InVEST

uses rainfall intensity to estimate soil erosion and retention efficiencies and sediment depositions along the flow paths. For SWAT, a key factor for accurate estimation of sediment yield is an accurate estimation of streamflow. Erosion rates recommended for various land uses and activities were used (e.g., Kim et al. 2012, Donigian 2013) to provide additional insight into the quality of the model calibration. The error statistics between InVEST simulations and observations is 2% indicating the model is calibrated enough against the average sediment yield observed for the period of 1996-2006. Similar to our comparisons for water yield, the performance of the InVEST sediment model was also evaluated by comparing with the sediment yields generated by SWAT at the 13 HUC12 scale that make up the Upatoi creek at McBride Bridge gauge (Figure 6.3.2.13).

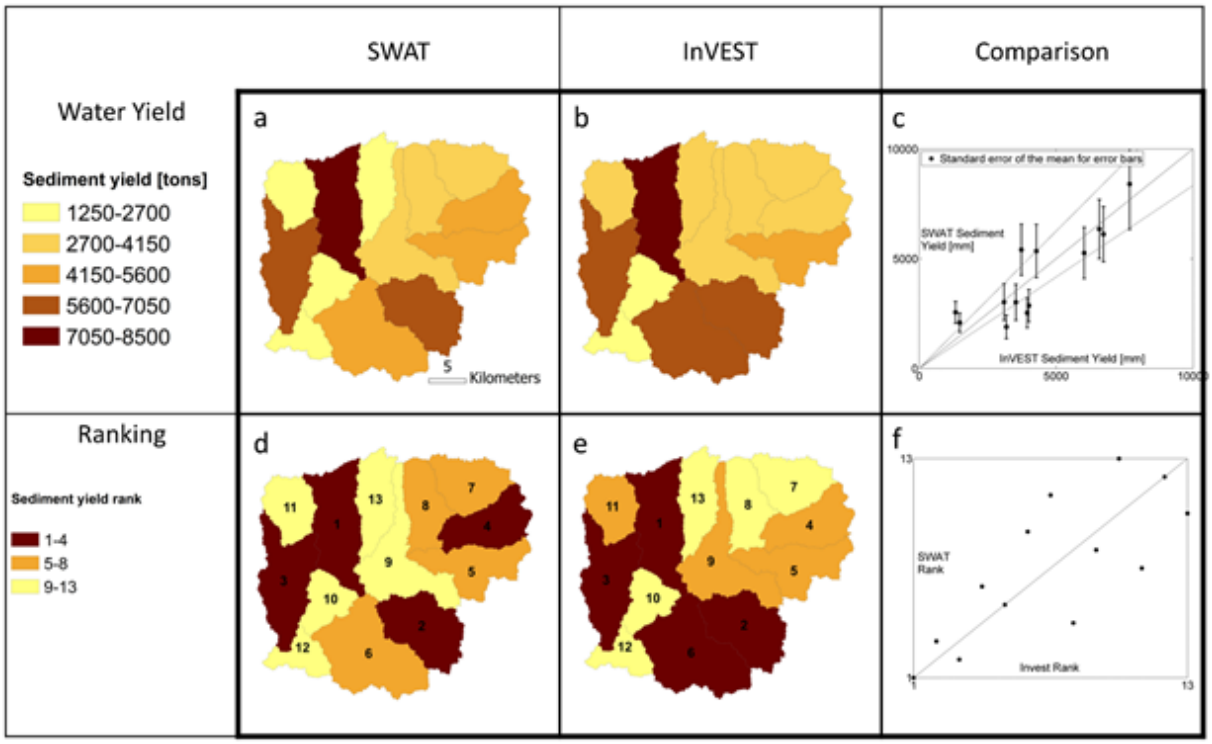


Figure 6.3.2.13. Sub-basin sediment yields and rank comparison between Soil Water Assessment Tools (SWAT) and InVEST.

The SWAT and InVEST agree in identification of the high and low sediment yield sub-basins (Figure 6.3.2.13 c), yet some sub-basins show significant differences in sediment yield estimates between the models. The correlation between the two models is 0.87. Better streamflow gage data could help reduce the spatial variation in model comparisons. Nevertheless, the errors are within the acceptable limits established by DoD personnel, and the results demonstrate that the InVEST model is capable of identifying sources of erosion and sinks across Fort Benning.

Objective 6: Incorporate rate uncertainty into service-provision estimates for at least two key services of interest

Uncertainty stems primarily from three main sources: uncertainty related to input variables (e.g., measurement errors), uncertainty due to possible errors in different sets of model parameters (e.g., lack of information to calibrate all parameters), and uncertainty due to model inadequacy (Loucks et al. 2005, Li and McNulty 2007). Our analysis focuses on the first two sources for analyzing uncertainty associated with the InVEST sediment model. To determine the parameters contributing most to the output uncertainty, a sensitivity analysis was first conducted for all of the 5 parameters (rainfall erosivity-R, soil erodibility-K, flow threshold, crop factor-C, and retention efficiency) of the InVEST sediment model. A technique of single parameter sensitivity analysis was used by changing one parameter at a time under deviations of -30, -15, 15 and 30 percent relative to their calibrated values. Then, an index of relative error in the sediment outputs caused by a given percentage change in model input was calculated. As shown in Figure 6.3.2.14, the relationships between model inputs and model outputs was found to be linear, as expected, with a 30% increase/decrease of K or R results and a 30% percent increase/decrease of the sediment estimates. InVEST estimates showed a slightly non-linear response to changes of C factor. A 15% increase in C-factor resulted in 8% increase in soil erosion, 7.8% increase in sediment retention, and 11.3% increase in sediment export. Variations in flow threshold and retention efficiency had no or little impact on soil erosion and sediment retention.
Next, we determined the relative contributions of each parameter to the uncertainty associated with the model prediction of soil erosion, sediment retention, and export (Figure 6.3.2.15). Changes in particular model input values can affect model output variables in different ways. The results from the sensitivity analysis (Figure 6.3.2.14) indicate a strong linear relationship between individual model parameters and the outputs. Hence, regression equations were developed to examine the probable error contribution of each parameter to the output variables.

The simulation strategies were:
By defining probability distributions of the values of parameters p to normal, 1000 p values were randomly generated.
For each realization p, the regression equations were run 1000 times to obtain a statistical description of system performance variability.
Assuming the parameters errors are independent, the relative error contribution due to parameter p was then calculated by

$$E_p = \frac{{\sigma_p}^2}{{\sigma_{all}}^2}$$

where E_p is the fraction of error contribution by parameter p, ${\sigma_p}^2$ is variance in model output by the change of target parameter p, and ${\sigma_{all}}^2$ is the overall variances of the model obtained from the 5 parameters.

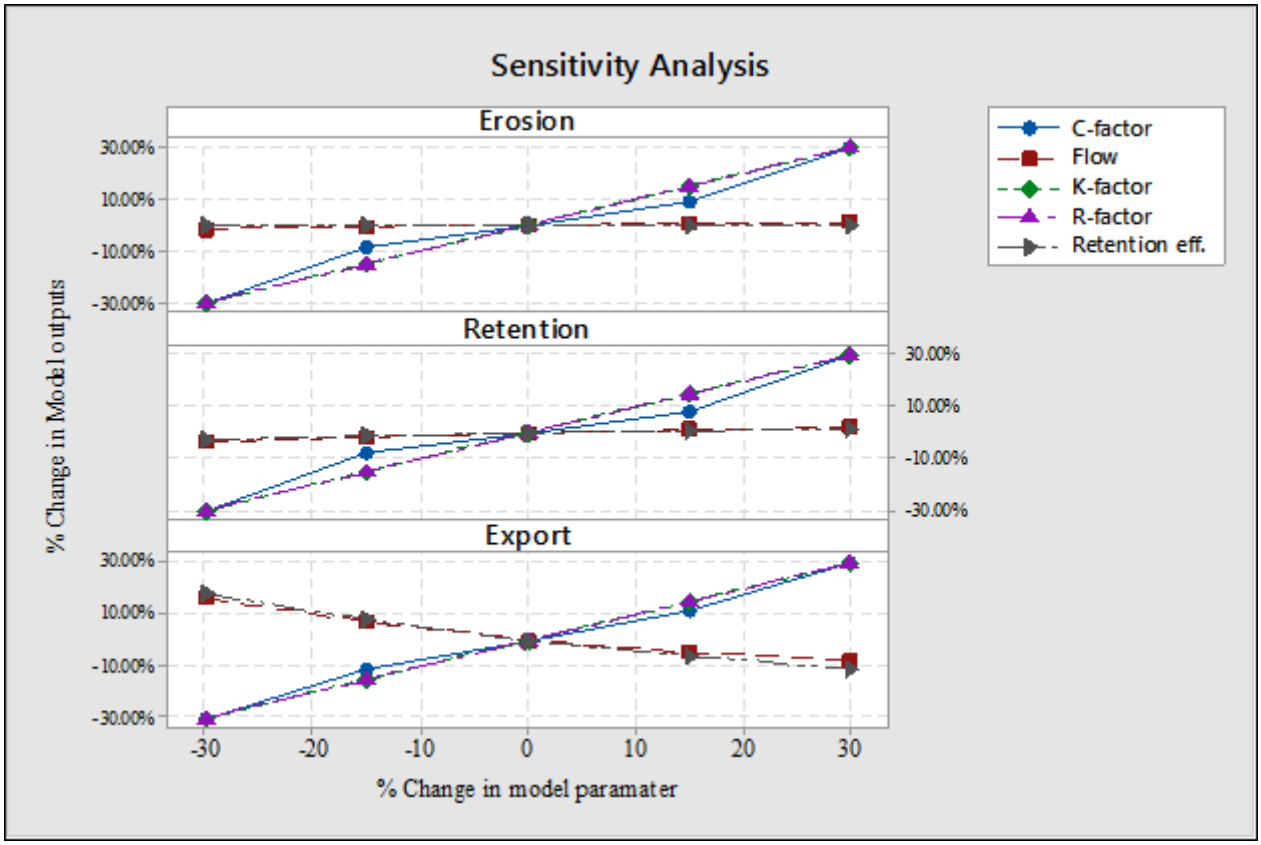


Figure 6.3.2.14. Sensitivity analysis for five parameters in the InVEST Sediment Retention Model.

For soil erosion and sediment retention, about 70% of the total parameter error variance is associated with erosivity and erodibility, and the remaining 29% is associated with the C-factor, and 1% is associated with the flow threshold. About 60% of the total parameter error variance in the sediment export estimate is associated with erosivity and erodibility, and the C-factor accounts for 27%, retention efficiency accounts for 8%, and flow threshold accounts for 5% of the variance (Figure 6.3.2.15).

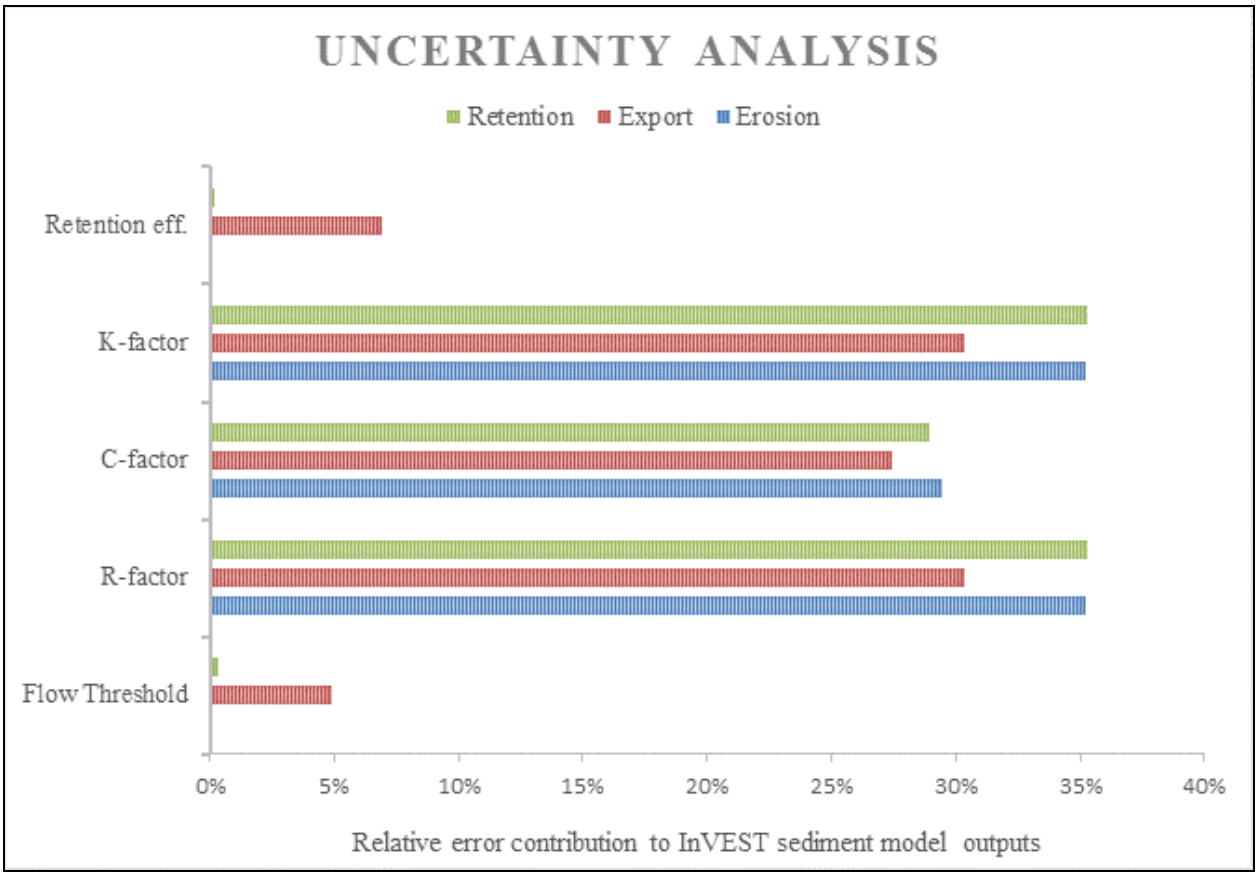


Figure 6.3.2.15. Uncertainty analysis for five parameters in the InVEST Sediment Retention Model.

