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Pacific Northwest NATIONAL LABORATORY

Final Report for SERDP Limited-Scope Project RC18-1605: Value and Resiliency of Ecosystem Services on Department of Defense Lands

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April 2020

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14. ABSTRACT
The objective of this work was to demonstrate the viability of an ecosystem services (ESs) simulation-valuation methodology tailored for Department of Defense (DoD) land management. The methodology (1) leveraged the U.S. Environmental Protection Agency's Final Ecosystem Goods and Services-Classification System (FEGS-CS) to identify beneficiaries and benefits, (2) leveraged previously-performed terrestrial ecosystem model simulations to quantify FEGS, and (3) adapted market and nonmarket valuation techniques to quantify benefits. While tradeoffs existed among land management options, land management was benefitial to ESs even under climate warming. The simulation-valuation methodology is viable. FEGS-CS was extended to include military-unique ESs and benefits. Although data limitations prevented comprehensively estimating economic values, the report provides a clear path to filling these gaps. Extending the methodology to aquatic and atmospheric environments, using more representative natural process models, and compiling valuation-related data are recommended for future research.

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Abstract

Introduction and Objectives

This report describes research performed under the Strategic Environmental Research and Development Program (SERDP) Limited Scope Project RC18-1605. The objective of this work was to demonstrate the viability of an ecosystem services (ESs; e.g., provisioning of training lands and threatened and endangered species (TES) habitat) simulation-valuation methodology tailored for U.S. Department of Defense (DoD) land management. The methodology is suitable for DoD land managers and other DoD staff to estimate benefits accrued to both the DoD and the public and to identify the relationships between natural capital and ESs across DoD lands under various management scenarios to improve resiliency of installation operations.

Technical Approach

The basic technical approach in developing the methodology (1) leveraged the U.S. Environmental Protection Agency's (EPA) Final Ecosystem Goods and Services-Classification System (FEGS-CS) to identify both DoD and public beneficiaries and the specific benefits they derive from DoD installation lands, (2) leveraged previously-performed terrestrial ecosystem succession model simulations to characterize and quantify ESs and other benefits, and (3) adapted market and nonmarket valuation techniques for quantification of DoD and public benefits in economic terms.

Results

The viability of the simulation-valuation methodology was demonstrated. FEGS-CS was extended to allow for inclusion of military-unique ESs and benefits. Linkages between natural process model's predictions and ESs were established for benefits to be measured in ecosystem units. Economic metrics were associated with ecosystem metrics to identify appropriate market and/or nonmarket valuation techniques. Examination of previously-performed simulations revealed site-specific, small tradeoffs between carbon uptake and TES habitat at three DoD installations, and these benefits were maintained under climate warming. A proof-of-principle application of the methodology at Joint Base Lewis-McChord valued a limited set of benefits and found data and methods gaps that require further research. These gaps prevented estimation of values of all benefits. Nevertheless, the research provided a clear path to resolving these issues.

Benefits

The simulation-valuation methodology can enable consistent quantification of benefits obtained by the DoD and the public while providing mechanistic insights into the relationships among natural capital, TES habitat, and military-unique ESs. While further research is needed to fill in identified gaps in data and methods, the methodology can be used to assess tradeoffs among land management options to enable sustained and resilient installation operations.

Executive Summary

Introduction

This limited-scope work was performed under SERDP Project RC18-1605. This report describes development of an ecosystem services (ESs) simulation-valuation methodology that can be used to value the benefits obtained by both the U.S. Department of Defense (DoD) and the public. A mechanistic, predictive, and adaptable valuation methodology is needed by DoD land managers to maintain resiliency of training and testing lands under increasing climatic, environmental, and land-use pressures. The mechanistic and predictive features of the simulation-valuation methodology would enable DoD land managers to evaluate a range of land management options under future climate scenarios for robust decision-making. While some past studies have attempted to value a limited set of ESs on DoD installations (e.g., Ma et al. 2016), no attempt has been made to quantitatively assess the benefits that accrue to the DoD and the public from the myriad of ESs provisioned on DoD lands. This work leveraged an existing ES classification system to systematically identify beneficiaries and benefits, leveraged existing simulations from a forest succession models to quantify ESs, and applied market and nonmarket valuation approaches to demonstrate a proof-of-concept application of the simulation-valuation methodology.

Objectives

The main objective of this project was to demonstrate that a simulation-valuation methodology could be developed and shown to be a viable approach to value the diverse range of benefits that are obtained from training lands on DoD installations. Toward this main objective, this report summarizes research that demonstrated how (1) beneficiaries and benefits could be systematically identified, (2) ESs could be characterized and quantified employing mechanistic natural process models, (3) tradeoffs among land management scenarios could be evaluated, and (4) well-established economic valuation techniques could be adapted to value a comprehensive range of benefits.

Technical Approach

Our overall technical approach is based on developing an integrated ES characterization, beneficiary and benefit identification, and valuation methodology (Figure ES-1). Climatic, hydrologic, and ecologic processes provision ESs on DoD lands. Some of these processes are affected by DoD land management, the effects of which are not shown in Figure ES-1 for simplicity. Appropriate natural process models are used to explicitly characterize the provisioned ESs in space and time. Beneficiaries and benefits are identified using the U.S. Environmental Protection Agency's (EPA) Final Ecosystem Goods and Service Classification System (FEGS-CS) (Landers and Nahlik 2013) as the starting point and augmented by including DoD-specific beneficiaries and benefits. Valuation of benefits is based on the measurement of benefits instantiated from ecosystem metrics that are extracted from natural process model simulations and the assignment of economic metrics to these benefits. Market and nonmarket valuation techniques are then employed to estimate the economic value of the benefits.

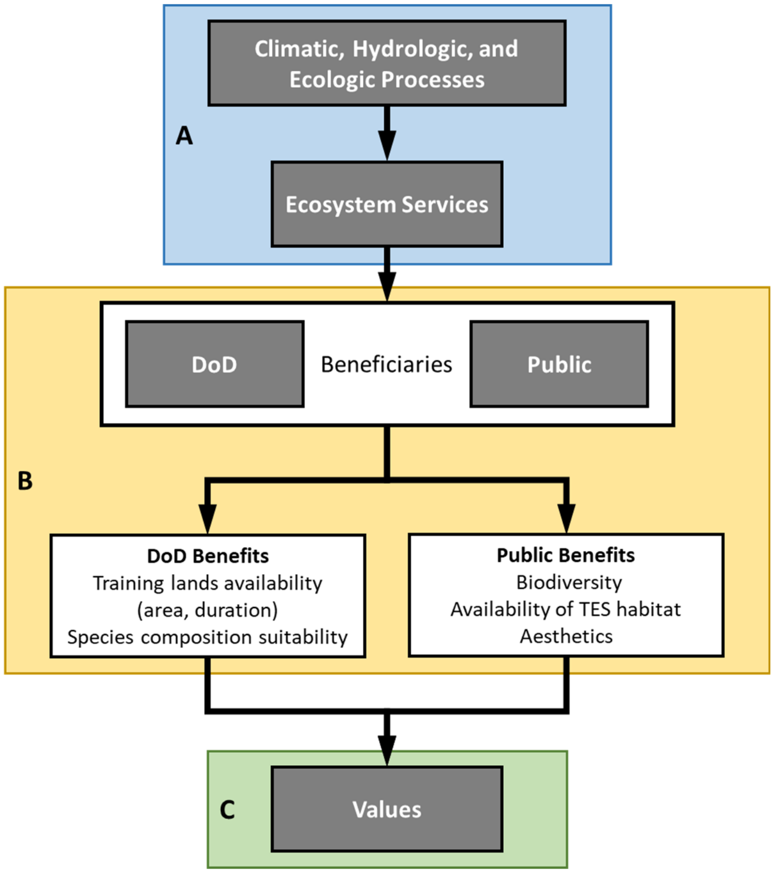

Figure ES-1. Basic approach for valuation of ESs on DoD lands. A: Provisioning of ESs: climatic, hydrologic, and ecologic processes enable ESs in the environment. B: Identification of beneficiaries and benefits: ESs in the environment can result in benefits, and C: Values: beneficiaries value specific goods and services.

Results and Discussion

<u>Identification of DoD-Specific Beneficiaries and Benefits</u>

To comprehensively and systematically identify beneficiaries and benefits obtained from DoD installation lands, FEGS-CS (Landers and Nahlik 2013) was employed. FEGS-CS classifies the environment into three classes: (1) aquatic, (2) terrestrial, and (3) atmospheric and 15 subclasses. FEGS-CS identifies 10 beneficiary categories with 38 subcategories among them. The potential benefits, or FEGS, are all intersections of environmental subclasses with beneficiary subcategories represented in a 15 × 38 matrix. Because not all beneficiary subcategories benefit from all environmental subclasses, FEGS-CS originally identified 338 unique FEGS.

This limited-scope study focused on DoD land holdings. Existing LANDIS-II simulations for the terrestrial ecosystem were available for three DoD installations (Fort Benning, Camp Navajo, and Joint Base Lewis-McChord (JBLM)). Therefore, the application of FEGS-CS was limited to only the terrestrial environment and to the environmental subclasses forests, grasslands, and scrublands and shrublands because these terrestrial environments are the primary landscapes on the three selected DoD installations.

The beneficiaries at DoD installations were identified by considering the original FEGS-CS categories and subcategories. To adequately capture military-unique benefits, some beneficiary subcategories were refined, and new ones added. One new beneficiary category, National Defense, was added. Altogether, 19 DoD-specific beneficiary subcategories were identified. Four new beneficiary subcategories were also identified (Table ES-1).

Benefits (check marks in Table ES-1) may overlap between certain beneficiaries. For example, timber extractors may be contracted to perform harvesting, which results in benefits to both timber extractors (e.g., profits from timber sales) and DoD foresters/wildlife biologists (e.g., harvesting fees obtained, management of training lands, improvements in habitat). These benefits are counted separately because they are distinct benefits provided to distinct beneficiaries.

Table ES-1. DoD-specific FEGS-CS matrix.

Beneficiary Category	Beneficiary Description	Environmental Subclasses		
		XY=21 (Forests)	XY=24 (Grasslands)	XY=25 (Scrublands/ Shrublands)
XY.01 Agricultural				
XY.0107	DoD foresters	X	X	X
XY.0108	DoD wildlife biologists	X	X	X
XY.02 Commercial and Industrial				
XY.0202	Timber extractors	X		
XY.0206	Resource-dependent businesses	X	X	
XY.03 Government, Municipal, and Residential				
XY.0303	DoD property owners	X	X	X
XY.0304	DoD military trainers	X	X	X
XY.0305	DoD military branches	X	X	X
XY.04 Commercial/Military Transportation				
XY.0401	DoD transporters of goods		X	X
XY.0402	DoD transporters of people		X	X
XY.06 Recreational				
XY.0601	Experiencers and viewers	X	X	X
XY.0603	Hunters	X	X	
XY.07 Inspirational				
XY.0701	Spiritual and ceremonial/tribal	X	X	X
XY.08 Learning				
XY.0801	Educators and students	X	X	X
XY.0802	Non-DoD researchers	X	X	X
XY.0803	DoD researchers	X	X	X
XY.0804	DoD soldiers	X	X	X
XY.09 Non-Use				
XY.0901	Non-users—existence	X	X	X
XY.0902	Non-users—option/bequest	X	X	X
XY.11 National Defense				
XY.1101	Citizens	X	X	X

Characterizing Benefits Using Natural Process Models

The spatio-temporal evolution of ESs on DoD lands is characterized using appropriate mechanistic, predictive, natural process model simulations. Use of mechanistic models enables characterization of ESs under a variety of land use management, DoD installation change, and climate change scenarios. LANDIS-II (Scheller et al. 2007) was the chosen natural process model. LANDIS-II simulations at the three installations were performed and evaluated against onsite observations (Martin et al. 2015, Laflower et al. 2016, Hurteau et al. 2016).

Existing LANDIS-II simulations were analyzed to obtain insights into the potential tradeoffs of land management options. Net ecosystem carbon exchange (NEE) was responsive to land management, although the response varied between sites (Figure ES-2).