The simulation results under the full range of the probabilistic parameter sets that much of the uncertainty in soil erosion, sediment retention, and export came from erosivity, erodibility, and the C-factor. However, even though erosivity and erodibility are the most influential parameters, they were obtained from detailed climate and soils information, respectively, for this study. Thus, erosivity and erodibility likely have relatively less uncertainty than the C-factor, retention efficiency, and flow threshold values, which were obtained from literature and adjusted using expert opinion.

Objective 1: Quantify provision of ecosystem services using existing GIS data
Objective 3: Provide spatially-explicit rendering of service provision
Objective 8: Estimate absolute and relative changes in each ecosystem service that will result from alternative management options

These objectives were assessed together in the section below as they are closely related.
We compared soil erosion and sediment yield resulting from SCT and SDT scenarios, which reflect differences in the expansion of unpaved roads, tank trails, and intensive military training across Fort Benning. Land use changes under these scenarios represent cumulative losses of

wetlands and native upland forests over the maneuver areas. These changes in vegetation have the potential to alter the natural drainage patterns and affect surface runoff and infiltration rates. We used the calibrated InVEST sediment model to predict spatially explicit, quantitative impacts of these land use changes in Fort Benning. Such prediction could serve as a basis for developing sound watershed management practices that ensures environmentally sound training sustainability.

Before evaluating the hydrological consequences of the SCT and SDT scenarios, we estimated soil erosion produced within and beyond installation boundaries. Such estimates are important to determine and relate to the installation's responsibility for control and mediation of sediment loads that may lead to river impairment (Sharif and Balbach 2008, Donigian 2013). Figure 6.3.2.16 depicts a basin-wide soil erosion map under development for the SCT. At the outlet of the basin, our analysis shows that about 32% of soil erosion originates from inside the installation and the remaining 68% derives from off-installation areas. Off-installation average soil erosion is estimated at 5.7 tons/ac/year, and the average erosion rate within the installation is predicted at 3.1tons/ac/year. Within the installation, most of the sediment yield originates from the maneuver areas, as expected. The maneuver areas (clear cut, dirt tank trials, unpaved roads, and impacted land uses) account for 10% of the installation area, but are responsible for 23% of the total soil erosion produced within installation. Outside the installation, the urban (developed) areas in the Columbus region and the agricultural areas in the northern part of the basin account for 47% and 6%, respectively, of the total sediment yield that flows into the rivers of the Fort Benning watershed. Basin wide average sediment export is estimated at 0.43 tons/ac/year. Approximately 9.2% of the total eroded soils are delivered into the streams. Most of the sediment retention service is provided by upland forests and voluntary riparian buffers within Fort Benning that are typically located within 50 feet from stream edges, and up to 100 feet from wetlands.

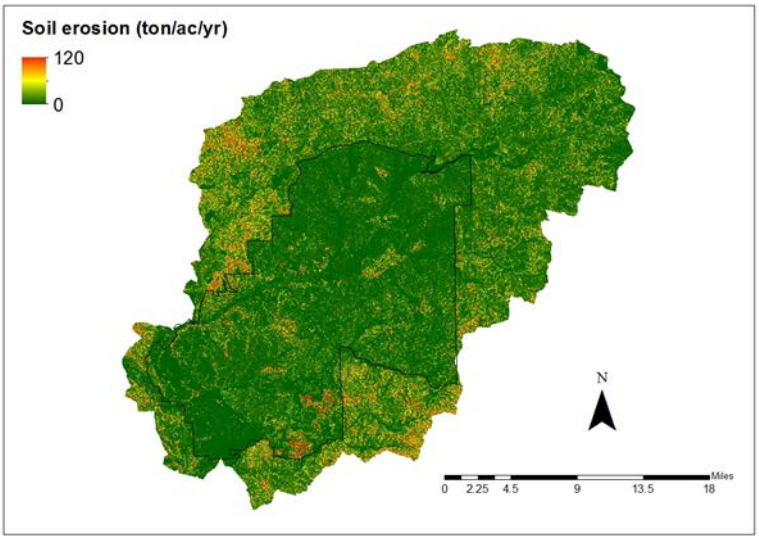


Figure 6.3.2.16. Soil erosion rates in the Fort Benning, GA, watershed

Figures 6.3.2.16 and 6.3.2.17 present the SCT- and SDT-based simulations side by side at 10-m grid and sub-basin (HUC12) scale resolutions, respectively. These plots allow visual inspections and comparisons between these two major land use change scenarios in terms of changes in soil erosion, sediment retention and export. Table 6.3.2.10 reports detailed statistical information that highlights the significance of improvements or losses in sediment yield resulting from each scenario. Both scenarios displayed similar erosion rates, sediment retention and export. For example, at the basin outlet, the SCT scenario yields relatively small overall increases in sediment relative to SDT: only 1.7% greater soil erosion, 1.1% higher sediment export, and 1.9% greater sediment retention rates. However, a closer examination of results indicates that the SCT scenario has a slightly lower erosion rate than the SDT scenario in the northern and southern maneuver areas due to reduced training intensities. A more significant difference in soil erosion rate, sediment retention and export between these two scenarios is observed in the GHMTA. The SCT-driven soil erosion is higher by as much as 10% than in the SDT scenario (Table 6.3.2.10). The excess soil erosion simulated under the SCT scenario is attributed to massive land use clearance for off-road training; the concentrated training activities compounded with highly erodible soils in the GHMTA result in much higher soil erosion rates.

In general, the sediment export and retention in the GHMTA were 10% higher under the SCT, as compared to the SDT scenario (Table 6.3.2.10). The contributions of different vegetation types to the overall sediment retention service were: forest (evergreen deciduous, mixed) at 58%, and grassland and wetlands at 21% and 5%, respectively. In contrast, the proposed BMPs (sediment basins, berm and swale, rip-rap lined channels and filter socks, filter dams) under the SCT scenario are estimated to retain less than 1% of the total sediment retention service provided by the landscape.

Table 6.3.2.10. Comparisons between Short-term concentrated Training (SCT) and Short-term Diffuse Training (SDT) scenarios and resulting soil erosion, sediment retention, and sediment export values in the Good Hope Manuever Training Area and at the watershed level at Fort Benning, GA.

	Good Hope Manuever Training Area			***Watershed***		
	Sediment export (tons/yr)	Soil erosion (tons/yr)	Sediment retention (tons/yr)	Sediment export (tons/yr)	Soil erosion (tons/yr)	Sediment retention (tons/yr)
SDT	14114.73	276467.15	258819.82	159001.63	1937317.45	1649828.46
SCT	15726.55	307276.10	287630.95	160698.73	1971120.98	1681530.29
Difference	**10.25%**	**10.03%**	**10.02%**	**1.06%**	**1.71%**	**1.89%**

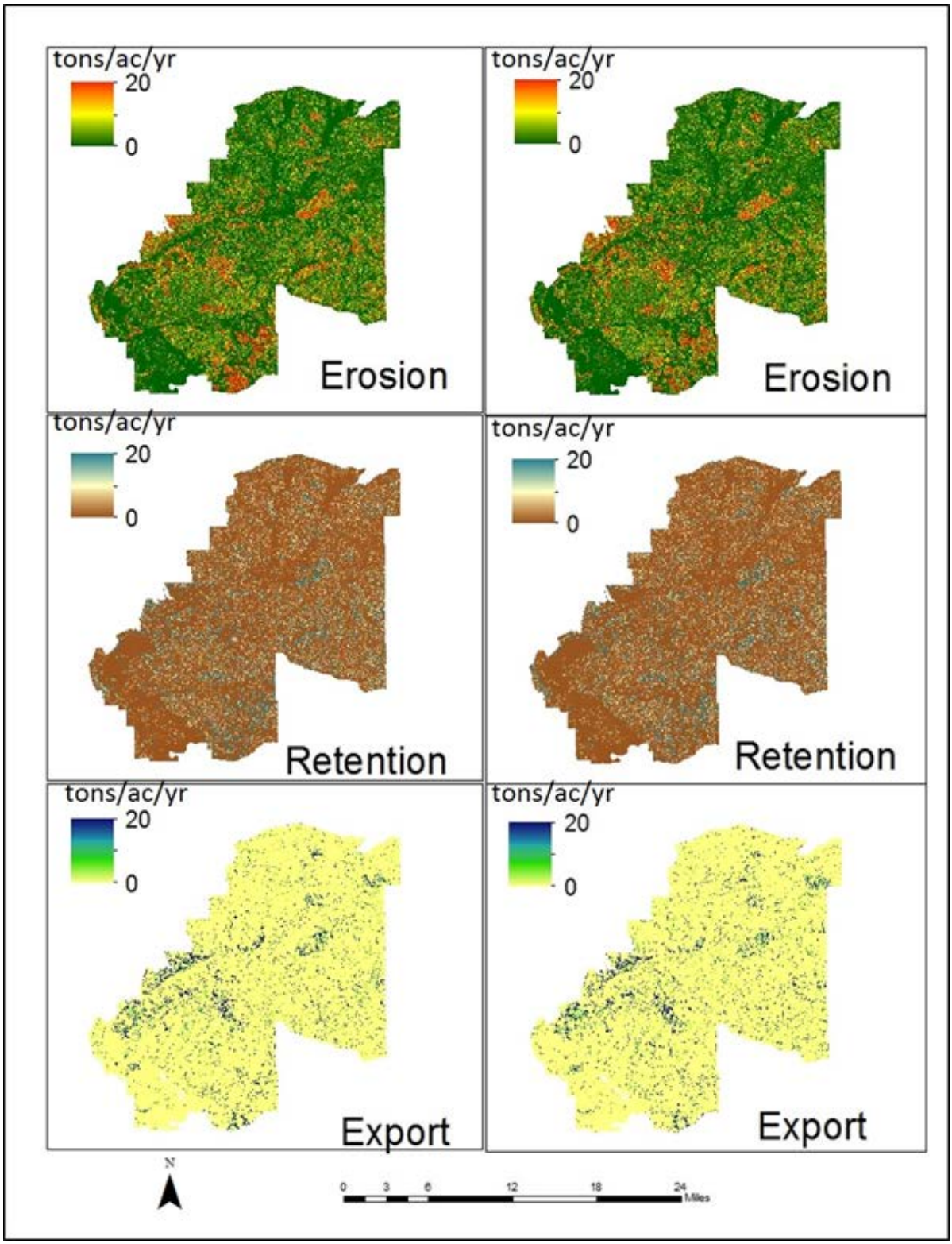


Figure 6.3.2.17. Soil erosion, sediment retention, and export prediction at 10-m grid resolution for Short-term Concentrated Training (SCT; left panel) and Short-term Diffuse Training (SDT; right panel) management scenarios at Fort Benning, GA.

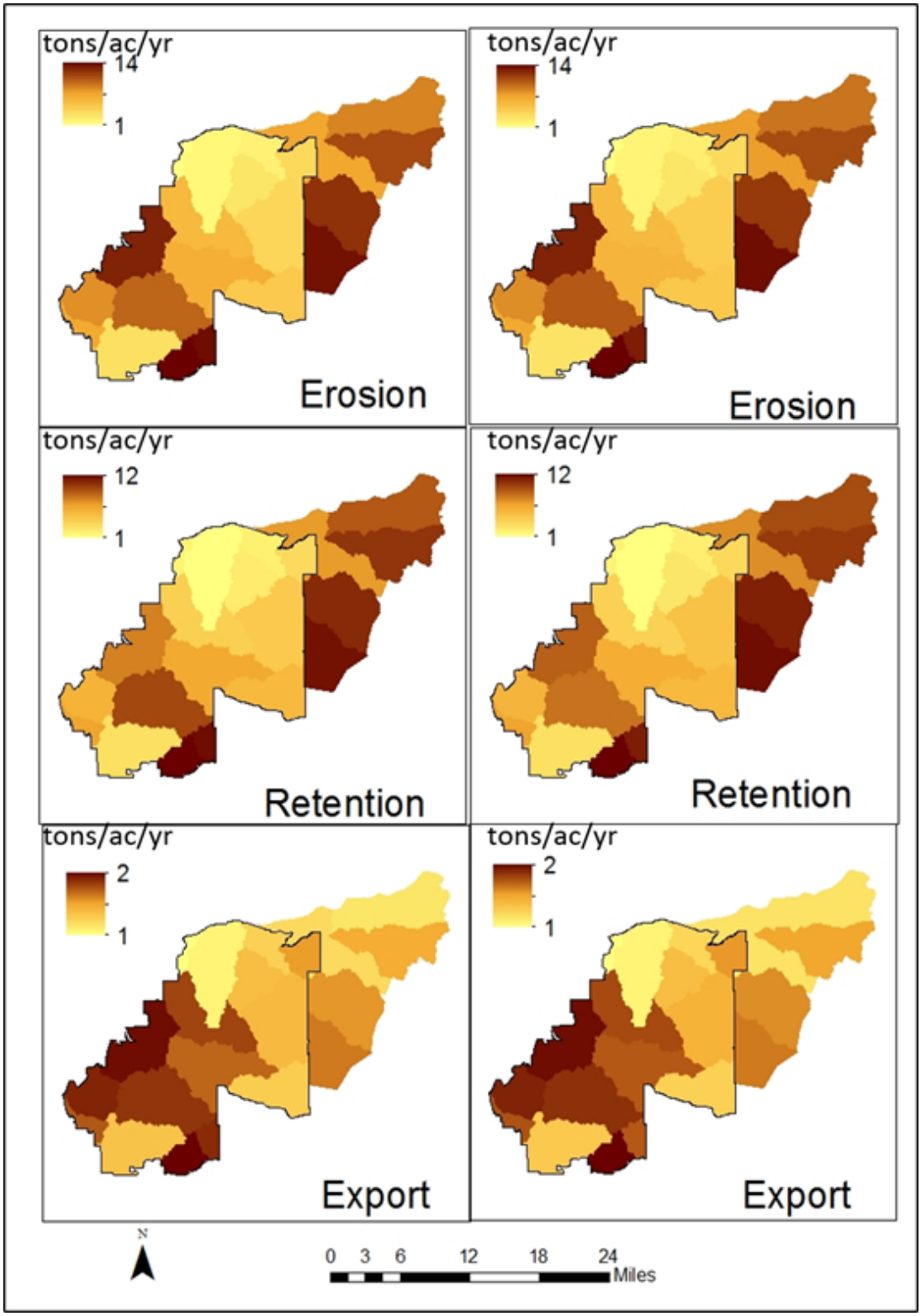


Figure 6.3.2.18. Average soil erosion, sediment retention, and export predictions for sub-basins (HUC12) for Short-term Concentrated Training (SCT; left panel) and Short-term Diffuse Training (SDT; right panel) management scenarios at Fort Benning, GA.

The southern ACUB area near Fort Benning also experienced high soil erosion rates in the models (6.4 tons/ac/year), ranked second to erosion in the GHMTA (13 tons/ac/year). The high erosion in ACUB is attributable to highly erodible soils due to their high proportion of sand and low organic matter content. The northeastern part of the ACUB area also is exposed to high risk of accelerated erosion due to loose soil particles and steep slopes. However, most of the detached soils in the northeastern area of ACUB remain in situ due to the high retention efficiency of forests and grasslands (Figure 6.3.2.18, middle panel).

Objective 2: ***Quantify values of ecosystem services in metrics relevant to DoD using existing service provision data and social/economic data***

The economic value of sediment retention provided by vegetation is often estimated using the avoided cost method, which treats the remedy expenditures that people would actually make in absence of the ecosystem service as a proxy for value. InVEST calculates the avoided cost using marginal cost of sediment removal and the sediment loads to be removed over a threshold determined by water quality regulations or the capacity of facilities (Sharp et al. 2014). Fort Benning has six stream segments occurring on or near the installation "water quality limited" due to sedimentation based on a TMDL evaluation conducted in 2003 (GA EPD 2003). However, given the ineffectiveness of setting and measuring a numeric TMDL, the Georgia TMDL Implementation Plan recommends the implementation of BMPs to ensure no net increase in sediment delivered (USCHPM 2008). Thus, we adopted the cost of the structural controls for soil erosion, such as sediment basins and riprap, as an avoided cost of sediment retention at Fort Benning, as opposed to the dredging cost or water treatment cost that are commonly used with InVEST (Sharp et al. 2014).

We calculated the marginal cost of structural controls for sediment retention based on a conceptual erosion control plan that provides specific locations and costs for a set of BMPs in the GHMTA (Fort Benning 2012). We calculated sediment retained by major BMPs (i.e., sediment basins, Berms and Swales, Rock Filter Dams, Rip-Rap, and Compost Filter Sock) by comparing the difference of sediment retention on landscape units containing these BMPs between two scenarios—one incorporates the BMPs and one does not. We derived the median values of sediment retention for each type of BMP to minimize influence from extreme cases. Then we matched the sediment estimates with their installation costs to assess the average expense for controlling one ton of sediment per year by each type of BMPs. The conceptual plan provides total installation cost for each type of BMP, which covers basic engineering processes such as excavation, fill, compaction, outlet structure, rip-rap, and partial tree removal (Fort Benning 2012). We calculated the annualize cost over the scenario time horizon, 20 years, with a discount rate of 3% that is recommended for government cost benefit analysis by the Office of Management and Budget.

We assessed the average erosion control cost by combining the installation cost of major BMPs

in the GHMTA and their sediment retention estimates (Table 6.3.2.11). The median retention ranges from 1.01 ton per single rock dam to 35.6 ton per single sediment basin. We calculated the total sediment retention from each type of BMP by multiplying the number of BMP units and the median retention per unit. The annualized installation cost also shows a wide range, from $893,000 per year for sediment basins to $42,000 for composite filter socks. While combining the installation cost with sediment retention estimates, composite filter socks appear to be most cost-effective at $29/ton, whereas the rip-rap lined channels are most expensive at $671/ton. The average annual erosion control cost is around $258/ton, which can be used as a marginal avoided cost for valuing the sediment retention service. This value is comparable with a previous erosion control cost assessment conducted at Fort Benning, which predicted an annual cost of $6,729,600 for reducing 28,816 tons of off-site sedimentation (i.e., $234/ton) (USDA 2008). Because the value of the sediment retention service only applies to additional sediment removal above a threshold defined by water quality regulations, we are not able to assess the total economic value of this service due to lack of information about this threshold.

Table 6.3.2.11. Erosion control cost estimates based on proposed Best Management Practices (BMPs) in the Good Hope Maneuver Training Area at Fort Benning, GA.

BMPs	Number of BMP units in GHMTA	Median sediment retention per BMP unit (ton/year)	Total sediment retention (ton/year)	Total installation cost for BMPs ($)	Annualized installation cost over 20 years at 3% discount rate ($/year)	Annual erosion control cost ($/ton/year)
Berm and Swale	115	15.5	1781	8,769,422	572,275	314
Rock Dam	43	1.0	43			
Sediment Basin	92	35.6	3274	13,677,579	892,571	273
Rip-Rap Lined Channel	51	8.4	429	4,416,981	288,243	671
Composite Filter Sock	55	26.1	1434	643,990	42,025	29
Total			**6963**	**27,507,972**	**1,795,114**	**258**

Objective 4: ***Provide spatially-explicit rendering of the DoD-relevant values of two key ecosystem services***

As explained in under Objective 2, we are not able to map the total economic value of this ecosystem service due to lack of information about a threshold defined by water quality regulations. However, if such information is available in future, the economic value mapping can be conducted at the sub-basin level, similar to Figure 6.3.2.18, using the marginal cost of erosion control derived in Table 6.3.2.11.

In sum, our analysis has shown that the InVEST sediment model can be a valuable tool for the DoD in modeling soil erosion and downstream sediment delivery due to disturbances such as vegetation clearing, soil compaction, demolition trainings, and field fortifications that are common activities in training facilities like Fort Benning. As is common with all modeling exercises, we have used simplifying assumptions to parameterize the land use change and disturbances that have happened in the past and are projected to occur in the future under BRAC and MCOE management changes in our models. We simulated streamflows, soil erosion, and subsequent sediment retention and export in rivers after calibrating our models against observations, values recommended in the literature, and in consultation with scientific experts. The InVEST models allowed improved understanding of where changes in land use and land cover are predicted to result in the highest change in downstream sediment exports. The BRAC and MCOE initiatives are predicted to increase soil erosion and sediment export to rivers in Ft. Benning. This increase is mainly driven by the conversion of natural vegetation to military training facilities and areas experiencing training with heavy vehicles. As a result, rainfall interception by plant canopies and temporary water retention by natural depressions declined. Soils and associated humus in forest areas were reduced by training activities, resulting in a lower capacity of the landscape to retain sediments. At the watershed level, our results show no significant difference between the SCT and SDT scenarios in terms of soil erosion and sediment export. However, the SCT scenario has a massive footprint in the GHMTA where concentrated training activities are planned, even when the positive effects of BMPs are fully considered in modeling. The economic valuation also suggests the costs of erosion control through these BMPs are substantial to the installation.

6.3.3 Tradeoff and Synergy Analysis

Objective 9: Use service maps to evaluate multi-service impacts of alternative management options for at least two services

We used an ecosystem services approach to address two primary management questions at Fort Benning.

1) To what extent does the distribution of mechanized training across Fort Benning impact carbon storage and sequestration, risk to red-cockaded woodpecker (RCW) habitat, and sediment retention? Furthermore, what is the spatial distribution of these impacts across Fort Benning and adjacent Army Compatible Use Buffer (ACUB) lands?
2) What are the short-term (20-yr) versus long-term (100-yr) benefits of ecological forestry management to carbon storage and sequestration, risk to RCW habitat, and sediment retention? Furthermore, what is the spatial distribution of these benefits across Fort Benning and adjacent ACUB lands?

We addressed the first question by quantifying, mapping, and comparing carbon storage and sequestration, risk to RCW habitat, and sediment retention between two short-term (20-yr) scenarios that differed only in the distribution of mechanized training: (1) mechanized training concentrated in the GHMTA, and (2) training diffusely distributed among three maneuver areas. These scenarios were developed based on guidance from Ft. Benning personnel. The more diffuse distribution of mechanized training had relatively small, but positive effects on all three ecosystem services/impacts modeled. Spreading out the distribution of mechanized training led to an increase of 12,832 metric tons (8.6%) of sequestered carbon, an increase of 80 ac of low-risk RCW habitat (0.3%), and a decrease of 1612 tons/year in exported soil (10% in GHMTA, 1% in watershed). A more diffuse distribution of mechanized training improved carbon storage and sequestration and reduced soil export in management units 13, 15, and 16 (based on Hydrologic Unit Code [HUC] 12 definitions) within the GHMTA (Figure 6.3.3.1). In contrast, under the same scenario, increases in the availability of low-risk RCW habitat were more broadly distributed in other locations across the base where the area covered by off-road maneuver corridors decreased (Figure 6.3.2.8.).

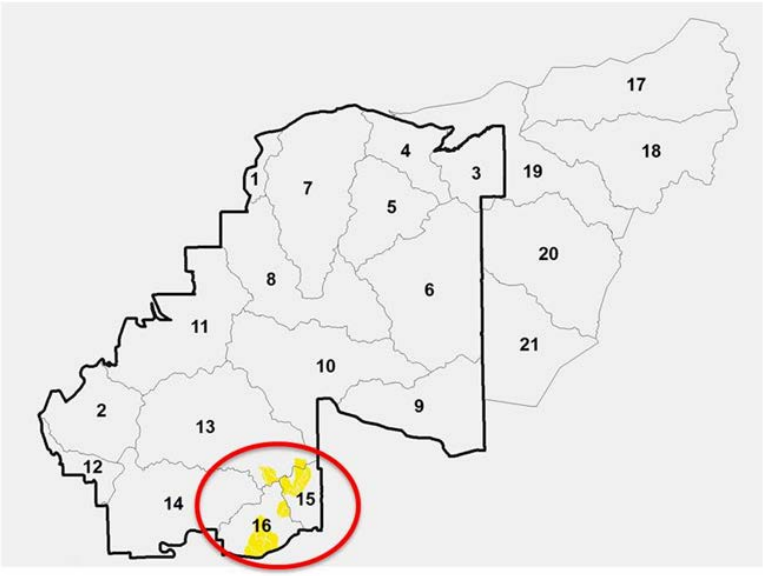


Figure 6.3.3.1. Management units based on Hydrologic Unit Code (HUC) 12 across Fort Benning, GA, and adjacent Army Compatible Use Buffer (ACUB) lands. Management units 13, 15, and 16 contain the areas most impacted by concentrated mechanized training (highlighted in yellow within the red circle).

We addressed the second question by quantifying, mapping, and comparing the same three ecosystem services/impacts under two alternative management scenarios that both included a concentrated distribution of mechanized training, but differed in forestry management through time. As with the first management question, each scenario was developed by request of Ft.

Benning personnel. One scenario had a short-term horizon (20-yr); this scenario included the conversion of ~1500 ac of loblolly pine plantations outside RCW-designated areas to longleaf pine (LLP) forest within the 20-yr time horizon. The alternative scenario had a long-term horizon (100-yr) and included an 'ecological forestry' transition as a gradual conversion of dead loblolly/shortleaf pine and mixed pine stands to LLP forest over the 100-yr time horizon. The long-term (100-yr) ecological forestry (LEF) scenario (i.e., gradual conversion of loblolly/shortleaf pine to LLP) had a large, positive impact on both carbon storage and sequestration and greater availability of low-risk RCW habitat. Whereas carbon is lost during restoration activities, it is gained with the aging of forest stands. Thus, an additional 415,189 Mg/ha (972 Mg/ha annualized) of carbon is gained during the LEF scenario, relative to the Short-term (20-yr) Concentrated Training (SCT) scenario; this is an increase of 520% (24% annualized). Similarly, low-risk RCW habitat increased with the aging of forest stands in the 100-yr LEF scenario so that high-risk areas remained only where open habitat with little cover extended in patches greater than 150m, potentially acting as movement barriers for RCW. An additional 56,115 acres of low-risk RCW habitat is gained during the LEF scenario relative to the SCT scenario; this is an increase of 31% of low-risk habitat.