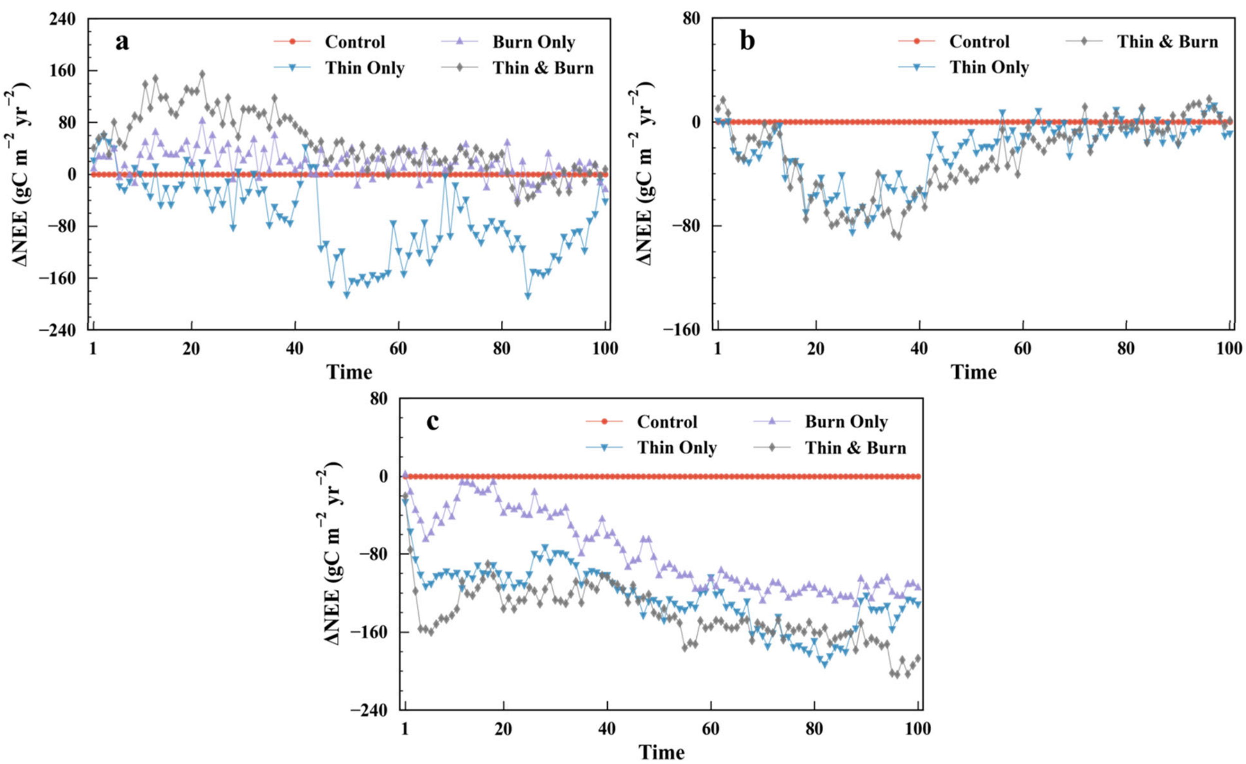

Figure ES-2. Comparison of ΔNEE time series under different land-management scenarios at (a) Fort Benning, (b) Camp Navajo, and (c) JBLM. ΔNEE is calculated as NEE deviation from the control experiment. Time is in years since start of the simulations. Notice that the vertical scales for the three sites have different ranges.

Threatened and Endangered Species (TES) habitat was sensitive to management disturbances at Fort Benning and Camp Navajo, but much less sensitive at JBLM (Figure ES-3). TES habitat at Fort Benning is characterized by open stands of longleaf pine that are >30 years old for red-cockaded woodpecker (RCW) roosting habitat and >60 years old for nesting habitat. Forest growth and development following management activities is required to achieve these conditions (Figure ES-3a). TES habitat at Camp Navajo is characterized by high canopy cover of larger trees for Mexican spotted owl (MSO) nest sites and a diversity of structural conditions for foraging. Similar to Fort Benning, achieving these conditions requires stand development following treatment. At JBLM, habitat for the state-listed western gray squirrel (WGS) was largely un-impacted by thinning and burning because the WGS forages for Garry oak acorns, which are available on only a small subset of the installation. Habitat for the NSO is characterized by older forests (≥100 year old Douglas-fir) with moderate to high canopy closure (≥60%) with large over-story trees containing large cavities, large accumulation of fallen trees/debris on the ground, and sufficient open space for flying (JBLM 2017). While NSO habitat gradually increased in all scenarios, the increase rate was largely un-impacted by management disturbance.

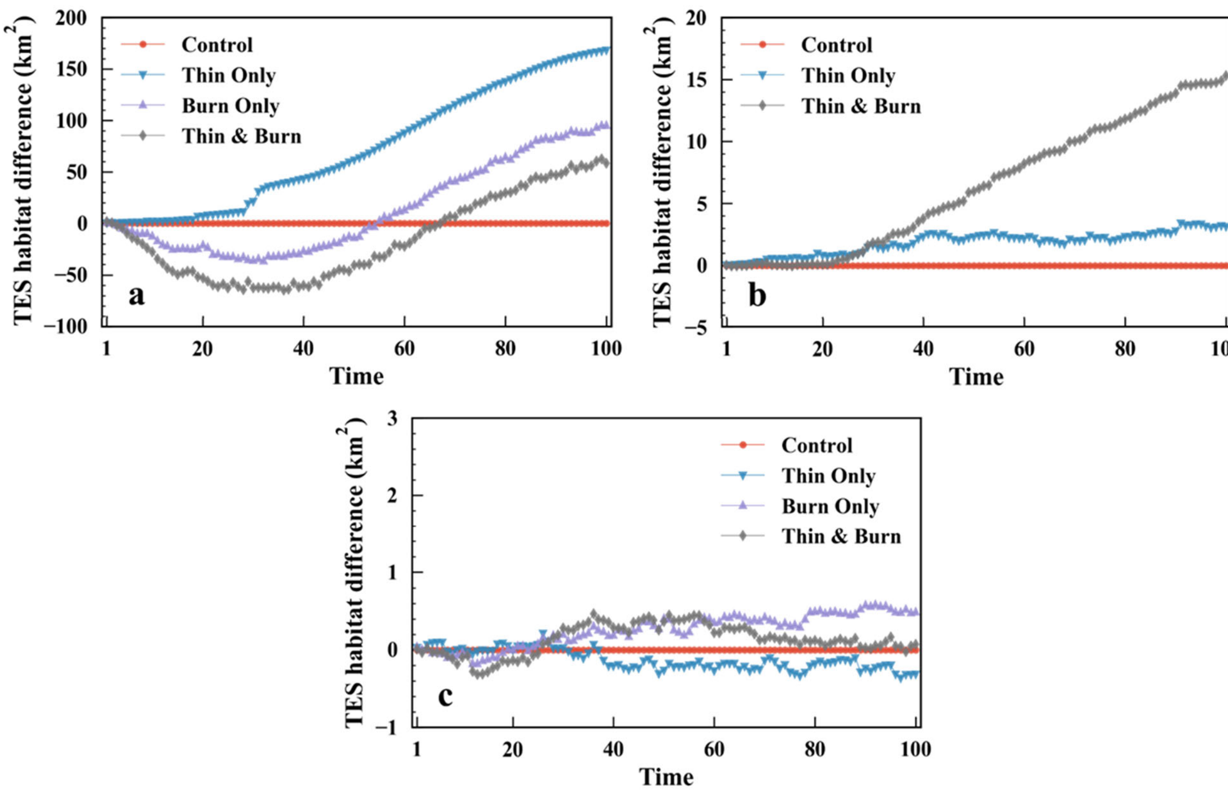

Figure ES-3. Comparison of time series of TES habitat area deviation from the control experiment under different land-management scenarios at (a) Fort Benning, (b) Camp Navajo, and (c) JBLM. Time is in years since start of the simulations. Notice that the vertical scales for the three sites have different ranges.

Examining the relationships between TES habitat and NEE in response to the treatments revealed tradeoffs for management (Figure ES-4). Carbon uptake increased with TES habitat area at Fort Benning (Figure ES-4a), but no strong tradeoff between NEE and TES area was found at Camp Navajo or JBLM (Figure ES-4b, c).

The effect of climate warming on ΔNEE and TES habitat was examined at JBLM (Figure ES-5). The response of ΔNEE to warming was a significant reduction in carbon sink potential (more positive NEE; Figure ES-5a); however, thinning and burning treatments allowed a larger carbon sink (more negative NEE). TES habitat was reduced significantly by warming, with little differences between stand-entry treatments (Figure ES-5b).

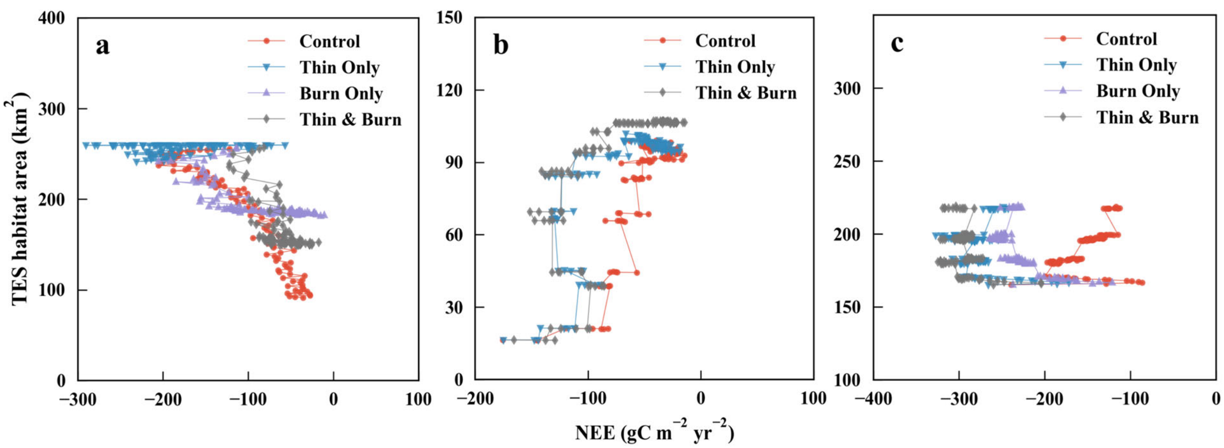

Figure ES-4. Relationships between NEE and TES habitat area under different land-management scenarios at (a) Fort Benning, (b) Camp Navajo, and (c) JBLM. Notice that the scales for the three sites have different ranges.

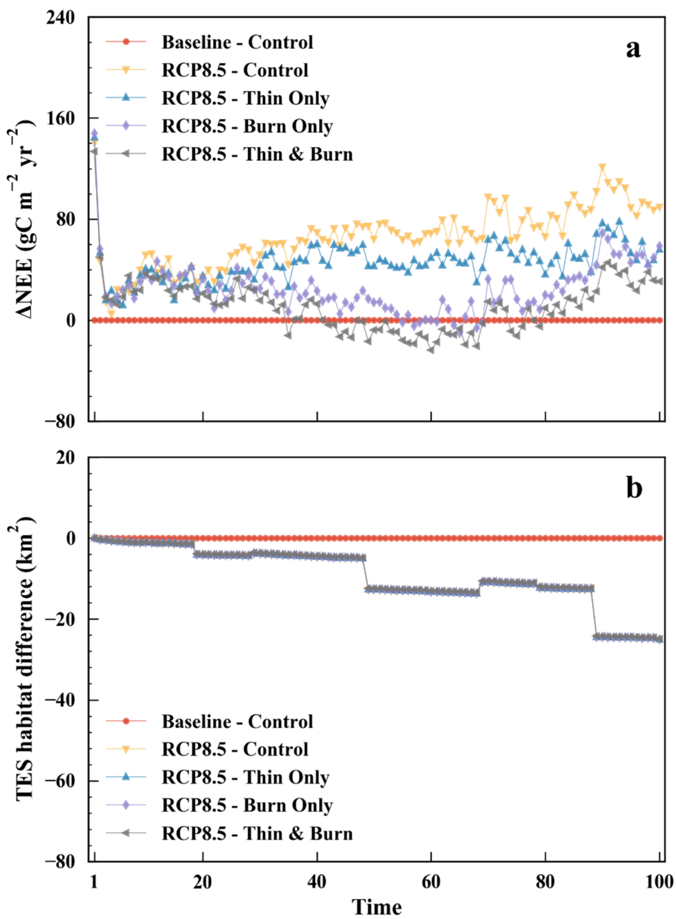

Figure ES-5. Climate change impacts on NEE and TES habitat at JBLM. In panel (a), the response of NEE compared to the baseline climate, control treatment (no-stand entry) is shown. In panel (b), the response of TES habitat to the same treatments and climate are shown. Time is in years since start of the simulations.