We summarized data across the three modeled ecosystem services/impacts to examine total ecosystem service changes (benefit or loss) per management unit across Fort Benning and adjacent ACUB lands. To normalize scores of carbon storage and sequestration within each management unit, we calculated carbon sequestration for individual management units, examined the distribution of calculated values across the base, and then assigned benefit scores for each management unit based on whether its calculated value for carbon sequestration was in the top quartile (high benefit = 1), bottom quartile (low benefit = -1), or interquartile (medium benefit = 0) of all management unit values (Figure 6.3.3.2). Scoring for negative impacts was reversed. For risk to RCW habitat and sediment export, a management unit received a high benefit score (1) when its calculated value of risk or sediment export was in the lowest quartile of values calculated across the base, and a low benefit score (-1) when its calculated value was in the highest quartile of values (Figure 6.3.3.2). Finally, to score total ecosystem benefit, we summed scores for carbon sequestration, risk to RCW habitat, and sediment export within each management unit, so that values ranged from 2 to -3. We scored and mapped total ecosystem benefit for the 20-yr SCT scenario and the 100-yr LEF scenario, and the difference between the two scenarios (Figure 6.3.3.2). An examination of total ecosystem benefit across Fort Benning and adjacent ACUB lands indicates the increase in relative benefits of all three services/impacts are greatest under the 100-yr LEF scenario in management units 3, 5, and 21 (Figure 6.3.3.2). In contrast, relative improvement in benefits across the three services/impacts is lowest in management units 17-19 within the ACUB lands (Figure 6.3.3.2).

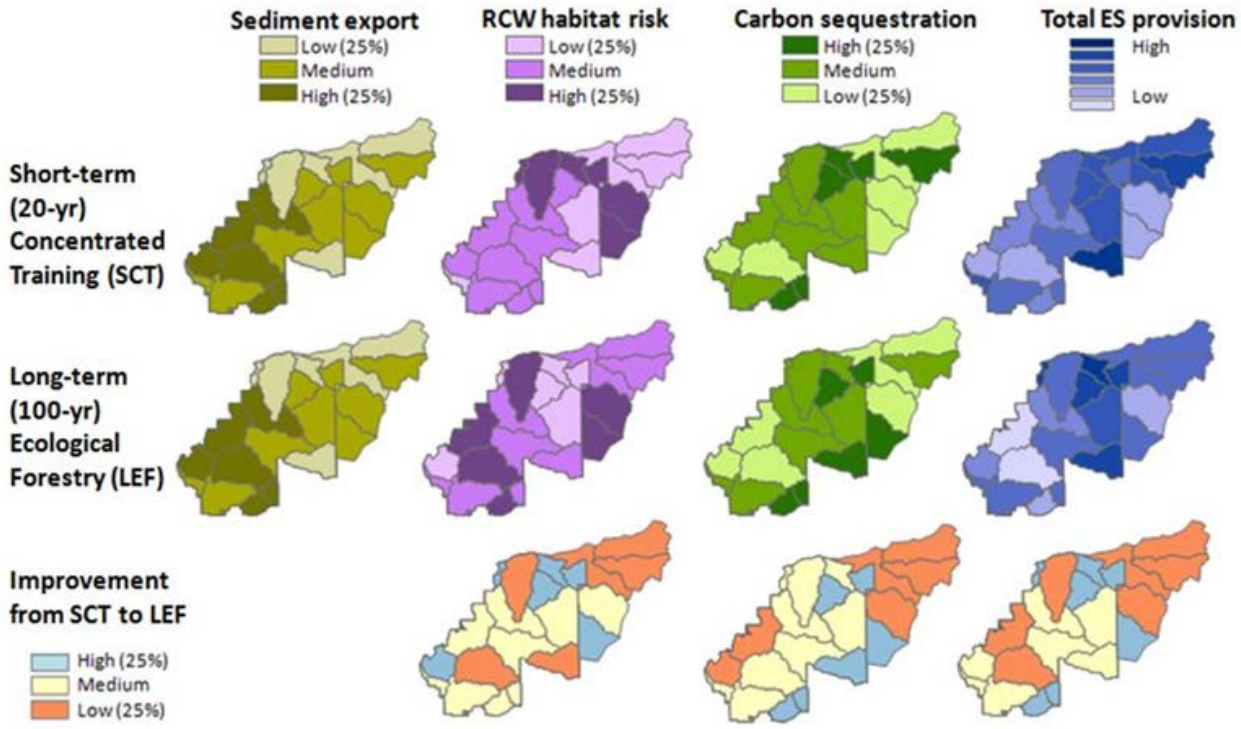


Figure 6.3.3.2. Ecosystem service/impact (sediment export, risk to red-cockaded woodpecker [RCW] habitat, carbon sequestration, and total ecosystem service [ES] provision) per management unit across Fort Benning, GA, and adjacent Army Compatible Use Buffer (ACUB) lands under the Short-term (20-yr) Concentrated Training (SCT) scenario and Long-term (100-yr) Ecological Forestry (LEF) scenario, and the improvement from the SCT to LEF scenario. See text for scoring methodology.

6.3.4 Qualitative analysis

This section presents our assessment of the four qualitative objectives for this Demonstration (10-13). All four qualitative objectives were successful. We identified several priority DoD management themes and ecosystem services to be used in modeling scenarios (Objective 10) and suggest two primary opportunities for InVEST models to inform and improve natural resource decisions at Fort Benning (Objective 11). We examine the ease of use of InVEST as compared to more complex models (SWAT and HexSim) (Objective 12), and we assess user acceptance of project outcomes (Objective 13).

Objective 10. Identify priority DoD management themes and ecosystem services to be used in modeling scenarios.

We identify DoD management themes and associated ecosystem services at Fort Benning in Table 6.3.4.1. We used both InVEST models and Auxiliary models listed in Table 6.3.4.1 to quantify the ecosystem services of interest at Fort Benning.

Table 6.3.4.1. Management themes and associated ecosystem services at Fort Benning, GA; and InVEST models and auxiliary models used to quantify ecosystem services.

Management Theme*	**Ecosystem Services**	**InVEST models**	**Auxiliary models**
Land Deconfliction	Habitat provision for training, habitat provision for red-cockaded woodpecker (RCW), carbon storage and sequestration, sediment retention	Habitat Risk Assessment (HRA), Carbon Storage, Sediment Retention	HexSim, SWAT
Forestry	Habitat provision for RCW, carbon storage and sequestration, soil retention	HRA, Carbon Storage, Sediment Retention	HexSim, SWAT
Soil Conservation	Erosion Control	Sediment Retention,	SWAT
Threatened & Endangered Species	Habitat provision for RCW	HRA	HexSim

*Drawn from the most recent Fort Benning INRMP (Fort Benning 2006)

We used the models listed in Table 6.3.4.1 to quantify ecosystem services listed in Table 6.3.4.1 under Baseline (2013) conditions and three alternative management scenarios. We developed two short-term (20-yr) scenarios that include clearcutting of loblolly and enhanced BMPs. To model the effects of mechanized training distribution on the three ecosystem services listed above, we used the short-term vegetation management scenarios and varied how mechanized training is distributed (concentrated on tank trails and within the GHMTA versus diffuse presence on tank trails in all three maneuver areas) (Figure 6.3.1.1). We developed an additional long-term (100-yr) scenario to model the effects of Longleaf Pine (LLP) replantation, increased acreage protected by the ACUB program, and enhanced BMPs on the same ecosystem services (Figure 6.3.1.1). We designed a flow diagram to illustrate how management practices and other drivers were reflected in scenarios, and how results from ecosystem service modeling can inform management decisions at Fort Benning (Figure 6.3.1.1). Formal feedback collected by surveying Fort Benning staff following on-base presentation of this diagram and model results (Appendix

C) indicated that staff agreed (Likert survey score = 4) that the developed scenarios are realistic and relevant to developing resource management strategies at Fort Benning (Table 6.3.4.2).

Objective 11. Identify opportunity for ecosystem services approach in land-management on base.

We identified a number of opportunities for the DoD to benefit from an Ecosystem Service (ES) approach to managing their lands and waters. Ecosystem service information can be useful in informing five major types of land-use planning decisions regularly made on DoD installations:

1) Spatial Planning & Resource Management: The DoD can use an ES approach to help in comprehensive spatial planning and natural resource management on base. InVEST software is designed to be used in spatial planning decisions, such as siting of military training grounds. An ES approach is particularly useful in natural resource management decisions where InVEST models can provide ecosystem service information in a spatially-explicit manner. Spatial information on changes in ES can be easily included in the existing Ecosystem Based Management (EBM) processes practiced on DoD installations.

Potential Users: Directorate of Planning, Training, Mobilization and Security (DPTMS)

2) Tradeoff Analysis: NatCap's ES approach uses potential future scenarios to map and value synergies, conflicts, and tradeoffs in ecosystem services. Such scenario-driven analyses can help reduce costs of unanticipated or unintended conflicts. Scenario elicitation is a useful part of a stakeholder input process guided by management. Results from tradeoff analyses can help people visualize what changes might look like over time and space, and what impact land use changes driven by climate or management interventions might have on ecosystem service provision.

Potential Users: Environmental/Public Works Directorate

3) Environmental Impact Assessment: An ES approach, including spatially-explicit outputs provided by InVEST can help inform NEPA assessments. Ecosystem Service information can also be used to address land and water use issues related to habitat provision for protected and endangered species, as well as problems with invasive species or diseases, such as laminated root rot.

Potential Users: NEPA Compliance Specialist

Table 6.3.4.2. Average scores on a Likert scale of 1-5 (i.e., strongly disagree to strongly agree) for responses of Fort Benning personnel to survey questions addressing qualitative Performance Objectives. Note that not all respondents provided responses to every survey question.

PO	Survey question	Scenario or model	Average score	No. respondents
7	**Do you agree that the following land use/land cover scenarios are realistic and relevant to developing resource management strategies at Ft. Benning?**	20-year concentrated training	3.56	9
		20-year diffuse training	4.22	9
		100-year ecological forestry	4.11	9
		Over all scenarios	**3.96**	**9**
3	**Is the scenario-based, spatially explicit ecosystem service mapping useful to inform decision-making at Ft. Benning?**	RCW Habitat (InVEST)	3.67	9
		RCW Habitat (HexSim)	3.67	9
		Carbon Sequestration & Storage (InVEST)	4.11	9
		Sediment Retention (InVEST; Annual)	4.56	9
		Sediment Retention (SWAT; Daily)	4.50	8
		Over all models	**4.09**	**10**
5	**In your opinion, is the model performance acceptable given the degree of agreement between model outputs and observed data?**	RCW Habitat (InVEST)	3.88	8
		Carbon Sequestration & Storage (InVEST)	3.88	8
		Sediment Retention (InVEST; Annual)	4.33	9
		Sediment Retention (SWAT; Daily)	4.13	8
		Over all models	**4.06**	**10**
6	**Do you think the representation of uncertainty is useful for resource management and land use planning at Ft. Benning?**	Carbon Sequestration & Storage (InVEST)	4.50	8
		Sediment Retention (InVEST; Annual)	4.56	9
		Sediment Retention (SWAT; Daily)	4.63	8
		Over all models	**4.56**	**10**
11	**Do you agree that appropriate opportunities were identified to incorporate ecosystem services into land and resource management decisions at Ft. Benning?**		**4.13**	**8**
12	**Given the time and effort it takes to run the various models, is InVEST a useful alternative to more complex models, such as SWAT or HexSim, for resource management decisions?**		**3.90**	**10**
		Average score over all questions	**4.13**	

4) Ecological Forestry Management: An ES approach can help forest and installation managers optimize the value of their forests for training, habitat provision for species-at-risk, and the provision of other ecosystem services. Spatially-explicit, simple outputs can make it easy for

decision makers to assess tradeoffs under various scenarios of forest use which supports the long-term goal of the DoD to manage their forests for multiple uses. An ES approach may also be useful for complying with any future regulations on carbon, as forests can also be managed to sequester and store carbon.
Potential Users: Forest Manager, Garrison Commander, IMCOM, SERDP, ESTCP

5) Regulation Compliance: An ecosystem service approach can help the DoD comply with environmental laws and regulations while minimizing or eliminating the impact compliance will have on other base activities. An ES approach can be particularly helpful in addressing environmental regulations such as the Clean Water Act and the Endangered Species Act.
Potential Users: Environmental/Public Works Directorate, NEPA Compliance Specialist

Including ecosystem services in the already existing Ecosystem Based Management (EBM) process on base may be the easiest and most cost-effective means to including ecosystem service information in DoD decisions. The DoD is required to take an EBM approach to decisions and practices related to natural resources. In doing so, decision-makers are to consider the mission-related goals, as well as "foster the long-term sustainability of ecosystem services" on base, and conduct all research using the best "scientifically sound conservation procedures, techniques, and data."

An ecosystem service approach can be easily incorporated into an ecosystem based management plan. Ecosystem Based Management (EBM) is designed to meet multiple objectives. If relevant ecosystem services are included up front as objectives in an EBM approach, they can readily be incorporated into the following EBM assessment (Figure 6.3.4.1). Thus, information on ecosystem services can be useful as one of many layers of information needed for multi-use management planning. The combined strategy can help meet the long-term natural resource management goals of the DoD and support the mission, the environment, and the community.

An EBM approach to base management is a comprehensive strategy that can address multiple objectives and can be designed to meet the needs of competing stakeholders and user groups. It can also be useful in the deconfliction process in siting decisions on military installations. An EBM approach also has the added benefit of accounting for synergies and tradeoffs between uses and alternative land use scenarios. Finally, including ecosystem services in an EBM approach is especially useful when incorporating natural resources in decisions because results, synergies, and tradeoffs are both quantitative and spatially explicit. Together, ecosystem service and EBM approaches can support and strengthen long-term natural resource management on US military bases.

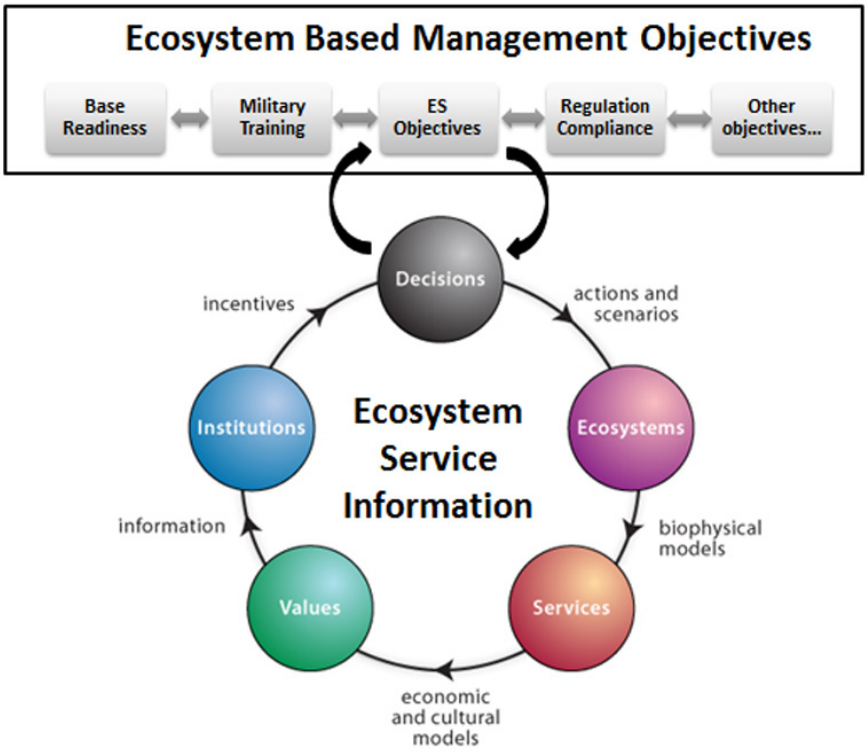


Figure 6.3.4.1. Schematic illustrating how ecosystem service information can be included in a comprehensive ecosystem based management process.

We identified two specific opportunities for incorporating an ecosystem service approach in land management on Fort Benning. First, an ecosystem service approach can be used to examine short-term (20-yr) versus long-term (100-yr) ecosystem benefits of ecological forestry management and inform the spatial and temporal extent of implementation of LLP restoration, protection/management of land in the ACUB program, and enhanced Best Management Practices (BMPs) for soil and water management. Second, an ecosystem service approach can be used to inform training site selection for the concentrated training initiative associated with the Base Closure and Realignment Commission/Maneuver Center of Excellence (BRAC/MCoE; Figure 6.3.4.1), as well as future training initiatives. Such an ES approach also is useful for indicating any areas that should be monitored for potential negative impacts of training after sites are selected. Additionally, the most useful ecosystem service approaches are iterative (Ruckelshaus et al. 2013), and thus they readily establish a foundation for improvement and adaptation in resource management. Monitoring outcomes of changed land use/land cover (e.g., establishment of new training site, replantation of LLP) provides data that can be used to test predictions of ecosystem service models, and to modify parameters for improved performance when examining new scenarios in the future.

Formal survey feedback collected from Fort Benning staff indicated staff agreed (Likert survey score = 4) that an ecosystem service approach is useful to inform decision-making at Fort

Benning (Table 6.3.4.2). However, the level of agreement was slightly lower for models of RCW habitat (InVEST HRA model and HexSim). Discussions with staff at Fort Benning suggested that the RCW habitat models might be less useful to inform decision-making at Fort Benning than other models because suitable modeling tools for RCW developed by Dr. Bruggeman (Ecological Services and Markets, Inc.) are already being effectively incorporated into the EBM approach on this installation.

Objective 11. Ease of use of InVEST as compared with more complex models (SWAT and RCW models).

We compared the ease and relevance of using InVEST models versus auxiliary models to quantify two ecosystem services, sediment retention (Table 6.3.4.3) and risk to, or quality of, nesting habitat for red-cockaded woodpecker (RCW) (Table 6.3.4.4). Furthermore, we assessed ease of use and relevance for each model as perceived by installation personnel by surveying these individuals during our concluding visit to Fort Benning.

Comparison: InVEST versus SWAT

The InVEST and SWAT comparison demonstrates that each model has its own strengths and limitations. InVEST is a reasonably simple, user-friendly model and does not require a high level of expertise. In contrast, SWAT requires extensive skill and knowledge of hydrological processes to set up and run the model. InVEST input data include readily available, annualized and spatially distributed hydrological data. SWAT, on the other hand, requires detailed climatic data as a series of daily values, as well as detailed soils and land use information. Furthermore, because SWAT requires significant parameterization, it is subjected to a higher degree of uncertainty than InVEST. InVEST is computationally more efficient than SWAT, but SWAT better captures the non-linearity in the hydrological response (runoff, sediment dynamics) to rainfall. Furthermore, InVEST is limited in its capacity to assess water yield under some conditions and to predict baseflow-dominated streamflows (Sánchez-Canales et al. 2012, Hamel and Guswa 2014, Terrado et al. 2014). However, performance of InVEST (Sánchez-Canales et al. 2015) and SWAT are comparable in assessing mean annual sediment yield. Whereas InVEST provides spatially explicit output and is capable of tracking the services and values provided by specific ecosystems, SWAT does not track services provided by a landscape and is not directly linked to economic models.

Table 6.3.4.3. Comparison of model attributes for InVEST and Soil Water Assessment Tools (SWAT) models.

	InVEST	SWAT
Hydrological process	Lumped	Integrates surface, subsurface and groundwater interactions
Time scale	Annual	Daily
Spatial scale	Grid	Hydrologic response unit (HRU)
Complexity	Simple	Complex (requires skill and knowledge)
Data requirement	Low	High (significant parameterization)
Services	Explicit (can be tracked)	Not explicit
Accuracy	Relatively less accurate	Relatively accurate
Linkage	Linked to economic valuation	Not linked to economic valuation

Comparison: InVEST versus HexSIM

The InVEST Habitat Risk Assessment (HRA) model is a relatively user-friendly model requiring little ecological or quantitative expertise, and in contrast, the HexSIM model requires a great deal of expertise and a significant time investment to run. Both the HRA model and HexSIM are flexible in data requirements and can run on a variety of spatial scales and resolutions. Whereas both the HRA model and HexSIM provide spatially explicit output, the metrics differ, and the decision to use either model should be based on the specific questions of interest. The HRA model provides a value for cumulative risk (and individual sources) to habitat/species per spatial unit (i.e., map cell) calculated using a risk assessment framework (Arkema et al. 2014). Given the history of risk assessment in diverse business and governmental settings, the approach is generally supported and readily adopted by regulatory agencies charged with implementing policies and guidelines. Thus data provided by the HRA model can be of utility under several government policies and guidelines. HexSim, in contrast, can provide an assortment of outputs, including reports that track population size and maps that illustrate changes in population size per unit area (i.e., hexagon-shaped map cell) over a given period of time. Data provided by HexSim are useful for questions related to population-scale issues (e.g., number of individuals, breeding pairs). If a relationship is established between risk to a given spatial unit and a population-oriented measurement from that spatial unit, the HRA model can offer a user-friendly alternative to the more data-intensive HexSim model.

Table 6.3.4.4. Comparison of model attributes for InVEST Habitat Risk Assessment (HRA) and HexSim models.

	InVEST	HexSim
Spatial scale	Square pixel	Hexagon unit
Complexity	Simple	Complex (requires skill and knowledge)
Data requirement	Flexible	Flexible
Accuracy	Data-dependent	Data-dependent
Linkage	Not linked to economic valuation	Not linked to economic valuation
Output	Value for risk (or cumulative risk) per pixel	Population-oriented measurement per hexagon

Survey feedback collected from Fort Benning staff indicated that installation personnel agreed (Likert survey score = 4) that given the time and effort it takes to run the various models, InVEST is a useful alternative to more complex models, such as SWAT or HexSim, for resource management decisions. While six of the ten respondents provided scores $\geq$ 4, the average score was lowered by one score of 2 provided by a respondent whose comments indicated the low score was based on a comparison between the RCW models (HRA and HexSim) and the modeling tools provided by Dr. Bruggeman via Ecological Services and Markets, Inc.

Objective 13. Assess user acceptance of project outcomes.

We created a post-demonstration survey consisting of six questions addressing the relevance and utility of an ecosystem approach and of InVEST models to resource management decisions at Fort Benning (Performance Objectives [POs] 3,5,6,7,11,12; Table 6.3.4.2). Responses were scaled on a Five-point Likert scale of 1-5, where 1 indicated strong disagreement with a statement and 5 indicated strong agreement (Table 6.3.4.2). The number of respondents for each question varied from 8-10. The average response score for each survey question ranged from 3.9 to 4.56, indicating respondents generally agreed with statements assessing demonstration success in meeting each PO. Furthermore, the average score across all survey questions was

4.13, indicating overall agreement with survey statements and acceptance of project outcomes (Table 6.3.4.2).

The lowest respondent scores were made in response to statements regarding the realism and relevance of the Short-term (20-year) Concentrated Training scenario (score = 3.56; Table 6.3.4.2). Written comments received with the post-demonstration survey state that scenarios are deemed realistic if data are accurate; and that scenarios are deemed relevant when confidence in both the input data and assumptions generating a scenario are high. Discussion with staff on base indicated relatively low confidence in the assumptions regarding the extent of clearcutting in the short-term (20-year) Concentrated Training scenario, resulting in the relatively lower score for that survey question.

The highest respondent scores were regarding the utility uncertainty representation for resource management and land use planning at Fort Benning (scores = 4.50-4.63; Table 6.3.4.2). NatCap is continuously updating and implementing "best practices" for representing uncertainty associated with the quantification and mapping of ecosystem services. Survey responses emphasize that efforts to do so are paying off; and are key in ensuring user acceptance of the InVEST ecosystem service models, and more generally, our ecosystem service approach.

A comparison of respondent scores regarding the performance and utility of individual ecosystem service models indicated staff at Fort Benning found the models used to assess risk to red-cockaded woodpecker habitat were less relevant and useful than models assessing carbon sequestration and storage and sediment retention. Comments included with the post-demonstration survey and discussion with Fort Benning staff, indicated that both the InVEST HRA model and HexSim were perceived as less useful than the other models because suitable modeling tools developed by Dr. Bruggeman (Ecological Services and Markets, Inc.) are already used effectively to evaluate RCW habitat at Fort Benning.

6.3.5 Summary and discussion

This case study at Fort Benning demonstrated how an ecosystem service approach and InVEST tools might inform resource management decisions at DoD installations by illustrating their use to address two specific management questions. Here, we evaluated the impacts of changes in distribution of mechanized training required under Base Closure and Realignment Commission/Maneuver Center of Excellence (BRAC/MCoE) on provision of low-risk habitat for Federally endangered red-cockaded woodpecker (RCW), sediment retention, and carbon sequestration. We also compared benefits to these three ecosystem services between short-term and long-term ecological forestry management scenarios to inform future forestry strategies at Fort Benning and adjacent lands purchased, or soon to be acquired, as part of the Army Compatible Use Buffer (ACUB) program. In describing how we used InVEST tools and the NatCap approach to address these specific management questions, we demonstrate specifically

how ecosystem services can be incorporated into the existing ecosystem-based management framework on DoD installations. Furthermore, we illustrate the synthesis of multiple and diverse types of information (e.g., positive impacts of carbon sequestration, negative impacts of risk to RCW nesting habitat) to support a more comprehensive assessment than typically practiced in the natural resource management decision-making process, both on and outside DoD installations. Additionally, although not included in the case study at Fort Benning, our framework allows the inclusion of non-environmental information, such as cultural resources and sensitive military areas, in these assessments. Given the diverse natural and cultural resources managed on DoD lands, we believe the implementation of such comprehensive natural and cultural assessments could help grow public support for management; and prove the DoD a leader in resource management, setting a standard for other government agencies and nongovernmental organizations.

Recent approaches to modeling regional tradeoffs and mission-related constraints at Fort Benning include quantification of noise and air quality by mLEAM (RC-1257; Deal and Westervelt 2007) and RSim (RC-1259; Dale 2007). Both approaches project changes over time in urban land use. Whereas the mLEAM approach focuses on forecasting results of planning decisions by simulating changes in urban patterns in response to local, county and state planning, the RSim approach simulates changes in urban land by a rule-based model derived from the SLEUTH model (http://www.whrc.org/midatlantic/modeling_change/SLEUTH/sltuh_overview.htm). Like InVEST models, both mLEAM and RSim rely on LULC inputs and other spatial information, such as military boundaries, land ownership, and roads by type; they differ from InVEST primarily in their focus on urban land use. Thus, both approaches could be used to complement modeling conducted using InVEST, by quantifying and mapping changes in urban land use surrounding DoD installations. Additionally, RSim has the capability to model other types of land use on installations (i.e., 18 types of landcover) and similar to InVEST, is able to provide spatially explicit quantification of habitat and water quality. However, unlike InVEST models, RSim has not been implemented at locations outside the Fort Benning area and it is unknown how broadly the approach could be applied to DoD installations across the country. Direct comparisons of InVEST and RSim applications to alternative scenarios both on Fort Benning and other DoD installations could reveal where the approaches overlap, producing either similar or contrasting results, and where simultaneous use might be complementary.