Valuing DoD-Specific Ecosystem Services

While EPA's FEGS-CS is useful in consistently identifying beneficiaries and benefits (FEGS) from ESs, the system does not provide ways to measure FEGS or to quantify the value of specific FEGS. Our simulation-valuation methodology builds on FEGS-CS by including ecosystem metrics derived from natural process models (used to measure FEGS in ecosystem units), economic metrics (used to measure FEGS in economic units), and instantiating subsequent values (using appropriate market or nonmarket valuation approaches). Figure ES-6 shows the conceptual representation of valuation. Table ES-2 shows the ecosystem metrics associated with the identified FEGS. Ecosystem metrics measure the FEGS in units that are related to the ecosystem. For example, one FEGS associated with DoD foresters is harvested products, which is most appropriately measured in harvested quantity (e.g., tons of timber). Multiple ecosystem metrics may be associated with a single FEGS. The idea here is to capture the metrics that can describe aspects of FEGS that beneficiaries value, often differently. Ecosystem metrics also address is frequency of availability of a FEGS (e.g, days per year a training land parcel may be suitable for use).

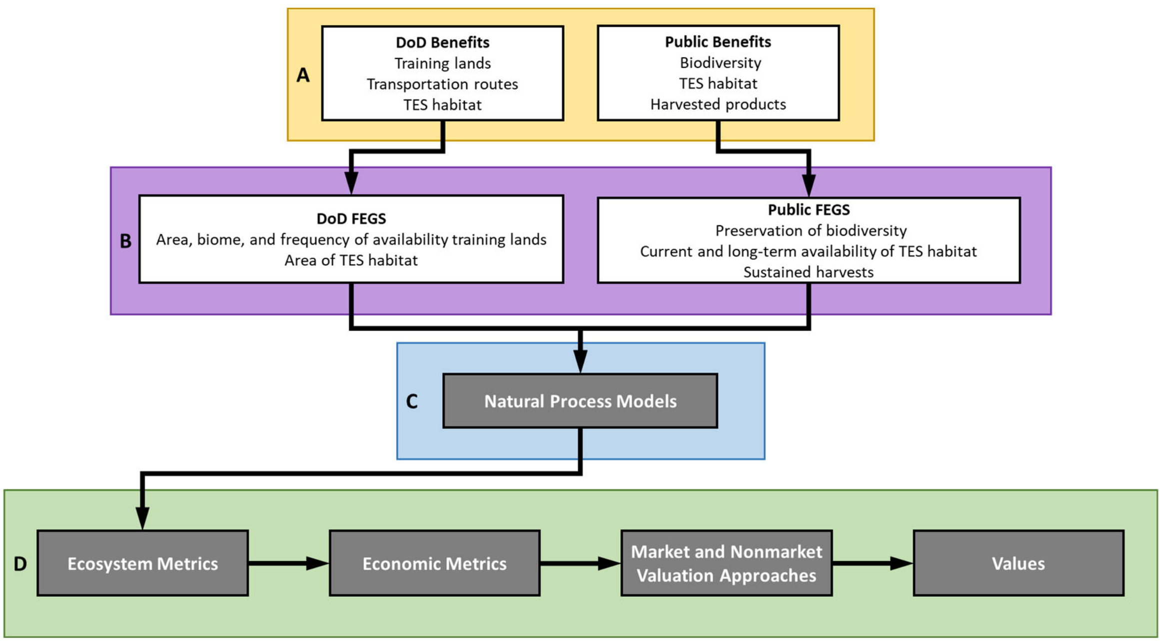

Figure ES-6. Conceptual representation of valuation of FEGS derived from ESs on DoD lands. A: benefits to DoD and the public identified following FEGS-CS. B: Determination of FEGS associated with the DoD and the public benefits. C: Characterization and quantification of DoD and public FEGS using natural process models. D. Measuring FEGS in ecosystem and economic metrics and application of market and nonmarket valuation approaches to determine total value of FEGS derived from DoD lands.

To enable the valuation of FEGS, ecosystem metrics are paired with economic metrics (Table ES-3). The listing shows that economic metrics can be assigned to FEGS based on their ecosystem metrics. The economic metrics can be related to productivity (e.g., revenue from harvested goods, value of a trained soldier, value of sustained national production) or costs related to avoiding adverse impacts (e.g., costs to implement TES recovery plans, costs to restore national production). Economic metrics may be based on market values (e.g., harvested products) and others may be based on nonmarket values (e.g., willingness to pay (WTP) for TES habitat preservation). For the identified economic metrics, well-established economic valuation approaches, both market and nonmarket exist. However, valuing FEGS can be highly site-specific and subject to data availability.

Table ES-2. Ecosystem metrics used to characterize and measure FEGS.

Beneficiary Category	Beneficiary Description	FEGS	Ecosystem Metrics (Ecosystem Units)
XY.01 Agricultural			
XY.0107	DoD foresters	training lands harvested products TES habitat	area (km^2), biome, frequency of availability (d/y)[§] harvested quantity (tons) area (km^2), fragmentation
XY.0108	DoD wildlife biologists	TES habitat	area (km^2), biome, fragmentation[†]
XY.02 Commercial and Industrial			
XY.0202	Timber extractors	harvested timber	harvested quantity (tons)
XY.0206	Resource-dependent businesses	harvested products	harvested quantity (tons)
XY.03 Government, Municipal, and Residential			
XY.0303	DoD property owners	land for buildings	area (km^2), fragmentation
XY.0304	DoD military trainers	training lands	area (km^2), biome, frequency of availability (d/y; y/10y)[‡]
XY.0305	DoD military branches	training lands	area (km^2), biome, frequency of availability (d/y; y/10y)
XY.04 Commercial/Military Transportation			
XY.0401	DoD transporters of goods	routes	length (km), frequency of availability (d/y)
XY.0402	DoD transporters of people	routes	length (km), frequency of availability (d/y)
XY.06 Recreational			
XY.0601	Experiencers and viewers	recreation	area (km^2), frequency of access (d/y)
XY.0603	Hunters	recreation	area (km^2), frequency of access (d/y)
XY.07 Inspirational			
XY.0701	Spiritual and ceremonial (tribal)	the environment	area (km^2), frequency of access (d/y)
XY.08 Learning			
XY.0801	Educators and students	the environment	area (km^2), frequency of access (d/y)
XY.0802	Non-DoD researchers	the environment	area (km^2), frequency of access (d/y)
XY.0803	DoD researchers	the environment	area (km^2), frequency of access (d/y)
XY.0305	DoD soldiers	training	area (km^2), biome, frequency of availability (d/y)
XY.09 Non-Use			
XY.0901	Non-users—existence	the environment	area (km^2)
XY.0902	Non-users—option/bequest	the environment	area (km^2), long-term availability (km^2)
XY.11 National Defense			
XY.1101	Citizens	military readiness	sustained military training capacity (area (km^2), biome, frequency of availability (d/y; y/10y))

[§] Fragmentation occurs when the area related to a FEGS is broken up into smaller, more isolated patches. Fragmentation is measured by spatial characteristics like total edge length and edge density of FEGS parcels (e.g., area suitable for a TES).
[†] d/y denotes days per year
[‡] y/10y denotes years per decade

Proof-of-Principle Application

The proof-of-principle application of the simulation-valuation methodology used the JBLM site. DoD FEGS included in the proof-of-principle application were training area (mounted and dismounted) and TES habitat. The proof-of-principle application included public FEGS which were harvest area, recreation area, and area of the environment for non-use benefits. Ecosystem metrics for these FEGS were the respective provisioned areas. Ecological descriptions combined with DoD land use restrictions were used to extract these FEGS' ecosystem metrics from LANDIS-II simulations (Table ES-4).

Table ES-3. Economic metrics associated with FEGS.

FEGS	Ecosystem Metrics	Economic Metrics
training lands	area (km^2), biome, frequency of availability (d/y)	1. Cost of land used for training 2. Value of diverse training conditions 3. Distance and cost to travel to training areas 4. Cost to maintain training areas 5. Value derived from training
harvested products	harvested quantity (tons)	1. Revenue or cost per ton
TES habitat	area (km^2), fragmentation	1. Cost of alternative land management 2. Cost of restoring and maintaining habitat 3. Contribution of TES to ecosystem productivity 4. Willingness to pay (per km^2) for species preservation
land for buildings	area (km^2), fragmentation	1. Cost of using land for buildings and residential area 2. Sale price of residential/commercial land in area
routes	length (km), frequency of availability (d/y)	1. Cost for unusable routes, cost of alternative routes 2. Damages/costs due to transportation 3. Cost of changing or not using routes, cost of maintenance 4. Cost of TES habitat destruction 5. Changes in transportation costs given changes in environment
recreation	frequency of access to areas including training areas (d/y)	1. Distance traveled, and dollars spent 2. Willingness to pay (WTP) for access to areas 3. Value attributed to recreation from revenue generating services on land 4. Characteristics of land and contribution to recreational activities
the environment	area (km^2), and long-term availability (km^2)	1. WTP for preservation of desired environment 2. Contribution of land to TES habitat, land use, etc.
training	area (km^2), biome, frequency of availability (d/y)	1. Value attributed to training (e.g., meeting training goals) 2. Value of obtained skillset in military and post-military professions
military readiness	sustained military training capacity (area (km^2), biome, frequency of availability (d/y; y/10y))	1. Value of sustained national production 2. Cost to restore lost national production from compromised national assets

Table ES-4. LANDIS-II modeled parameters used to extract FEGS from model simulations.

Provisioned Area Description		LANDIS-II Modeled Parameters
Habitat	Bald Eagle	Forest grid cell within an 800-m buffer along Muck Creek and Nisqually River
	NSO	Forest grid cells with ≥100 years-old Douglas Fir trees
	WGS	Grid cells with Garry Oak within an 800-m buffer adjacent to grassland, shrubland/scrubland, or savanna
Training - Mounted		Grassland, shrubland/scrubland, and savanna grid cells
Training – Dismounted		Forest grid cells excluding habitat and ceremonial areas
Harvest		Grid cells within forest, grassland, shrubland/scrubland, or savanna areas, if removed biomass was larger than zero for the control and thin only treatments or if the removed biomass was larger than the removed biomass by burning only for the thin-and-burn treatment
Note: Areas provisioned for recreation and the environment are derived from those listed in this table and the ceremonial area (which is assumed fixed at 3.9 km^2).		

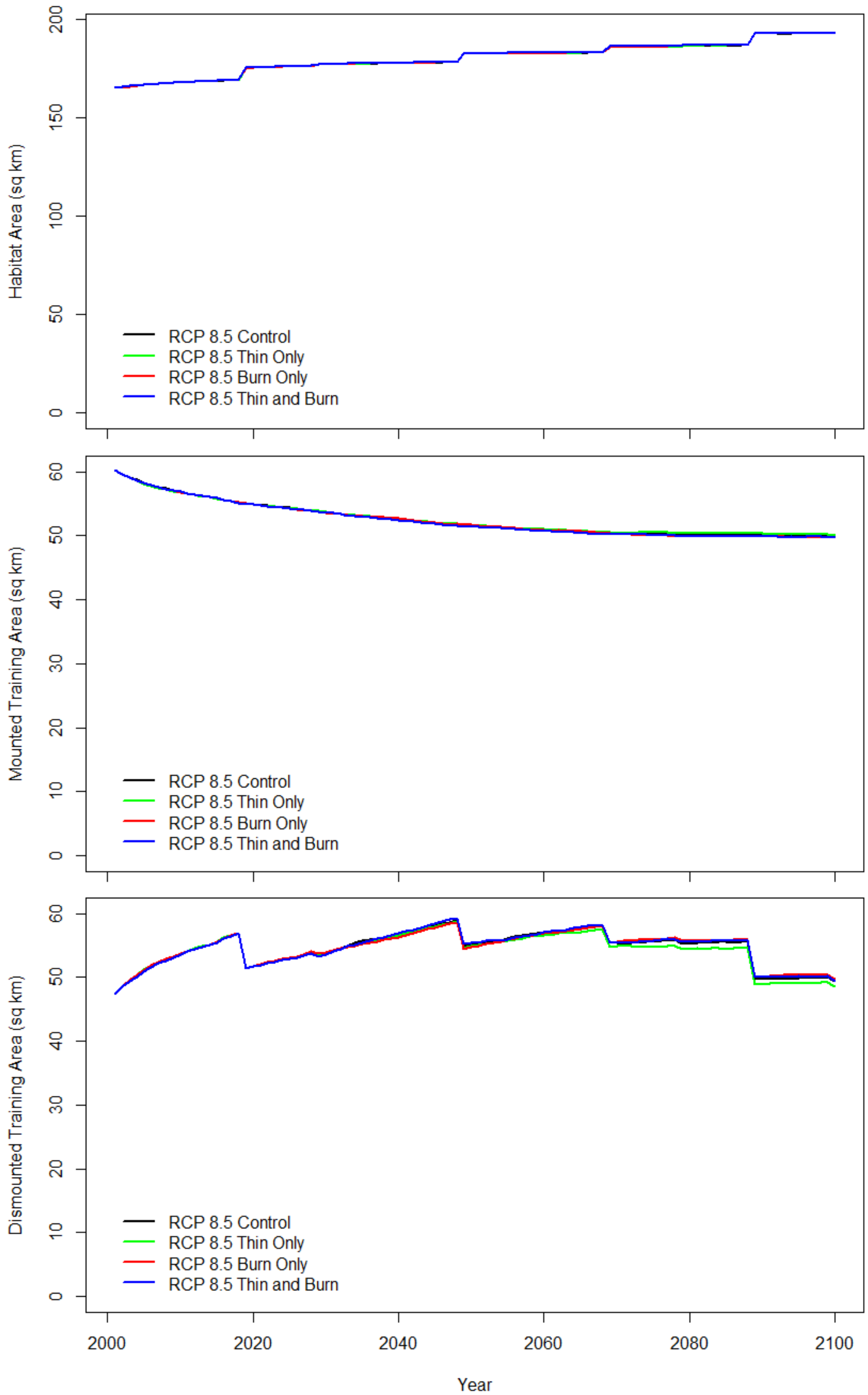

Figure ES-7. Time series of TES habitat area, mounted training area, and dismounted training area extracted from LANDIS-II simulations for the three land management scenarios under the RCP 8.5 climate scenario.