6.4 CROSS-SITE SUMMARY

We have demonstrated that our approach to ecosystem service assessment can support sustained testing and training realism, sound infrastructure development, and the maintenance of ecosystem integrity. By generating maps of ecosystem service provision and value, we were able to identify the specific tradeoffs or synergies that exist when siting testing and training activities

or planning changes in land use to comply with environmental regulations. These maps will also be useful in identifying ways to improve the environmental returns of off-installation conservation or restoration efforts, particularly through the Army Compatible Use Buffer (ACUB) program. Below, we discuss the achievements reached through application of our ecosystem approach at each installation included in this project.

Joint Base Lewis-McChord (JBLM): We applied our ecosystem services approach at the military training region (excluding airfield and cantonment, i.e., barracks) of JBLM and examined tradeoffs and synergies among five ecosystem services (prairie habitat provision, infantry and vehicle training capacities, timber production and carbon sequestration) under scenarios of varied training intensities and budgets for resource management, two factors that influence management practices and can lead to changes in land use and land cover (LULC). Under a business-as-usual scenario and four alternative scenarios, we were able to (1) communicate how information on ecosystem services may affect budgetary and training decisions on a DoD installation; (2) estimate the magnitudes of ecosystem services and their potential for improvement in specific training areas; and (3) examine tradeoffs and synergies occurring among training, biodiversity, and other ecosystem service objectives under different management scenarios.

Fort Pickett: We evaluated the ecological suitability of alternative siting choices for a hypothetical training range as a quick demonstration of our ecosystem service approach. We identified nine reasonable siting locations and assessed the ecosystem impacts on carbon storage, biodiversity and sediment export from creating the new firing range on each location. We provided recommendations of suitable siting choices based on the aggregated ecosystem impacts. This hypothetical application demonstrates how the ecosystem service approach might inform future environmental impact assessments with its spatially-explicit, quantitative measures and modular framework.

Fort Benning: We applied our ecosystem services approach to Fort Benning and adjacent lands purchased, or soon to be acquired, as part of the Army Compatible Use Buffer (ACUB) program and examined tradeoffs and synergies among three ecosystem services (provision of low-risk habitat for federally endangered red-cockaded woodpecker [RCW], sediment retention, and carbon sequestration) under scenarios varying in (1) distribution of mechanized training and (2) forestry management strategies. We evaluated the impacts due to changes in distribution of mechanized training in order to examine how changed LULC under Base Closure and Realignment Commission/Maneuver Center of Excellence (BRAC/MCoE) affected ecosystem services. We compared benefits to ecosystem services between short-term and long-term ecological forestry to inform future forestry strategies.

Application of our ecosystem service approach at three installations varying in size, location, and management priorities emphasized the necessity for an approach that is flexible and can adapt to

a variety of management priorities, types of land use and cover, data availability, and rapid changes in these parameters. Because our ecosystem service approach is an iterative process, changes can be made continuously, and at any stage of implementation. Furthermore, the primary software package we used to conduct ecosystem service modeling, InVEST, is free, open-source, and data-flexible, allowing broad application. In addition, we have demonstrated that our ecosystem services approach is also open to incorporating other ecosystem service models found outside the InVEST software package when desired. Indeed, we demonstrated development of an entirely new ecosystem service model (i.e., training capacity) in our work on JBLM to address the most pressing management questions at that installation.

Although implementation details will vary across sites, we also noted common interests across the three site applications. Military testing and training is the mission of the DoD at each installation, and we expect siting of training and testing activities will be a primary goal at most installations. Successful implementation of our ecosystem service approach, performance of ecosystem service modeling, and uncertainty associated with results, will likely depend on the availability and resolution of data describing current training and testing on an installation. Furthermore, when planning for changes in land use to comply with environmental regulation, the availability and resolution of data describing environmental resources (e.g., populations of species-at-risk) will also be important in supporting an ecosystem service approach. Continued cooperation with government agencies and non-governmental organizations will thus improve the potential for successful implementation of our ecosystem services approach and compliance with regulation.

In sum, through implementation of our approach at JBLM, Fort Pickett, and Fort Benning, and successful attainment of the majority quantitative and qualitative performance objectives, we have demonstrated an integrated ecosystem service methodology for incorporating the provision and value of ecosystem services and biodiversity into management decisions of installations. We also have demonstrated use of a novel, open-source software package to estimate the relative benefits of alternative land uses, military activities, and protection or restoration of habitats for species at risk on base. Last, we have provided the DoD with sufficient support to enable technology integration into overall installation management.

7.0 COST ASSESSMENT

This section estimates the costs of a full implementation at a given installation. It will present a cost model to communicate the added benefit of adopting our approach to developing management objectives and land use scenarios, modeling select ecosystem services with InVEST, and interpreting results to inform installation planning and decision-making.

7.1 COST MODEL

The primary cost of quantifying and valuing ecosystem services to inform installation management, including using InVEST software, is the specialized labor involved in applying the models and interpreting results. Results are presented in person months, to avoid implying that the estimates are accurate to the hour. General Service (GS) staff levels are included to allow installations to apply the correct labor cost rate for their area.

Hydrology Data - In the US, hydrology data often are available at no cost from USGS, USDA, EPA and many other research institutions. InVEST also provides global/regional average data for some water model inputs as a starting point when local data are not available. However, depending on objectives of the study, for some services (e.g. sediment yield), local data may be more desirable. Obtaining these data may require additional resources, either to purchase data sets, or to purchase monitoring equipment and accounting for the labor required to collect data. Other potential data that users may want to spend additional resources to obtain at finer scales are streamflow, nutrients (N and P), some biological data (e.g., fish and benthic invertebrates) and turbidity as a surrogate for SSC (Suspended Sediment Concentration).

The cost of obtaining hydrology data is thus a very wide range: $0 to $300,000+ in the rare occasions where original data are desired.

Non-hydrology data, such as real estate prices, if desired, are estimated to cost $150. Standard personal computers are required; and although most staff already have personal computers, the cost to acquire new computers is $1,000 each for a desktop model. Either free, open source Geographic Information Systems (GIS) software such as QGIS, or commercially available ESRI-ArcGIS software (for which DoD has a site license), is required by each team member for managing the project, running models and analyzing the results.

Scaling of the application of InVEST across the DoD will require security certification of InVEST software. This would be a one-time cost to the department, but would not affect individual sites once the software was certified for use.

Table 7.1. Cost elements and estimates

Cost Element	Data Tracked During Demonstration	Estimated Costs
Hydrology data collection	a) Material costs of hydrology measurement equipment and b) Labor (contract for tech. time) for collecting hydrology data	$0-$300,000
Non-hydro data collection	a) Cost of purchasing local real estate data b) Other purchased data collections (if needed & acquired)	$149
Computer & Software	Cost of 5 laptops and ArcGIS software	$10,000
Project Manager (GS-9)	Management time (person months) to determine relevant models, set up team, manage implementation & scenario development	3 +/-1 person months $
Geographic Information Systems Analyst (GS-7 or -9)	Time (person months) applying InVEST to installation, including data collection, scenario development, model runs, and post model decision analysis. Includes several iterations of modeling.	7.5 +/-1.5 person months $
Subject Matter Experts (installation dependent) (GS-9)	Time (person months) working on applying InVEST to installation, including data collection, scenario development, model runs, and post model decision analysis. In this demonstration, we included an economist as part of the team at all three installations, and a hydrologist and ecologist at 2 installations. Additional expertise, such as in fisheries or coastal engineering, may be required at installations on the coast, depending on the objectives.	21.2 +/-1.5 person months $
Installation Management (deconfliction management)	No data tracked	

We describe the labor types and expertise requirement for applying InVEST at DoD sites below. The descriptions below can also be used as job descriptions for hiring.

- **Project Management** labor is required for coordinating the group of subject matter experts, selecting which InVEST models to include, developing scenarios, managing the implementation of InVEST, and synthesizing the results.

- **Geographic Information System (GIS) Analyst i**s required for collecting and pre-processing data, processing models, and post-processing results, such as creating maps and other graphics representing outputs from alternative scenarios. Skills required are:
  - Strong expertise in Geographic Information Systems tools and geospatial analysis
  - Experience applying ecological models in the context of natural resource and/or land-use management
  - Ability to collect, manage, and integrate GIS data
  - Ability to overcome challenges with data collection, processing, and documentation, as well as ecosystem model execution
  - Ability to work independently, and also effectively collaborate with multidisciplinary experts

- **Subject matter expert** labor is required for collecting relevant data, developing spatially explicit scenarios, executing model runs, and performing post analysis based on the model outputs. The expertise and skill levels for future applications are described below. While quantification and valuation of ecosystem services to inform installation management will always require a Project Manager and GIS Analyst, selection of other subject matter experts will depend on site-specific requirements. During the demonstrations in this work, the following subject experts were used.

  Ecologist - skills required are:
  - Broad training in ecology or natural resource management, including both fundamental theory and real-world application
  - Expertise in species distribution modeling, with knowledge of common data collection methods and modeling tools
  - Experience mapping distribution data and conducting basic spatial analyses
  - Ability to work with GIS and statistical software (e.g., R, SYSTAT, SPSS) at an intermediate level
  - Ability to work independently, and also effectively collaborate with multidisciplinary experts

  Hydrologist- skills required are:
  - Extensive knowledge of hydrologic processes
  - Experience in GIS software and computer aided modeling
  - Ability to set up stream monitoring programs to monitor discharge and sediment loads
  - Ability to exercise hydrological judgment in problem definition, data collection, scenario development, parameter description, calibration and validation and impact assessment
  - Ability to work independently, and also effectively collaborate with multidisciplinary

experts

Social Scientist/Economist- skills required are:

- Expertise in natural resource and environmental management or ecological economics
- Experience conducting qualitative and quantitative analysis for social/economic valuation and impact assessment
- Ability to collect and refine social/economic data and apply appropriate models/methods for specific site and decision context
- Ability to work with GIS software and statistical/econometric tools (e.g., R, STATA)
- Ability to work independently, and also effectively collaborate with multidisciplinary experts

- **Installation Management** (deconfliction management) is required for developing scenarios and using the final outputs for informing land-use decisions. This decision making process is a significant ongoing installation cost, but using InVEST's ability to analyze multiple overlapping constraints, and spatially represent outputs from alternative scenarios, should help reduce this cost over current practices. Since Installation Management (deconfliction management) time records were not available to this project, this cost was not tracked.

- **Stakeholder engagement** is a critical step for applying the ecosystem service approach and InVEST tools at DoD installations, especially for developing scenarios. Skills listed below are helpful for project manager, subject-matter experts, and GIS analyst to work with stakeholders. These skills are commonly possessed by DoD resource managers, specialists, and consultants who have worked with stakeholders from installations and neighboring communities.
    - Knowledge of natural resource management and installation management
    - Ability to extract key information from background materials related to installation resource management
    - Ability to facilitate discussion with stakeholders from multiple divisions
    - Ability to understand and summarize key information provided by stakeholders and present to them quickly and accurately
    - Ability to maintain continuous interaction with stakeholders for follow-up discussions

7.2 COST DRIVERS

The primary, direct cost of quantifying and valuing ecosystem services is scientific or technical labor, with most labor at a GS-9 salary level. Labor costs for professional, scientific, and

technical labor have risen approximately 2%/year[8] over the past 5 years.

Data availability is a key potential cost. Costs are falling with the availability increasing of good, low cost, or free data; and costs are dropping for primary data collection. If primary hydrological data are required, newer technologies are allowing lower cost collection techniques.

The cost of computing power and software costs also are falling.

Installation management will continue to experience growing indirect costs for managing installation lands as performance demands and regulatory constraints increase. Additional considerations will arise as neighboring communities intensify their land-use and put further pressures and constraints on installations. The NatCap approach and InVEST tools, allowing management to quantify multiple ecosystem service trade-offs and present clear, spatially explicit management options, will productively focus the decision process, and reduce the uncertainty and indirect costs that come from working with multiple stakeholders and constraints.

The major cost of stakeholder engagement is scientific and technical labor required for reviewing background information, scheduling stakeholder meetings, discussing with stakeholders, synthesizing information, and follow-up interactions with stakeholders. Figure 7.1 outlines labor elements for stakeholder engagement associated with each step of scenario development. For external consultants, travel cost for stakeholder engagement meetings are also required. These estimates are not necessarily solely attributable to adoption of an ecosystem services approach per se, since other public engagement processes adopted by the DoD (e.g., community outreach for EBM, etc.) will involve similar skills and time commitments of personnel.