Figure ES-7 shows the time series of TES habitat area, mounted training area, and dismounted training area. Even under the RCP 8.5 climate scenario, TES habitat area showed an increase of 18% over 100 years which was primarily driven by the expansion of forests in grassland/savanna areas. Under all land management scenarios, a steady decline was observed in mounted training area, with the differences in land management scenarios becoming noticeable after about 70 years. Early in the LANDIS-II simulations (the first two decades), the rate of increase of dismounted training area was quite rapid (about 10 km^2 over 20 years, a 22% increase). However, the rate of rise following the abrupt declines seemed to gradually reduce, with almost no gain seen following the abrupt decline 70 years into the simulation.

Before values of ESs obtained from JBLM lands can be estimated, the FEGS need to be quantified in economic metrics. The economic metrics related to FEGS were identified (Table ES-3). Because only limited valuation data, not site-specific to JBLM, were available, the benefit transfer method was used. While the benefit transfer method is subject to potential inaccuracies, if it is implemented properly, the results can be quite reasonable for valuation purposes. Using these data, a limited number of FEGS were valued at JBLM (Table ES-5).

Table ES-5. Preliminary valuation of certain FEGS at JBLM.

FEGS	Average Annual WTP (2006$)	JBLM Annual Value (2006$)[†]
TES – Bald Eagle	$39 per household	Less than $102 million
TES - Owl	$65 per household	Less than $170 million
Old-growth Forest	$28 per acre	$1.1 to $1.3 million
Critical Habitat[§]	$86 million to $171 million statewide	Less than $86 million to $171 million

[§] Because critical habitat value in **Error! Reference source not found.** applies to the whole state of Oregon, it was scaled for the state of Washington using the two states' 2006 populations. The underlying assumption is that the residents of the two states value critical habitat similarly on a per capita basis.
[†] The annual values for TES and critical habitat at JBLM would be less than the corresponding statewide values as stated in Column 3. Further research is needed to determine how JBLM's share of statewide value should be determined.

However, significant gaps exist in valuation data (e.g., cost of training lands, value of diverse training conditions, distance and cost of travel to training areas, cost to maintain training lands, site-specific TES values). With additional work, these gaps can be filled. Nevertheless, the proof-of-principle application clearly demonstrated that the simulation-valuation methodology can be successfully applied to value benefits from DoD installations.

Implications for Future Research and Benefits

Gaps in both methods and data were identified during this project. These are described below and are recommended for future research.

DoD-Specific FEGS-CS Gaps

The DoD-specific FEGS-CS matrix described in this report is limited to the terrestrial environment only. DoD installations also provide benefits from the aquatic and the atmospheric environments. Moreover, even at the scale of DoD installation areas, significant interactions among the terrestrial, aquatic, and atmospheric environments exist. To enable more comprehensive accounting of ESs and the benefits that accrue from them, the simulation-valuation methodology should be expanded to include aquatic and atmospheric ESs with appropriate accounting for interactions among environments.

Natural Process Model Gaps

The natural process model used in this project did not explicitly account for the effects of military training on habitat areas and any associated feedbacks on ESs. The predictions from natural process model used in the study were only available at annual timesteps. Therefore, no seasonal characterization of ESs could be attempted. In future work, more representative natural process models that capture seasonal variations in ESs should be employed.

The inclusion of natural process models to characterize all three environmental classes—aquatic, terrestrial, and atmospheric—has the potential to complicate the ES simulations because of myriad of interactions these models may need to represent. It may be possible to develop and employ reduced-form models that adequately capture the interactions without making the computations intractable.

The models employed in the simulation-valuation methodology contain several sources of uncertainty that arise from natural variations and from incomplete knowledge of the natural system and processes. Future research should explicitly characterize known sources of uncertainty to provide a measure of confidence in the predictions of ESs' provisioning.

Valuation Gaps

This project identified that while some of the ecosystem metrics can be readily obtained from natural process models (e.g., TES habitat area), some require additional information from DoD installations (e.g., fragmentation caused by training, frequency of harvests, routes used for training, number of troops assigned). There are some gaps in intermediate data that are required to derive economic metrics from ecosystem metrics. For example, the area of training lands needs to be represented as quantifiable metrics such as training areas to support of a specified number of dismounted troops, a specified number of field artillery officers, or a stryker brigade. Finally, quantification of ESs in economic metrics also has gaps (e.g., DoD costs to maintain training areas/routes, restoring habitat, using alternative routes). Some valuation-related data exist (e.g., market value of harvested goods, sale price of residential/commercial land, WTP for habitat/species preservation, salaries paid to well-trained leaders) and some need to be obtained from site-specific surveys (e.g., WTP to access DoD lands for recreation, citizens' WTP for military readiness).

Acronyms and Abbreviations

EPA	(U.S.) Environmental Protection Agency
ES(s)	ecosystem service(s)
FEGS	Final Ecosystem Goods and Services
FEGS-CS	Final Ecosystem Goods and Services Classification System
FWS	(U.S.) Fish and Wildlife Service
JBLM	Joint Base Lewis-McChord
MSO	Mexican spotted owl
NEE	net ecosystem carbon exchange
NSO	northern spotted owl
RCP	representative concentration pathway
RCW	red-cockaded woodpecker
SERDP	Strategic Environmental Research and Development Program
TES	threatened and endangered species
WGS	western gray squirrel
WTA	willingness to accept
WTP	willingness to pay

Keywords

Ecosystem Services, Land Management, Simulation, Valuation

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1.0 Introduction

This limited-scope work performed under SERDP Project RC18-L1-1605 describes development of an ecosystem services (ESs) simulation-valuation methodology, specifically tailored for U.S. Department of Defense (DoD) land management. The methodology is suitable for use by DoD land managers that need to estimate the benefits accrued to both the DoD and the public and quantify the resilience of ESs under alternative land-management options.

For our purposes, ESs are defined as hydroecological processes and functions in the environment (e.g., carbon and nutrient storage, species diversity, and habitat suitability for threatened and endangered species (TES)). Benefits may be goods (e.g., timber) or services (e.g., provisioning of habitat suitable for TES) that the society ultimately values. The benefits accrued as services, as described here, are closely related to final ESs defined by Boyd and Banzhaf (2007).

The primary objectives of this limited-scope work were to 1) provide a proof-of-concept of a mechanistic, predictive, and adaptable valuation methodology, 2) determine technical gaps in the methodology (both related to data and approaches), and 3) determine whether the identified technical gaps can be filled in future research. In this limited-scope work, we narrowed the focus to the terrestrial environment on DoD installations.

1.1 Ecosystem Services of Interest to DoD

The DoD strives for "… ecologically sustainable management of its forests so as to maintain the continued supply of desired ecosystem services, including realistic training settings and mission support in general and maintenance of native biological diversity" (SERDP 2019). DoD's management of terrestrial ecosystems must accomplish realistic training settings and mission support while maintaining native biological diversity.

A primary ES of interest to DoD is the continued provisioning of lands for various testing and training purposes. DoD installations provide a variety of military training areas depending on ecosystems supported at the installations (e.g., open or forested land for dismounted training; scrubland or shrubland for tank maneuvering training and artillery, missile, or munitions testing; areas with buildings for urban warfare training; airfields, etc.). To support testing and training, DoD installation lands also are used for buildings—residential buildings to house troops and support personnel; offices for operational use; storage buildings for various supplies; maintenance facilities for military, communications, and support equipment; and medical facilities. Installation lands also may be used for transportation of people, equipment, and supplies (e.g., airfields, roads, docks, etc.).

While meeting the testing and training needs, DoD land managers strive to maintain suitable TES habitat, protect sensitive species, and provide access for public use of installation lands. Their sustainable approach to land management is based in ecological forestry that promotes integrity of ecosystems at landscape scales (SERDP 2019). Natural process models assist the land managers in science-based characterization of ecosystem integrity. These same models can be used to quantify natural capital and related ESs provisioned on DoD installations under a variety of future climate scenarios and land-management alternatives.

1.1.1 Benefits to the DoD

The primary DoD benefit is mission readiness that accrues both to the DoD and to the Nation as a whole. Mission readiness enables the military to meet the defense needs of the Nation. Well-trained soldiers and well-maintained equipment that are ready for deployment are a result of testing and training conducted at DoD installations that provides the DoD the return on investment made via the national defense budget.

Another class of benefits accrues to the soldiers that train on DoD installations. The soldiers acquire combat and decision-making skills. Combat skills are reflected in mission readiness described above. The number of trained soldiers with various skillsets also is reflected in mission readiness described above. The soldier, as an individual, also benefits from the education and decision-making skills that he or she acquires while in training. These skills may be reflected in the soldier's military and post-military careers.

DoD may also benefit from sale of harvested products from installation lands. These benefits may often be secondary and minor.

1.2 Ecosystem Services of Interest to the Public

For our purposes, the public is defined as any individual, business, or organization that is not affiliated with DoD. The terrestrial environment on the DoD installations may support a variety of ESs of interest to the public (e.g., provisioning of timber, recreation, education, TES habitat, etc.). Usually public access is limited to DoD installation lands. Public access for recreation and education may be provided during certain times and at certain locations such that public use of DoD lands does not interfere with testing and training activities. Timber extractors and natural-resource-dependent businesses may depend on ESs that enable provisioning of profitable harvested products. Hunters may depend on ESs that provision sustainable game on DoD lands. Researchers, educators, and students may depend on ESs themselves or ecosystems that they provision to provide research and/or educational opportunities.

1.2.1 Benefits to the Public

Public benefits from ESs provisioned on DoD lands may be both use (e.g., timber extraction, recreation, research) and non-use (e.g., TES preservation) benefits. Non-use benefits arise even when a beneficiary does not directly use an ES. Non-use benefits can be related to existence of an ES (i.e., just the knowledge that TES habitat exists) or bequest (i.e., preserving an ES for future generations such as continued preservation of TES habitat).

Another non-use benefit from ESs provisioned on DoD lands accrues to the public and, indeed, the Nation as a whole—that of national defense. The benefit of a mission-ready military provides our Nation the capability to defend itself. All citizens derive this benefit.

1.3 The Simulation-Valuation Methodology

As described in the previous sections, there are a variety of benefits that are derived from ESs provisioned on DoD lands. To value these benefits, an integrated ES characterization, beneficiary and benefit identification, and valuation methodology is needed. This methodology is briefly described in this section and further described in subsequent chapters of this report.

Figure 1 shows our basic approach for valuing benefits obtained from ESs on DoD lands.