[8] (BLM Employment Cost Index Series Id:CIU2015400000000A)

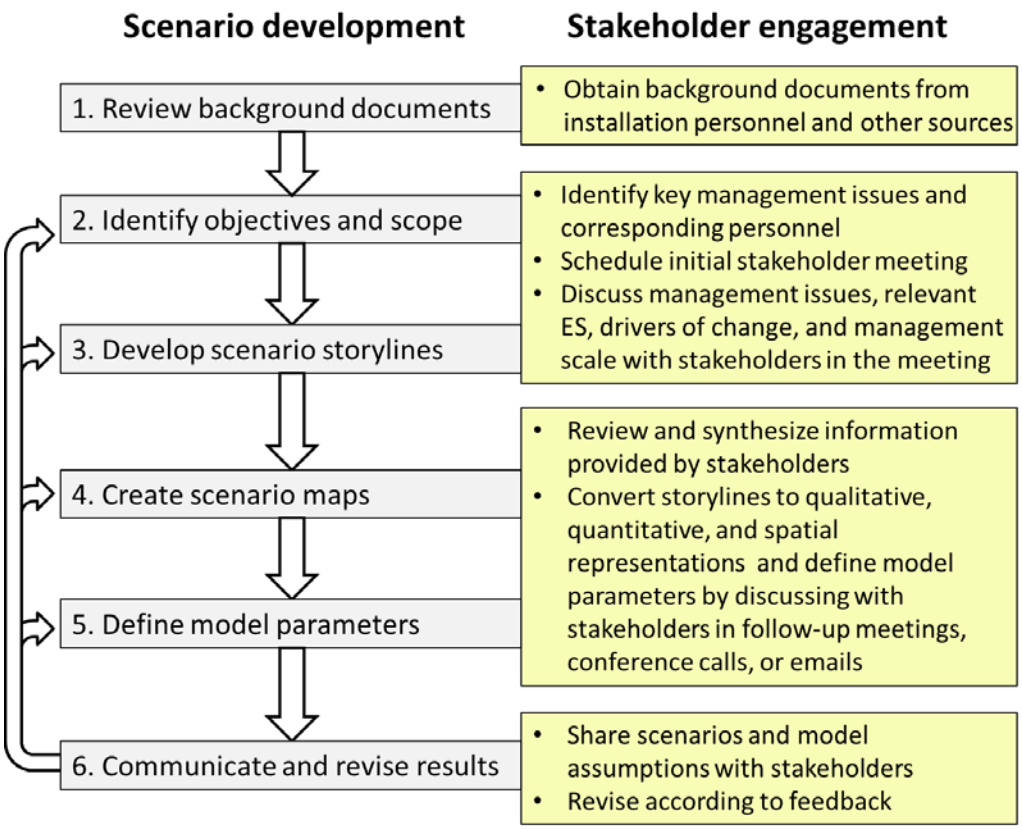


Figure 7.1. Labor elements for stakeholder engagement associated with scenario development.

7.3 COST ANALYSIS AND COMPARISON

A basic DoD site is assumed to have multiple environmental and operational constraints on land use, such as training mission, threatened species, and downstream water users. It may also have multiple stakeholder groups, including neighboring communities and multiple departments at the installation.

For the purpose of cost analysis, we assume the installation has:

- A decision context that would motivate installation management involvement and benefit from an ecosystem service valuation approach
- Multiple natural resource managers from different divisions who are willing to participate in scenario development
- A site license for ESRI ArcGIS software
- Sufficient data to proceed with using InVEST models
- Labor rates are similar to the locality pay area of Atlanta-Sandy Springs-Gainesville, GA-AL

The time frame for quantifying and valuing ecosystem services to inform installation

management takes 8+months for an installation that has an upcoming decision and can get installation management input for scenario selection. The usual time periods are:

1. Learn InVEST - 2 weeks ($12,000)
2. Collect and pre-process data 1-2 months ($24,000)
3. Develop Scenarios: 2 months ($48,000)
4. Model Runs (steps 2-4 will iterate and overlap) 2 months ($48,000)
5. Post model decision analysis 1-2 months ($48,000)

The actual time may take much longer if there are delays in getting input from installation management and other stakeholders. Subsequent iterations of the basic steps above can occur much more rapidly and thus are likely to be less costly.

The life cycle for a decision process is normally less than 1 year. Experience with the process and reuse of earlier data would theoretically allow future decisions to be made more quickly and less expensively. The table below shows our actual cost through the demonstration summarized by cost elements listed in Table 7.1.

Stakeholder engagement is an integrated component of the life cycle described above, and is especially important for scenario development. The typical stakeholder engagement practices, as shown in Figure 7.1, account for the majority of time cost estimates for scenario development. Our experience shows an average of 3.8 person months per site on scenario development across three installations (a portion of time from each person in Table 7.3). Time required ranges from 1.2 months for the abbreviated application at Fort Pickett to 8.4 months for our more in-depth engagement and demonstration at Fort Benning. It is difficult to track the exact time of stakeholder engagement because scenario development is an iterative process of collecting, processing, and exchanging information with stakeholders. The travel cost of initial stakeholder engagement meetings is about $4,200, assuming three external consultants visiting an average U.S. location for 3 days (2 nights). Our average cost per site for initial stakeholder meetings across three installations was $3,800.

Table 7.3. Demonstration: experience at three installations.

Cost Item	**Predicted Cost**	**Avg Actual Cost**	**Ft. Benning Cost**	**Joint Base Lewi-McChord Cost**	**Ft. Pickett Cost**
Total Data Collection Costs	$77,000	$100,049			
subtotal: data set purchases	$2,000	$49		$146	
subtotal: Hydrology equipment & tech time	$75,000	$100,000	$300,000	$0	$0
Computers & Software for all 3 installations	$12,000	$4,000			
Project Manager - person months	2.5	4.2 ($24,000)	3.9 ($22,000)	7.2	1.6
GIS Analyst - person months	7.5	7.3 ($41,000)	4.4 ($25,000)	13.9	3.6
Total Subject Matter Experts - person months	19.5	21.2 ($116,000)	35.3 ($98,000)	20.8	7.4
sub: Economist - person months	6	6.5	3.9	13.5	2.2
sub: Hydrologists - person months	6	8.5	21.1	0	4.4
sub: Ecologist - person months	7.5	5.6	10.3	5.7	0.8
Total	**$255,000**	**$285,049**	**$545,000**	**$226,000**	**$70,000**

The ecosystem service approach and InVEST tools will not replace any existing technology, but will likely to improve current methodologies and tools for natural resource management and land use planning, implying potential benefits or cost savings to the installations.

InVEST enables installation personnel to predict the ecosystem impacts under alternative management scenarios. These spatially explicit estimates can be useful to various management decisions, such as forestry planning, wildlife habitat protection, military facility siting, and installation master land use planning. In addition, installations often need to assess and monitor water quality or species habitat quality to comply with environmental regulations. The ecosystem service approach and InVEST tools can help assess the magnitudes of water pollutants or habitat risk, which would inform targeted monitoring site selection, and thus reduce the costs of resource monitoring for regulation compliance. Further, InVEST outputs may facilitate communications among different installation divisions, installation commanders, neighboring communities, and between the DoD and other public agencies, to better resolve conflicts in land use.

These management cost savings vary widely on a case-to-case basis and thus are difficult to track. See sections 6.1.4, 6.2.4, and 6.3.4 for more details of potential opportunities for applying our technology at three installations.

8.0 IMPLEMENTATION ISSUES

This section summarizes lessons learned during the demonstration project, our support for technology transfer to the DoD, and a comparison of technical requirements for adoption at central office and installation levels.

8.1 LESSONS LEARNED

In this section, we describe lessons learned over the three sites and synthesize their implications for implementation across DoD installations generally. We highlight end-user concerns, factors influencing application of an ecosystem services (ES) approach in decision-making, and the potential challenges for implementing an ES approach across the DoD.

1. An iterative and interactive approach to define when and what kind of ecosystem service (ES) information is critical to create useful, credible science and change in a decision process and outcomes. The iterative nature of developing alternative scenarios, amassing inputs for assessment tools, interpreting early results and repeating as needed is invaluable for building trust among scientists, stakeholders and decision makers; creating a mutual understanding of the problem and how to use outputs to inform decisions; and providing a structured, facilitated process for repeated input and negotiation that leads to agreement on a specific policy or plan (Ruckelshaus et al. 2013). An interactive science-policy process −meaningfully involving scientists, local experts, stakeholders and decision makers to produce results−enhances the credibility, salience and legitimacy of ES information, increasing likelihood of use and opportunities for transparent discussion of tradeoffs.

2. It is important to understand the appropriate use of InVEST. As InVEST is designed to require relatively few data to broaden the range of applicable locations and decision contexts, some simplifying assumptions are made in individual models. InVEST is most useful for comparing tradeoffs of multiple alternatives to guide land use planning and natural resource management (Hamel and Guswa 2014). When decision making is guided by comparisons among relative values, InVEST is capable of incorporating a wide array of mission-related constraints, such as noise and air quality regulations. Whereas InVEST does not yet include models designed to quantify and map noise or air quality, auxiliary models could be used to quantify these mission-related constraints under alternative scenarios and our ecosystem approach would allow an evaluation of avoided costs for these constraints with changes in LULC.
It is important to highlight that InVEST is flexible in data requirements so that it can be applied to a broad range of locations and contexts and used to compare tradeoffs among alternative management scenarios. However, InVEST outputs are not as reliable for predicting precise estimates of the absolute magnitudes of ecosystem services at a particular place or time. The tradeoff between ease and relative speed of a simple modeling process and comprehensiveness of

model outcomes will help dictate an appropriate modeling approach to match the questions and regulatory or policy needs.

3. Value of ecosystems should be conveyed in measures related to the organization's decision context. Although economic values of ecosystem services are commonly understandable and convenient in supporting decisions, via a benefit-cost analysis for example, non-monetary measures of ecosystem services often play a more vital role in government decision-making, as we observed in the three DoD demonstrations. Ecosystem services measured in biophysical units are often preferred in aiding land use planning, environmental impact assessment, and resource management prioritization for DoD installations. For example, sediment or nutrient water quality thresholds and the number of suitable sites for an endangered species are more useful metrics than prices one could attach to those services. In our ecosystem services approach, we first asked DoD personnel what metrics are most relevant to their decisions. In the case of the three installations involved in our study, we provided biophysical measures of ecosystem services that can directly inform DoD decisions. When appropriate, we also calculated economic values from the DoD's perspective (e.g., net present value of timber considering local market price and installation's cost of production) as additional reference for installation decision makers.

4. Successful adaptation of InVEST requires technical capacity within organizations. While several sources are made available through NatCap (see Section 8.2), there are additional technical requirements to be addressed in order to properly run the InVEST models, including information technology capacity, knowledge gaps, and tools and procedures. Information technology capacity includes computer software and hardware to manage input data, run the InVEST software, and visualize/interpret the outputs. Knowledge gaps include information needed to implement InVEST for decision making at an installation-level. Tools and procedures include processes required to effectively apply InVEST and analyze the results. The ability to perform each issue is summarized in Section 8.3 from the installation perspective and central office perspective in one of three categories (easy, moderate, and difficult; Table 8.1).
Our applications of an ecosystem services approach using InVEST at DoD installations suggest that creating relevant and realistic scenarios for InVEST can be time-intensive - as is the case for all ecosystem service models. In addition, successful iterations of model runs would require GIS expertise at an installation. As current technical capacity and staff time tend to be relatively limited at DoD installations, broader adoption and potential adaptation of the ecosystem service approach and InVEST tools would require additional training of installation personnel or external consultancy. Moreover, security certification of InVEST software through the DoD system is also an important pre-condition for its adoption. We estimate the time and costs associated with use of InVEST models and the ecosystem services approach in section 7.3 "Cost Analysis and Comparison".

5. Policy incentives and centralized data support may facilitate adoption of InVEST and the ecosystem service approach. Some barriers for adopting InVEST and the ecosystem service approach at installations, e.g., limited technical capacity and staff time, are partly because ecosystem service assessment is deemed complementary, but not necessary, to current natural resource management processes. If implementation policies include more explicit direction to encompass ecosystem services into ecosystem- based management, installations are more likely to overcome these barriers and adopt the ecosystem service approach and tools into their existing natural resource management routines. The time and personnel efficiencies associated with such an alignment are likely to be high. A central data repository that compiles and maintains common datasets (e.g., forest inventory, population and habitat for species at risk, soil property) for applying the ecosystem service approach would greatly improve the efficiency of application at individual installations and facilitate the rate of adoption.

8.2 TECHONOLGY TRANSFER

To help DoD users assess the appropriateness of individual InVEST models, we provide information on data requirements, biophysical outputs, and valuation outputs (when available) on the models used throughout this demonstrations in Section 5.3, "Design and Layout of Technology and Methodology Components" of this report. We also provide a detailed comparison of data requirements, biophysical outputs, and valuation outputs (when available) for InVEST models and more complex ancillary models (i.e., SWAT, HexSim) in Section 6.3.5, "Qualitative Analysis" of this report under "Objective 12". Additional resources providing guidance for installation managers to review and continuously reference in the application of InVEST and the NatCap approach include: the InVEST User Guide (Sharp et al. 2014), guidance for scenario development (McKenzie et. al 2012, Rosenthal et al. 2014), and peer-reviewed publications of InVEST applications (e.g., Goldstein et al. 2012, Ruckelshaus et al. 2013, Bhagabati et al. 2014, Hamel and Guswa 2014, McKenzie et. al 2014, Sanchez-Canales et al. 2015). A complete list of publications related to the application of InVEST and the NatCap approach can be found on the Natural Capital Project's website (http://www.naturalcapitalproject.org/publications.html).

During our demonstration, we provided tailored InVEST training to Fort Benning staff at our final workshop on September 17, 2014, and to one of the JBLM personnel at our public training in Burlington, VT, on June 12-14. We also offer in-person trainings several times a year at various locations that are announced on our website. Presentations and videos from previous InVEST training events are also available at our website. User support is provided through an actively-maintained online user forum (http://ncp-yamato.stanford.edu/natcapforums/).

As part of this ESTCP project, we developed two resources to facilitate adoption of our ecosystem service approach and InVEST tools across the DoD.

- **Development of processing capabilities**

We developed pre- and post-processing capabilities to standardize some labor-intensive work necessary for applying and interpreting InVEST models.

Data collection and preparation is often a time-consuming step for InVEST applications. Thus, we provide the following products to accelerate input preparation for InVEST:

  - A list of public data sources for common inputs used for DoD applications;
  - Detailed instructions for processing USGS soil data for InVEST;
  - GIS script to process raw DEM (Digital Elevation Model) data—a fundamental input for all hydrology models;
  - GIS script to generate scenario maps from user-defined principles of land use changes.