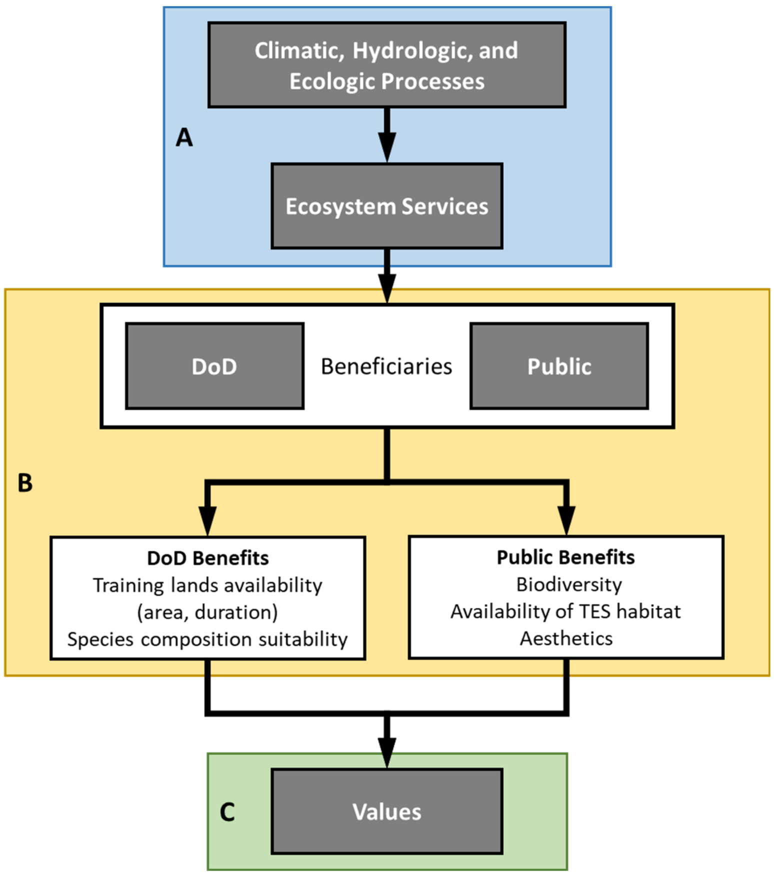

Figure 1. Basic approach for valuation of ESs on DoD lands. A: Provisioning of ESs: climatic, hydrologic, and ecologic processes enable ESs in the environment. B: Identification of beneficiaries and benefits: ESs in the environment can result in benefits, and C: Values: beneficiaries value specific goods and services.

Climatic, hydrologic, and ecologic processes provision ESs on DoD lands. Some of these processes are affected by DoD land management, the effects of which are not shown in Figure 1 for simplicity. In our simulation-valuation methodology, an appropriate set of natural process models are used to characterize the provisioned ESs. These ESs can be explicitly characterized in space and time by simulations of the natural process models. Because the natural process models are driven by prevailing and expected hydroclimatic and ecosystem conditions, effects of future variability (e.g., from global climate change) and alternative management practices (e.g., land-management scenarios) can be explicitly incorporated in ESs' characterization. Chapter 3.0 describes the characterization of ESs using natural system models.

As described in Sections 1.1 and 1.2, a myriad of beneficiaries and benefits can be associated with ESs on DoD lands. To comprehensively and consistently identify these beneficiaries and benefits, we use the Final Ecosystem Goods and Services Classification System (FEGS-CS; Landers and Nahlik 2013). FEGS-CS was developed under funding from the U.S. Environmental Protection Agency (EPA) Office of Research and Development. The system is composed of two independent hierarches—one associated with the environment and the other with the beneficiary. Using FEGS-CS in our methodology provides consistency in beneficiary and benefit identification. During this work, we needed to extend FEGS-CS as described by Landers and Nahlik (2013) to account for some unique benefits that are derived from DoD lands. Chapter 2.0 describes the adaptation of FEGS-CS for use in our methodology.

Finally, the identified benefits need to be valued. Our approach to valuation incorporates associating benefits to specific beneficiaries, assigning ecosystem metrics to measure these benefits, and applying appropriate economic valuation approaches to express benefits in economic metrics. We identified multiple economic approaches that are available to value benefits from DoD lands. Chapter 0 describes these economic approaches.

1.4 DoD Installations and Ecosystems

The simulation-valuation framework requires recognition of installation-specific ecosystems and ESs. Identification of the various ESs and unique characteristics of each installation increases accuracy in benefit calculations and enables the quantification of ES resilience given changes in land management. This work focused on ESs specific to three DoD installations: Joint Base Lewis-McChord (JBLM; located in Washington state), Fort Benning (located in Georgia), and Camp Navajo (located in Arizona). Appendix A includes a list of federally and state-listed species for the three DoD installations.

1.4.1 Joint Base Lewis-McChord

Army installation JBLM covers 91,126 ac (369 km^2) and is located roughly 36 miles south of Seattle, Washington in the Puget Sound Region. JBLM is home to three distinct landscapes: Douglas-fir forest (*Pseudotsuga menziesii*), mixed-forest (woodlands) with a substantial Douglas-fir component, and Willamette Valley upland prairie and savanna (Hurteau et al. 2015). Forests, woodlands and savanna compose 61,000 ac (247 km^2) whereas grasslands (prairies) compose 20,000 ac (81 km^2), wetlands cover 3850 ac (15.6 km^2) and forested wetlands cover 1200 ac
(4.9 km^2). Ponderosa pine covers 5300 ac (21.4 km^2) of the forested land at JBLM. Land-management objectives include the suppression of Scotch Broom (*Cytisus scoparius)* and forest thinning to promote oak and pine growth (Vander Haegen et al. 2007). Sustaining habitat through conservation measures including habitat restoration, native species reintroduction, and buffer zones is promoted at JBLM. In 2012, JBLM composed a U.S. Fish and Wildlife (FWS)-approved Endangered Species Management plan to protect the northern spotted owl *(Strix occidentalis caurina)* without triggering a critical habitat designation. Besides critical habitats, cultural sites cover 956 ac (3.9 km^2) of the total land area.

1.4.2 Fort Benning

Fort Benning is in the Sandhills ecological region of Georgia and is composed of approximately 185,329 ac (750 km^2) of predominantly forested landscape (Dilustro et al. 2002). Forested land is composed of longleaf pine (*Pinus palustris*), mixed pine, and mixed pine-hardwood.[1] Fort Benning contains some of the longest standing longleaf pine stands in Georgia, supporting critical habitat for the federally endangered red-cockaded woodpecker (*Picoides borealis*) (RCW). Stands older than 60 years are classified as critical habitat for RCW; 47% of Fort Benning's stands fit this classification (Hurteau et al. 2015). Fort Benning's RCW population is continually monitored, and onsite personnel manage RCW habitat through forest thinning and prescribed burns (FWS 2003). Fort Benning also practices nature conservation to enable bald eagles (Haliaeetus leucocephalus), wood storks *(Mycteria americana)*, American alligators (Alligator mississippiensis), gopher tortoise (*Gopherus polyphemus*), dusky gopher frog (Lithobates sevosus), and relict trillium (Trillium reliquum). The loss of longleaf pine due to deforestation and hardwood encroachment, Southern pine beetle (Dendroctonus frontalis) infestation, noise and fuel pollution are continually threatening the ESs. Habit conservation at Fort Benning is focused on the regeneration and prevention of two TES species; the RCW and the gopher tortoise.

1.4.3 Camp Navajo

Camp Navajo is a 28,417 ac (115 km^2) National Guard facility located in Bellemont, Arizona. The installation is heavily forested and primarily composed of ponderosa pine (*Pinus ponderosa*) and gambel oak (*Quercus gambellii*) (Hurteau et al. 2015). Camp Navajo is home to the Mexican spotted owl (*Strix occidentalis*) (MSO), a federally threatened species dependent on diverse old-growth forest. Historic logging and fire suppression resulted in homogenization of forest structure and the decline of the MSO habitat (Hurteau et al. 2015). Restoration of ponderosa pine forest and age-variant forest as well as fire risk-reduction are prioritized to enhance MSO habitat (FWS 2012).

[1] Mixed pines include are primarily composed of longleaf, loblolly (*P. taeda*), and shortleaf (*P. echinata*). Mixed pine-hardwoods include; southern red oak (*Quercus falcata*), blackjack oak (*Q. marilandica*), turkey oak (*Q. laevis*), and mockernut hickory (*Carya tomentosa*).

2.0 Adapting FEGS-CS to DoD Needs

This chapter describes the Final Ecosystem Goods and Services Classification System (FEGS-CS) and how it was adapted to the unique aspects of benefits derived from DoD lands. A brief background of FEGS-CS is provided, followed by the extensions of the system needed for DoD requirements.

2.1 Final Ecosystem Goods and Services Classification System (FEGS-CS)

FEGS-CS was developed by Landers and Nahlik (2013) under funding from the EPA Office of Research and Development. The system is based on the concept of "… final ecosystem goods and services (FEGS)," like the final ESs defined by Boyd and Banzhaf (2007), that a beneficiary ultimately values. FEGSs are beneficiary-specific (Landers and Nahlik 2013) and have two main advantages: 1) they provide an unambiguous definition of benefits accrued from ecological processes and functions and 2) they avoid double-counting by only considering "final" goods and services. Landers and Nahlik (2013) point out a distinction between FEGS and benefits; that is, FEGSs are endpoint goods and services produced by the environment; however, to realize a human benefit, some amount of effort (labor and/or capital) must be expended. For example, the environment may provide timber in forests, but timber must be extracted and used for its benefits to be realized. Similarly, open shrubland may be provisioned by the environment, but DoD must spend capital and labor to use the land for testing and training.

FEGS-CS is composed of two independent hierarchies—one associated with the environment and the other with the beneficiary. FEGS-CS classifies the environment into three classes: (1) aquatic, (2) terrestrial, and (3) atmospheric. The aquatic class contains six subclasses: (1) rivers and streams, (2) wetlands, (3) lakes and ponds, (4) estuaries and near-coastal marine, (5) open oceans and seas, and (6) groundwater. The terrestrial class contains eight subclasses: (1) forests, (2) agroecosystems, (3) created greenspace, (4) grasslands, (5) scrubland and shrubland, (6) barren and rock and sand, (7) tundra, and (8) ice and snow. Atmospheric is a subclass on its own. Altogether, there are 15 environment subclasses.

FEGS-CS defines beneficiaries as the interests of an individual, represented by its person, organization, household, or firm, that drive active or passive consumption and/or appreciation of ESs resulting in positive or negative impact on the individual's welfare (Landers and Nahlik 2013). In FEGS-CS, an individual may have multiple beneficiaries associated with it. For example, a farmer may rely on soil from land and water from a stream to grow crops; benefit from property protection by flood attenuation services of a wetland adjacent to the stream; value scenic views and recreation in a nearby National Park. Like individuals, organizations and firms may also have multiple beneficiaries associated with them; for example, DoD may benefit from its land holdings to support an Army base; provide training to troops under multiple vegetative covers (e.g., open or forested land for dismounted training, scrubland or shrubland for tank maneuvering training, areas with buildings for urban warfare training, etc.); and groundwater for potable and sanitary water supply. Currently, in FEGS-CS, there are a total of 10 beneficiary categories: (1) agricultural, (2) commercial/industrial, (3) government, municipal, and residential, (4) commercial/military transportation, (5) subsistence, (6) recreational, (7) inspirational, (8) learning, (9) non-use, and (10) humanity. These beneficiary categories are further classified into 38 beneficiary subcategories. Appendix B provides the FEGS-CS matrix layout with the 15 environmental subclasses laid out as columns and the 38 beneficiary subcategories laid out as rows. Each cell in the 15 × 38 matrix represents a FEGS (a potential benefit) to the corresponding beneficiary subcategory from the corresponding environmental subclass.

The two independent hierarchies in FEGS-CS are denoted using a two-part numeric coding system with the two numeric parts separated by a decimal point. The environmental hierarchy consists of two digits with the first digit representing the environmental class (i.e., 1 for aquatic, 2 for terrestrial, and 3 for atmospheric environment) and the second digit representing the environmental subclass (i.e., 1–6 for aquatic subclasses, 1–8 for terrestrial subclasses, and 1 for the only atmospheric subclass). The numeric codes for the environmental subclasses are shown in the header row of Table B.1. The beneficiary categories are represented using a two-digit identifier, 01 through 10. Beneficiary subcategories are represented by an additional two-digit identifier. Therefore, a FEGS in this system is uniquely identified by a numeric code of the form XY.AABB, where X denotes the environmental class, Y denotes the environmental subclass, AA denotes the beneficiary category, and BB denotes the beneficiary subcategory. For example, FEGS denoted by the code 11.0101 refers to potential benefits from river and streams (XY=11) to a beneficiary in the agricultural beneficiary category (AA=01), specifically an irrigator (BB=01). Because not all beneficiary subcategories derive benefits from all environmental subclasses, currently FEGS-CS identifies 338 unique FEGS (Landers and Nahlik 2013). Landers and Nahlik (2013) recognized that there may potentially be many more FEGS.

2.2 DoD-Specific FEGS-CS Matrix

Because this limited-scope study focuses on DoD land holdings and we have access to existing simulations for the terrestrial ecosystem only (LANDIS-II simulations at three DoD installations—Fort Benning, Camp Navajo, and JBLM—we limited the application of FEGS-CS to only the terrestrial environment). It is noted that the aquatic and atmospheric environments are an integral part, with interactions among all three environments, of any DoD installation, and they all must be considered in a comprehensive DoD simulation-valuation methodology. However, development and application of the methodology can be sufficiently illustrated with consideration of only the terrestrial environment. We further limited the environmental subclasses to forests, grasslands, and scrublands and shrublands because these terrestrial environments are the primary landscapes on the three selected DoD installations. Therefore, the classification system we use in this study contains three terrestrial subclasses—forests, grasslands, and scrublands and shrublands.

Next, we examined all 38 beneficiary subcategories in FEGS-CS to identify which were relevant to DoD installations and derive benefits from the three selected terrestrial subclasses. We identified 16 beneficiary subcategories of relevance to the selected DoD installations (some were renamed from their original FEGS-CS names to better reflect the benefits they derive). In addition, we also added one new beneficiary category (National Defense, denoted by identifier AA=11) and four new beneficiary subcategories (DoD wildlife biologists, AABB=0108; DoD soldiers, AABB=0305; DoD military branches, AABB=0306; and citizens, AABB=1101). Altogether, these beneficiaries are:

1. DoD foresters
2. DoD wildlife biologists (new)
3. Timber extractors
4. Resource-dependent businesses
5. DoD property owners
6. DoD military trainers
7. DoD military branches (new)
8. DoD transporters of goods
9. DoD transporters of people
10. Experiencers and viewers
11. Hunters
12. Spiritual and ceremonial/tribal
13. Educators and students
14. Non-DoD researchers
15. DoD researchers
16. DoD soldiers (new)
17. Non-users—existence
18. Non-users—option/bequest
19. Citizens (new).

In our simulation-valuation methodology, we distinguish between DoD foresters and DoD trainers. While DoD foresters are defined to be concerned primarily with local installation needs, DoD trainers are concerned with land-based needs across DoD installations to support longer-term planning. DoD foresters derive installation-specific benefits from FEGS through land management and provisioning of ESs. DoD trainers are concerned with managing FEGS in such a way as to optimize land management across installations both currently and in the future.

Appendix B provides a description of each beneficiary subcategory included in the DoD-specific FEGS-CS matrix. The DoD-specific FEGS-CS matrix is shown in Table 1.

Table 1. DoD-specific FEGS-CS matrix.

Beneficiary Category	Beneficiary Description	Environmental Subclasses		
		XY=21 (Forests)	XY=24 (Grasslands)	XY=25 (Scrublands/ Shrublands)
XY.01 Agricultural				
XY.0107	DoD foresters	X	X	X
XY.0108	DoD wildlife biologists	X	X	X
XY.02 Commercial and Industrial				
XY.0202	Timber extractors	X		
XY.0206	Resource-dependent businesses	X	X	
XY.03 Government, Municipal, and Residential				
XY.0303	DoD property owners	X	X	X
XY.0304	DoD military trainers	X	X	X
XY.0305	DoD military branches	X	X	X
XY.04 Commercial/Military Transportation				
XY.0401	DoD transporters of goods		X	X
XY.0402	DoD transporters of people		X	X
XY.06 Recreational				
XY.0601	Experiencers and viewers	X	X	X
XY.0603	Hunters	X	X	
XY.07 Inspirational				
XY.0701	Spiritual and ceremonial/tribal	X	X	X
XY.08 Learning				
XY.0801	Educators and students	X	X	X
XY.0802	Non-DoD researchers	X	X	X
XY.0803	DoD researchers	X	X	X
XY.0804	DoD soldiers	X	X	X
XY.09 Non-Use				
XY.0901	Non-users—existence	X	X	X
XY.0902	Non-users—option/bequest	X	X	X
XY.11 National Defense				
XY.1101	Citizens	X	X	X

2.3 Benefits Derived from DoD Lands

We determined that the following benefits are derived from DoD lands (the environmental subclasses the benefits depend on are shown with a check mark in Table 1):

1. DoD foresters derive benefits from the management of various ecosystems on DoD installations to optimize military training needs (e.g., availability of forested areas for dismounted training for a required training duration) and harvest (e.g., revenue for land management and supporting desired species composition), while protecting TES habitat.
2. DoD wildlife biologists derive benefits from, the continued provisioning of forests, grasslands, and scrublands/shrublands (e.g., to maintain sustainable habitat for various TES).
3. Timber extractors derive revenue from harvested timber.
4. Resource-dependent businesses derive revenue from harvested goods.
5. DoD property owners derive benefits from the current and future provisioning of environments suitable for constructing residential units, training facilities, storage facilities, and installation support buildings.

6. DoD military trainers derive benefits from continued provisioning of forests, grasslands, and scrublands/shrublands for various kinds of military training across installations.
7. DoD military branches derive benefits from troop training at the installation to support mission readiness.
8. DoD transporters of goods derive benefits from provisioning of a suitable environment for intra-installation transportation of training-related supplies.
9. DoD transporters of people derive benefits from provisioning of a suitable environment for intra-installation transportation of troops.
10. Experiencers and viewers derive benefits from the provisioning of environments used for passive and active (recreational) use and the frequency[2] with which that environment is available.
11. Hunters derive benefits from the provisioning of ecosystems that provides habitat for hunted game species and the frequency of access to this land.
12. Spiritual and ceremonial (tribal) beneficiaries derive benefits from the continued provisioning of forests, grasslands, and scrubland/shrublands important for historical, ceremonial and lifestyle purposes.
13. Educators and students derive benefits from the frequency of availability of forests, grasslands, and scrublands/shrublands sites conducive to educational endeavors.
14. Non-DoD researchers derive benefits from availability and frequency of access of forests, grasslands, and scrublands/shrublands sites suitable for their research.
15. DoD researchers derive benefits from the provisioning and the frequency of availability of environments suitable for analysis, development, and testing of innovations of interest to DoD.
16. DoD soldiers derive benefits from training at the installation to acquire skills, obtain education, and accumulate experience.
17. Non-users (existence) derive benefits from the current existence of forests, grasslands, and scrublands/shrublands and the associated habitat.
18. Non-users (option/bequest) derive benefits from the knowing that forests, grasslands, and scrublands/shrublands and the associated habitat will be available to future generations.
19. Citizens derive benefits from the provisioning of national defense needs (e.g., soldier training, mission readiness) from installation lands.

We note that benefits may geographically overlap between certain beneficiaries. For example, timber extractors may be contracted by an installation to perform land-management activities; such activities result in benefits to both timber extractors (e.g., market value of harvested timber) and DoD foresters/wildlife biologists (e.g., harvesting fees obtained, management of training

[2] Frequency of availability can be defined in two ways:

1. For training and research purposes, the duration during a year that a FEGS of interest is available (e.g., weeks or months per year).
2. For planning and bequest purposes, long-term availability of the FEGS (e.g., available at present levels for the next three decades, declining in subsequent decades).

lands, improvements in habitat). These benefits are counted separately because they are distinct benefits provided to distinct beneficiaries. However, double-counting is avoided by assigning only the profits (market value of harvested timber less the harvesting fees paid and operational costs) for the timber extractors. Similarly, beneficiaries in the recreational, inspirational, and non-use categories may attribute different values to the same area of land.

In Chapter 3.0, we further describe the characterization and quantification of DoD and public FEGS using natural process models. The valuation of FEGS is described in Chapter 4.0.

2.4 Extending FEGS-CS for Valuation

While EPA's FEGS-CS is useful in consistently identifying beneficiaries and benefits (FEGS) from ESs, the system does not provide ways to measure FEGS or to quantify the value of specific FEGS. Our simulation-valuation methodology builds on FEGS-CS to enable its application, currently specific to DoD lands, through the inclusion of ecosystem metrics (used to measure FEGS in ecosystem units), economic metrics (used to measure FEGS in economic units), and subsequent values (using appropriate market or nonmarket[3] valuation approaches). Figure 2 shows the conceptual representation of valuation of FEGS derived from ESs on DoD lands.

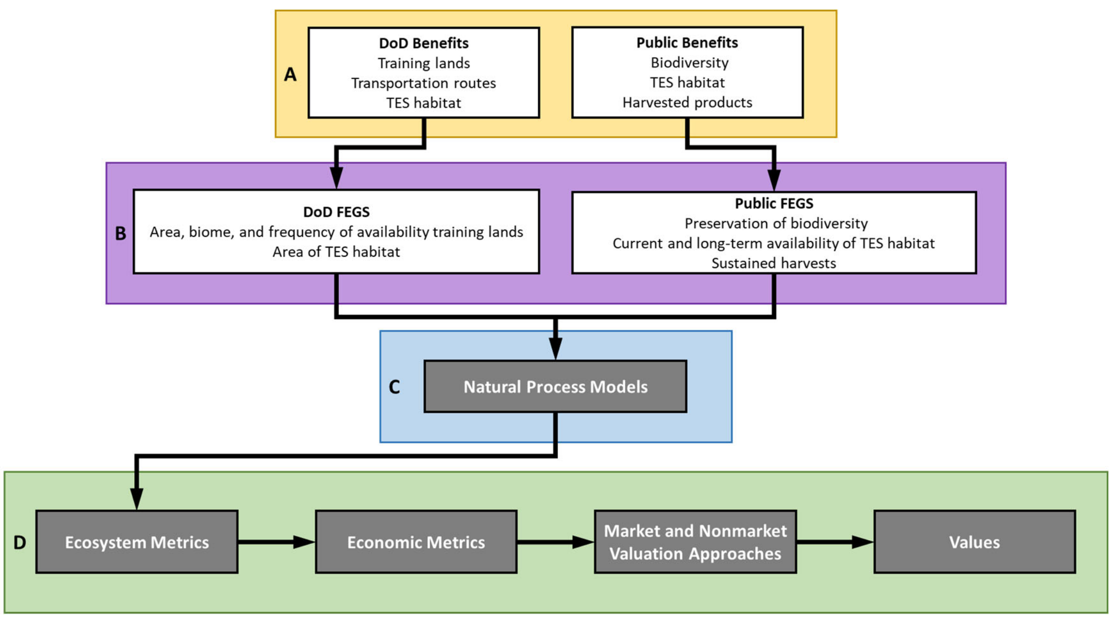

Figure 2. Conceptual representation of valuation of FEGS derived from ESs on DoD lands. A: benefits to DoD and the public identified following FEGS-CS. B: Determination of FEGS associated with the DoD and the public benefits. C: Characterization and quantification of DoD and public FEGS using natural process models. D. Measuring FEGS in ecosystem and economic metrics and application of market and nonmarket valuation approaches to determine total value of FEGS derived from DoD lands.

[3] Nonmarket value is the valuation of goods and services in monetary terms that are not priced in typical markets (Hanemann 2006). Such values can be use or non-use values.

2.4.1 Ecosystem Metrics for FEGS

Table 2 shows the ecosystem metrics associated with the FEGS identified for DoD lands. Ecosystem metrics measure the FEGS in units that are related to the ecosystem.

Table 2. Ecosystem metrics used to characterize measure FEGS.