Based on our experience with three DoD demonstration sites, we found outputs that synthesize multiple services and illustrate changes between scenarios are especially useful for informing decisions. Thus, we have created two GIS tools for users to create such outputs more easily:

  - GIS script to calculate changes between two scenarios;
  - GIS script to combine estimates for multiple ecosystem services and rank landscape units based on a multi-service composite score.

- **Introductory online training course**

We have developed a customized online training curriculum, which will serve as a primer on the ecosystem service approach and InVEST tools through the Stanford Online training platform. This course includes specific examples from DoD demonstration sites (Joint Base Lewis-McChord, WA, Fort Pickett, VA, and Fort Benning, GA) to illustrate how the approach has worked in each case and highlight key methods and tools available for future implementation by DoD and other land and resource management entities.

Split into four modules, this course first introduces the concepts of natural capital and ecosystem services, the stocks and flows of vital benefits flowing from nature to people, and their linkage to DoD decisions. The second module describes InVEST, NatCap's software tool for mapping, modeling, and valuing ecosystem services. In addition, it provides guidance on project scoping and on matching approaches and tools to a project's goals, decision context, timeline, capacity, and quality of data available. Modules 3-4 offer an overview of the steps involved in running InVEST models, including recommendations for how to effectively summarize and communicate model outputs to stakeholders and other audiences, with demonstrations using three DoD cases. This course will be open to all DoD personnel and other interested parties in 2015.

8.3 TECHNICAL REQUIREMENTS

In general, technical capacity should be relatively available for both levels of staff required for application of the approach demonstrated here. Installation-based staff will generally have less difficulty in scenario development and model application based on the specific needs for each installation (Table 8.1). However, the initial learning cost is high for individual installations, especially if installation personnel are occupied by other mandatory responsibilities. On the other hand, once central office staff is trained on the approaches and tools, they would be able to execute applications at multiple sites with minimal incremental cost. For staff at both levels, the cost of application will be significantly lower as they become more experienced.

Table 8.1. Technical requirements for running Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) at DoD installations.

Section	**Issue**	**Individual installations**	**Central office**
Information technology capacity	GIS software to pre-process InVEST inputs and visualize outputs	Easy	Easy
	Efficient computer capacity to run InVEST models	Easy	Easy
Knowledge gaps	Enlisting all relevant stakeholders for decision-making	Moderate	Difficult
	Having trained staff to identify drivers for scenario development at sites	Easy	Moderate
	Identifying appropriate data sources for InVEST models	Moderate	Moderate
	Having trained staff to properly run InVEST models	Easy/ Moderate	Easy/ Moderate
	Having trained staff to interpret InVEST results and output	Moderate	Moderate
Tools and Procedures	Developing InVEST scenarios at the site-level	Easy/ Moderate	Moderate/ Difficult
	Learning InVEST	Moderate	Easy/ Moderate
	Choosing InVEST models for site management	Easy/ Moderate	Moderate/ Difficult
	Collecting site-specific data	Easy/ Moderate	Moderate/ Difficult
	Applying InVEST output for management decisions	Easy/ Moderate	Moderate/ Difficult

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APPENDICES

Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Gretchen C. Daily	Stanford University 371 Serra Mall Stanford, CA 94305-5020	650-723-5920 gdaily@stanford.edu	Principal Investigator
Mary Ruckelshaus	The Natural Capital Project, School of Environmental and Forest Sciences, Univ. of Washington, Box 352100, Seattle, WA 98195	206-450-9742 206-860-3335 mary.ruckelshaus@stanford.edu	Demonstration Oversight
Shan Ma	Stanford University 371 Serra Mall Stanford, CA 94305-5020	650-725-5585 650-723-5920 mashan@stanford.edu	Project Manager, Economist

Appendix B: JBLM personnel interviews

Introduction

In August 2012 interviews were conducted with JBLM personnel involved in the natural-resource decision-making process. We spoke with four representatives for 30 to 45 minutes each to clarify current procedures for environmental management and to understand their perspective on the added value of an ecosystem services approach. Respondents were posed questions that focused on their specific role in environmental decision-making, their understanding and opinion of ecosystem services valuation, and the presence of the Army's mission-oriented sustainability approach on JBLM.

I. Current Decision Making Procedures

I.i Describe the decision-making process that you would be involved in should the Taylor's checkerspot butterfly, for example, be listed under the ESA. Who is involved in the process, who makes decisions, and who implements them?

According to respondents, the Garrison Commander makes the final decision on management of endangered species and gathers information on risks and relevant issues from the natural resources staff, particularly the resident biologist and those working with USFWS. Staff summaries are submitted to the Commander to indicate departments with potential conflicts or a need to review species management programs. The ITAM coordinator provides information to the Commander about how training will be impacted by any decision made, and then enforces the new restrictions or mitigations that are included in the INRMP. If a species living in the forest is listed, the timber sales representative derives a plan in consultation with the biologist to submit to USFWS.

What type of GIS information is used to decide how to adjust to new regulation?

How and when is this kind of information currently incorporated in decisions?

Respondents indicated the use of GIS software to map current and past environmental conditions on base. GIS information is used to survey wildlife and archaeology, create land use layers for mapping topography, site areas for construction activities, and keep records of past actions and impacts. Respondents indicated GIS is a useful to organize and present information in planning discussions, with one participant identifying it as "the primary tool" for deconfliction meetings. GIS has not been used in official capacity to project future conditions or scenarios, however participants expressed interest in exploring this process.

I.ii Describe your role in the natural-resource decision making process involving short-term and long-term land-use planning. Are you mostly involved with planning or implementation?

ACUB personnel on base at JBLM are involved in both the planning and implementation stages of land use practices, primarily relating to forestry activities. This includes timber sales during designated times of the year, reforestation, and planning controlled burns.

Timber sale foresters identify areas to thin, study them with GIS and assign a technician to evaluate potential issues or conflicts with other programs. They then send informal comment sheets to other programs, like the ACUB program, to initiate the deconfliction process. Deconfliction is emphasized as a process that is important to begin early, and is pre-decisional.

Biologists in the Natural and Cultural Resources Department provide counsel on both short-term and long-term decisions by examining their environmental consequences to sensitive species habitat and other resources of concern. ITAM Coordinators at JBLM are contracted but located within the Range Division. They work closely with the Natural Resource personnel and Range Officers on issues relating to land use and its relationship to training capacity. Teams produce priority lists of activities in coordination with the Environmental and Natural Resources Division (ENRD), and bring projects to the deconfliction meetings for discussion.

II. The Added Value of Ecosystem Services

II.i What do you understand by "natural-resource management" and how do you think other divisions

(Planning; Range; Environmental, etc.) interpret this term? Does its meaning differ from ecosystem services? If so, how?

Participants had mixed responses when asked about the differences between natural resource management and ecosystem services. One participant stated ecosystem services broadly construed is equivalent to natural resources, but in practice go 'beyond what you can see' on a landscape.This description may speak to the processes of ecosystems that provide benefits but aren't easily visible (e.g., sediment retention, carbon storage). Another respondent indicated ecosystem services as a part, or one kind of, natural resource management. A third respondent equated ecosystem management with natural resource management, indicating the precise difference was difficult to identify. One participant did indicate that "natural resource management" is likely to be better understood on base. Regardless of their interpretation of ecosystem services, participants emphasized the importance of sustainability and environmental stewardship in supporting training activities.

What was the most useful product so far in your engagement with NatCap?

One participant found the most value in the early scenario development planning, which involved identifying the resources of importance at JBLM. Preliminary strategic thinking was perceived as useful to tailoring projects to explore only those scenarios most relevant to the decision context. Another participant identified the visualization of change over time as the most helpful aspect of engagement with NatCap thus far. The presentation of data in a consistent, spatially explicit format enabled an accessible method of comparison.

Do you foresee any problems with using ecosystem services valuation? Do you anticipate difficulties in amassing data, establishing scenarios, running ecosystem services models, or reporting results?

Respondents indicated that they do not foresee particular problems with employing ecosystem services valuation, but that they expect some might arise when they begin running the models and interpreting the results. One respondent stressed the importance of producing outputs that are directly relevant and useful to decision makers, and indicated their potential to facilitate the NEPA process.

III. Army Sustainability and JBLM

III.i According to the 2004 Army Strategy for the Environment, the Army is undergoing a transition "from a compliance-based environmental program to a mission-oriented approach based on the principles of sustainability." How has this transition affected JBLM, if at all? What does this mean for conservation planning on base?

All of the participants described a movement towards sustainability at JBLM. This process has been reflected on the ground as environmental managers focus on proactive rather than reactive activities, and coordination in the conservation process improves. A participant described the "mindset" of sustainability as not just following rules, but working to improve areas with a science-based approach. Another participant described the emphasis on sustainability in the training division. Despite this embrace of sustainability at JBLM, one participant did express reservation about budgetary constraints, explaining that this priority wasn't adequately reflected in upper-level funding.

Appendix C: Fort Benning Post-Engagement Survey

Thank you very much for participating in this survey. The Natural Capital Project has been working with the Department of Defense at Fort Benning to include ecosystem services in installation resource management and land-use planning. The purpose of this survey is to determine how useful and applicable the information we have provided is in making resource management decisions at Fort Benning, and to evaluate how well we met our performance objectives in that regard. We greatly appreciate your opinion and honest feedback!

Name (optional):

Title/Position (optional):

Directions: Please circle your answer to each question.

1. **Do you agree that the following land use/land cover scenarios are realistic and relevant to developing resource management strategies on your installation?**

20-year concentrated training scenario

1. Disagree
2. Somewhat disagree
3. Neither agree nor disagr
4. Somewhat agree
5. Agree

20-year diffuse training scenario

1. Disagree
2. Somewhat disagree
3. Neither agree nor disagree
4. Somewhat agree
5. Agree

100-year ecological forestry scenario

1. Disagree
2. Somewhat disagree
3. Neither agree nor disagree
4. Somewhat agree
5. Agree

2. **Is the scenario-based, spatially explicit ecosystem service mapping useful to inform decision making at Fort Benning?**

Service	Not Useful	Not very Useful	Usefulness could be improved	Somewhat Useful	Useful
Red-cockaded Woodpecker (RCW) Habitat (InVEST)	1	2	3	4	5
RCW Habitat (HexSim)	1	2	3	4	5
Carbon Sequestration and Storage	1	2	3	4	5
Sediment Retention (InVEST; Annual)	1	2	3	4	5
Sediment Retention (SWAT; Daily)	1	2	3	4	5

3. **In your opinion, is the model performance acceptable given the degree of agreement between model outputs and observed data?**

Model	Unacceptable	Somewhat Unacceptable	Neither Acceptable nor Unacceptable	Somewhat Acceptable	Acceptable
RCW Habitat (InVEST)	1	2	3	4	5
Carbon Sequestration and Storage	1	2	3	4	5
Sediment Retention (InVEST; Annual)	1	2	3	4	5
Sediment Retention (SWAT; Daily)	1	2	3	4	5

4. **Do you think the representation of uncertainty is useful for resource management and land use planning at Fort Benning?**

Model	Not Useful	Not very Useful	Usefulness could be improved	Somewhat Useful	Useful
Carbon Sequestration & Storage	1	2	3	4	5
Sediment Retention (InVEST; Annual)	1	2	3	4	5
Sediment Retention (SWAT; Daily)	1	2	3	4	5

5. **Do you agree that appropriate opportunities were identified to incorporate ecosystem services into land and resource management decisions at Fort Benning?**
See text and diagram of opportunities to incorporate ecosystem services into land management decisions.
    1. Disagree
    2. Somewhat disagree
    3. Neither agree nor disagree
    4. Somewhat agree
    5. Agree

6. **Given the time and effort it takes to run the various models, is InVEST a useful alternative to more complex models such as SWAT, HexSim, or other complex models (e.g., BASINS, Bruggeman's model) for resource management decisions?**
    1. Not useful
    2. Not very useful
    3. Usefulness could be improved
    4. Somewhat useful
    5. Useful

Appendix D: Planned or in-progress publications

Duggan, J. M., B. Eichelberger, S. Ma, J. J. Lawler, and G. Ziv. Resubmitted. Informing management of rare species with an approach combining scenario modeling and spatially explicit risk assessment. Ecosystem Health and Sustainability.

Ma, S., Duggan, J. M., Eichelberger, B., McNally, B., Foster, J., Pepi, E., Conte, M., Daily, G., and G. Ziv. Submitted. Valuation of ecosystem services to inform management of multiple-use landscapes. Ecosystem Services.

Ma, S., G. Ziv, J. M. Duggan, B. Eichelberger, M. Ruckelshaus, G. Daily, et al. In Preparation. Informing federal land management with an ecosystem service approach. Frontiers in Ecology and the Environment.

Dennedy-Frank, R. A. Logsdon, I. Chaubey, and G. Ziv. In Preparation. Ecosystem service assessments for water resources decisions: A comparison of two tools. Journal of Environmental Management.

Duggan, J. M., B. Eichelberger, S. Ma, J. J. Lawler. Planned. Assessment of red-cockaded woodpecker nesting at Fort Benning.

Dennedy-Frank, P.J., P. Hamel, and Y.B. Ghile. Planned. Sediment yield estimates from similar source models with distinct routing algorithms.

Hamel, P., K. Falinski, P. J. Dennedy-Frank, and D. Auerbach. Planned. Estimating spatial distributions of sediment yield in distinct geographies.