Beneficiary Category	Beneficiary Description	FEGS	Ecosystem Metrics (Ecosystem Units)
XY.01 Agricultural			
XY.0107	DoD foresters	training lands harvested products TES habitat	area (km^2), biome, frequency of availability (d/y)[§] harvested quantity (tons) area (km^2), fragmentation
XY.0108	DoD wildlife biologists	TES habitat	area (km^2), biome, fragmentation[†]
XY.02 Commercial and Industrial			
XY.0202	Timber extractors	harvested timber	harvested quantity (tons)
XY.0206	Resource-dependent businesses	harvested products	harvested quantity (tons)
XY.03 Government, Municipal, and Residential			
XY.0303	DoD property owners	land for buildings	area (km^2), fragmentation
XY.0304	DoD military trainers	training lands	area (km^2), biome, frequency of availability (d/y; y/10y)[‡]
XY.0305	DoD military branches	training lands	area (km^2), biome, frequency of availability (d/y; y/10y)
XY.04 Commercial/Military Transportation			
XY.0401	DoD transporters of goods	routes	length (km), frequency of availability (d/y)
XY.0402	DoD transporters of people	routes	length (km), frequency of availability (d/y)
XY.06 Recreational			
XY.0601	Experiencers and viewers	recreation	area (km^2), frequency of access (d/y)
XY.0603	Hunters	recreation	area (km^2), frequency of access (d/y)
XY.07 Inspirational			
XY.0701	Spiritual and ceremonial (tribal)	the environment	area (km^2), frequency of access (d/y)
XY.08 Learning			
XY.0801	Educators and students	the environment	area (km^2), frequency of access (d/y)
XY.0802	Non-DoD researchers	the environment	area (km^2), frequency of access (d/y)
XY.0803	DoD researchers	the environment	area (km^2), frequency of access (d/y)
XY.0305	DoD soldiers	training	area (km^2), biome, frequency of availability (d/y)
XY.09 Non-Use			
XY.0901	Non-users—existence	the environment	area (km^2)
XY.0902	Non-users—option/bequest	the environment	area (km^2), long-term availability (km^2)
XY.11 National Defense			
XY.1101	Citizens	military readiness	sustained military training capacity (area (km^2), biome, frequency of availability (d/y; y/10y))

[§] Fragmentation occurs when the area related to a FEGS is broken up into smaller, more isolated patches. Fragmentation is measured by spatial characteristics like total edge length and edge density of FEGS parcels (e.g., area suitable for a TES).
[†] d/y denotes days per year
[‡] y/10y denotes years per decade

For example, one FEGS associated with DoD foresters is harvested products, which is most appropriately measured in harvested quantity (e.g., tons of timber). Another FEGS associated with DoD foresters is TES habitat, which is most appropriately measured in the area of a TES habitat. However, TES habitat quality is also an important consideration—one metric for habitat quality being fragmentation. Therefore, multiple ecosystem metrics may be associated with a single FEGS. The idea here is to capture the metrics that can describe aspects of FEGS that beneficiaries value, often differently. For example, TES habitat at two locations with same total area but one existing as a single parcel and the other fragmented into many may have different quality associated with them and therefore valued differently (one being more desirable than the other for TES sustainability).

Another aspect that ecosystem metrics address is frequency of availability of a FEGS. This metric is associated with several FEGS in Table 2. DoD foresters may value the area of training lands available at the required shorter-term frequency (e.g., days per year) to support the troops assigned to a particular DoD installation. DoD military trainers, from a Department-wide planning perspective, may also value longer-term frequency of availability (e.g., years per decade) of training lands at various DoD installations to estimate the number of troops that can be trained at those DoD installations.

2.4.2 Economic Metrics for FEGS

To enable the valuation of FEGS, ecosystem metrics are paired with economic metrics (Table 3).

Table 3. Economic metrics associated with FEGS.

FEGS	Ecosystem Metrics	Economic Metrics
training lands	area (km^2), biome, frequency of availability (d/y)	1. Cost of land used for training 2. Value of diverse training conditions 3. Distance and cost to travel to training areas 4. Cost to maintain training areas 5. Value derived from training
harvested products	Harvested quantity (tons)	1. Revenue or cost per ton
TES habitat	area (km^2), fragmentation	1. Cost of alternative land management 2. Cost of restoring and maintaining habitat 3. Productivity of TES in value contribution to ecosystem 4. Willingness to pay (per km^2) for species preservation
land for buildings	area (km^2), fragmentation	1. Cost of using land for buildings and residential area 2. Sale price of residential/commercial land in area
routes	length (km), frequency of availability (d/y)	1. Cost for unusable routes, cost of alternative routes 2. Damages/costs due to transportation 3. Cost of changing or not using routes, cost of maintenance 4. Cost of TES habitat destruction 5. Changes in transportation costs given changes in environment
recreation	frequency of access to areas including training areas (d/y)	1. Distance traveled, and dollars spent 2. Willingness to pay (WTP) for access to areas 3. Value attributed to recreation from revenue generating services on land 4. Characteristics of land and contribution to recreational activities
the environment	area (km^2), and long-term availability (km^2)	1. WTP for preservation of desired environment 2. Contribution of land to TES habitat, land use, etc.
training	area (km^2), biome, frequency of availability (d/y)	1. Value attributed to training (e.g., meeting training goals) 2. Value of obtained skillset in military and post-military professions
military readiness	sustained military training capacity (area (km^2), biome, frequency of availability (d/y; y/10y))	1. Value of sustained national production 2. Cost to restore lost national production from compromised national assets

This listing is preliminary and not intended to be exhaustive at this point in our research. However, the listing shows that economic metrics can be assigned to FEGS based on their ecosystem metrics. The economic metrics can be related to productivity (e.g., revenue from harvested goods, value of a trained soldier, value of sustained national production) or costs related to avoiding adverse impacts (e.g., costs to implement TES recovery plans, costs to restore national production). Notice that some of the economic metrics may be based on market values (e.g., harvested products) and others may be based on nonmarket values (e.g., WTP for TES habitat preservation).

For the identified economic metrics, well-established economic valuation approaches, both market and nonmarket exist. However, valuing FEGS can be highly site specific and subject to data availability. These issues are further described in Chapter 4.0.

3.0 Characterizing FEGS derived from DoD Lands

This chapter describes our approach to characterizing and quantifying FEGS derived by both the DoD and the public. FEGS vary in space and in time—for example, timber harvest is viable only in places where timber exists and training lands may not be suitable for certain kinds of military training during certain seasons. Moreover, these areas and time windows may also vary—for example, after harvests, forests need time to regenerate before they are suitable for harvest again. DoD land management, on an ongoing basis, aims to provision various kinds of training areas with suitable species composition. Given the effects of long-term variability, both from global climate change and human development pressures, DoD may also aim for medium to long-term planning to support training lands as the military's needs evolve.

Our approach to characterizing the spatio-temporal evolution of ESs on DoD lands and associated benefits is to use natural process models that can simulate future conditions under variable hydroclimatic conditions, changing land use, and alternative DoD land-management scenarios. As described earlier in Chapter 2.0, for this limited-scope study, we narrowed the focus to the terrestrial environment on the selected DoD installations. Nevertheless, we illustrate how natural process models can be deployed to characterize and quantify ecosystem metrics in a dynamic, spatially-explicit manner. The detailed spatio-temporal characterization of FEGS allows compilation of data suitable for installation to regional-scale decision-making.

The natural process model chosen to simulate alternative future scenarios was LANDIS-II (Scheller et al. 2007). LANDIS-II simulations at the three chosen DoD installations (Fort Benning, Camp Navajo, and JBLM) were previously performed and evaluated against onsite observations (Martin et al. 2015, Laflower et al. 2016, Hurteau et al. 2016). Simulations used in this study were performed using version 6.0 of the LANDIS-II code.

3.1 LANDIS-II Simulations

The LANDIS-II model simulates the forest dynamics of age-cohorts of species using species-specific life history characteristics to model dispersal, establishment, growth, and mortality (Scheller et al. 2007). LANDIS-II simulations were performed for Fort Benning, Camp Navajo, and JBLM as documented in three published studies (Martin et al. 2015, Hurteau et al. 2016, Laflower et al. 2016). Each of the three studies used the Century Succession extension to simulate ecosystem carbon dynamics and the Leaf Biomass Harvest and Dynamic Fire and Fuels extensions to simulate disturbance. The Century Succession model is based on the CENTURY soil model (Metherell et al. 1993, Parton et al. 1993) and simulates above- and below-ground carbon fluxes and pools as a function of species-specific attributes, soil characteristics, and climate (Scheller et al. 2011). The Leaf Biomass Harvest extension simulates user-defined management prescriptions that can be overlapping (Gustafson et al. 2000). The Dynamic Fire and Fuels extension simulates fuel conditions as a function of vegetation characteristics in a given grid cell. Fire is simulated stochastically based on a user-defined fire size distribution, probability of occurrence, and spread characteristics for each fuel type based on the Canadian Forest Fire Behavior Prediction System (Van Wagner et al. 1992, Sturtevant et al. 2009). Specifics for parameterization and validation for Fort Benning (Martin et al. 2015), Camp

Navajo (Hurteau et al. 2016), and JBLM (Laflower et al. 2016) can be found in the original studies.

Mean monthly air temperatures and precipitation depths for the three DoD installations are shown in Figure 3. The three locations had very disparate patterns of air temperature and precipitation. Mean annual temperature was 18.4, 6.1, and 9.7°C, while mean annual precipitation was 1249, 512, and 1472 mm at Fort Benning, Camp Navajo, and JBLM, respectively. These data were used in LANDIS-II simulations.

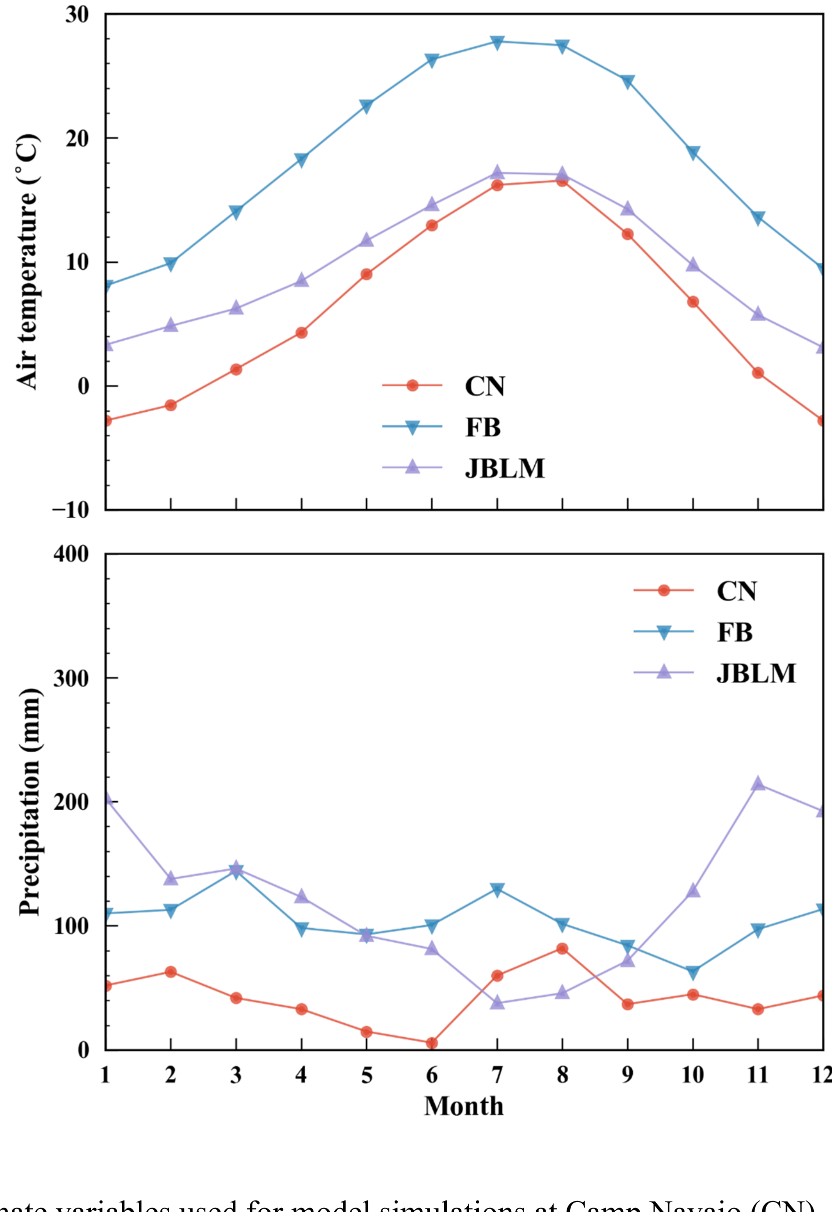

Figure 3. Climate variables used for model simulations at Camp Navajo (CN), Fort Benning (FB), and JBLM. Top panel: mean monthly air temperature, and bottom panel: mean monthly precipitation depth.

All three studies included combinations of thinning and prescribed burning developed based on the focal species at each DoD installation. Additionally, Camp Navajo and JBLM included the simulation of wildfire. Thinning treatments at Fort Benning were developed to increase the amount of forest area available for TES habitat for the RCW. While the prescriptions varied as a function of the initial forest conditions, the objective was to accelerate stand development toward mature longleaf pine. Prescribed fires were implemented to achieve a 3-year return interval that resulted in low-severity, surface fires characteristic of mature longleaf pine forest (Martin et al. 2015).

At Camp Navajo, thinning was implemented across the majority of the landscape during the first decade of simulations. Potential TES habitat for the MSO, which consisted of dense ponderosa pine cover on steep slopes, was excluded from thinning. The thinning prescription targeted young trees and removed approximately 30% of the biomass. Thinning treatments were followed by prescribed burning on a 10-year return interval (Hurteau et al. 2016).

Thinning treatments at JBLM were based on current land-management practices that harvest approximately 40% of net annual growth of Douglas-fir. Thinning targeted 70−180 year-old cohorts and was excluded from old-growth stands (>300 years old) and riparian areas. Prescribed fire was simulated on prairies and Douglas-fir forests that had established on prairie soils. This treatment was implemented to create more open conditions favorable for Garry oak to support western gray squirrel (WGS) habitat and used a 20-year return interval (Laflower et al. 2016). In these simulations, the NSO) inhabits stands of Douglas-fir that are >100 year old.

3.2 Insights from LANDIS-II Simulations

The objective was to examine the potential resource tradeoffs of land management, specifically prescribed thinning and burning, under both historical (all three locations) and future climate (one location, JBLM) scenarios. The two primary parameters chosen for this evaluation were net ecosystem carbon exchange (NEE) and TES habitat. We chose these response parameters because they are important metrics for scoring forest values and are interdependent; that is, a management choice for one parameter influences the outcome for the other.

NEE was responsive to stand management. Figure 4 represents an example of LANDIS-II output on NEE for multiple stand management scenarios at JBLM, in which shifts in NEE over time for the thinned, burned, and thinned and burned scenarios (Figure 4a) are compared to the control (no-stand entry) scenario in Figure 4b. As is apparent from Figure 4b, NEE becomes more negative (larger carbon sink) at JBLM under management scenarios in comparison to the unmanaged control scenario.

The response of NEE to stand management varied between sites, with a consistent increase in NEE (more negative values) relative to the control scenario at Camp Navajo and JBLM, but a decrease in NEE at Fort Benning (Figure 5). The pine-dominated Fort Benning site exhibited a decrease in carbon sink potential (more positive NEE), and Camp Navajo and JBLM showed the opposite pattern with increased carbon uptake due to treatments. The ponderosa pine-dominated Camp Navajo site showed an ephemeral shift in NEE relative to the control, and the Douglas-fir dominated JBLM site exhibited the most sustained and largest shift in NEE in relation to management disturbance.

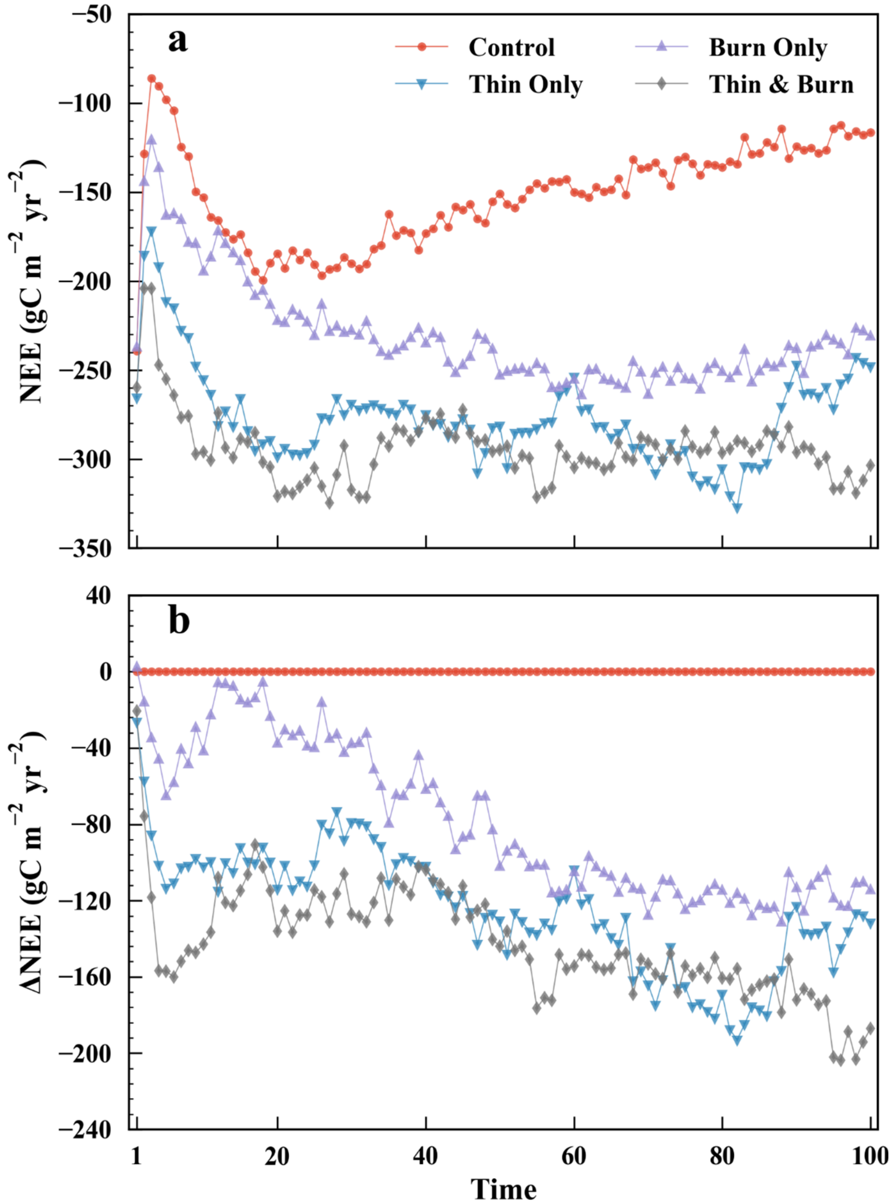

Figure 4. Comparison of (a) NEE and (b) ΔNEE time series under different land-management scenarios at JBLM. ΔNEE is calculated as NEE deviation from the control experiment. Time is in years since start of the simulations.

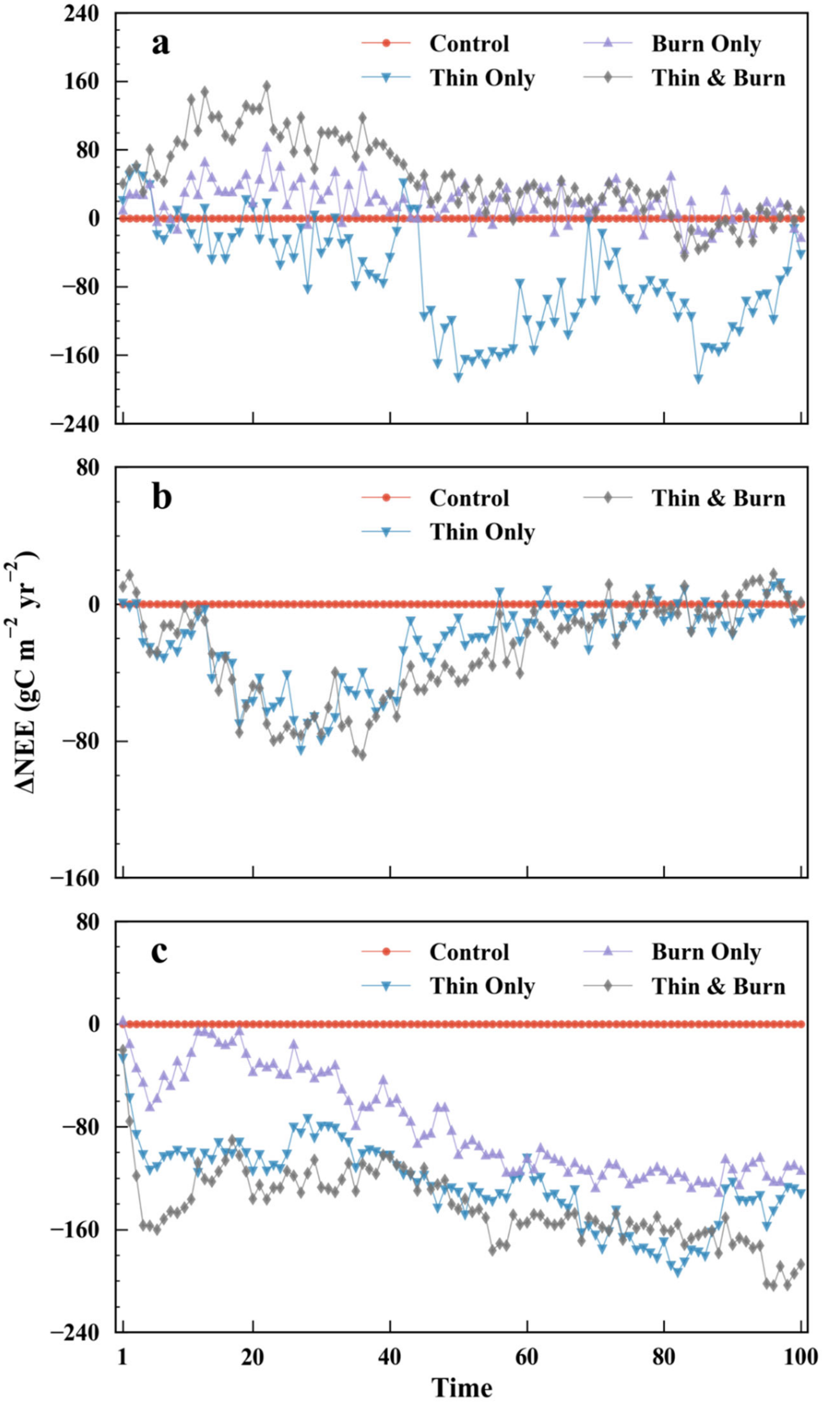

Figure 5. Comparison of ΔNEE time series under different land-management scenarios at (a) Fort Benning, (b) Camp Navajo, and (c) JBLM. ΔNEE is calculated as NEE deviation from the control experiment. Time is in years since start of the simulations.

TES habitat was sensitive to management disturbances at Fort Benning and Camp Navajo, but much less sensitive at JBLM (Figure 6). TES habitat at Fort Benning is characterized by open stands of longleaf pine that are >30 years old for RCW roosting habitat and >60 years old for nesting habitat. Forest growth and development following management activities is required to achieve these conditions (Figure 6a). TES habitat at Camp Navajo is characterized by high canopy cover of larger trees for MSO nest sites and a diversity of structural conditions for foraging (Ganey et al. 2003, Ganey et al. 2016). Similar to Fort Benning, achieving these conditions requires stand development following treatment. At JBLM, habitat for the state-listed WGS was largely un-impacted by thinning and burning because the WGS forages for Garry oak acorns, which are available on only a small subset of the installation. Habitat for the NSO is characterized by older forests (≥100 year old Douglas-fir) with moderate to high canopy closure (≥60%) with large over-story trees containing large cavities, large accumulation of fallen trees/debris on the ground, and sufficient open space for flying (JBLM 2017). While NSO habitat gradually increased in all scenarios, the increase rate was largely un-impacted by management disturbance.

Examining the relationships between TES habitat and NEE in response to the treatments reveals tradeoffs for management (Figure 7). Carbon uptake increased with TES habitat area at Fort Benning (Figure 7a), but no strong tradeoff between NEE and TES area was found at Camp Navajo or JBLM (Figure 7b, Figure 7c).

The effect of climate warming on ΔNEE and TES habitat was examined at JBLM (Figure 8). In this analysis, JBLM model runs are compared using the same stand-entry treatments as in Figures Figure 4-Figure 7, but two climate scenarios are presented: (1) the historical baseline climate data, which was used for Figures Figure 4–Figure 7, and RCP8.5, or (2) the business-as-usual fossil fuel emissions scenario (IPCC 2013). The response of ΔNEE to warming was a significant reduction in carbon sink potential (more positive NEE; Figure 8a); however, thinning and burning treatments allowed a larger carbon sink (more negative NEE). TES habitat was reduced significantly by warming, with little differences between stand-entry treatments (Figure 8b). Tradeoffs between NEE and TES habitat area were more pronounced under the climate warming scenario at JBLM (Figure 9). Relative to historical climate (baseline), warming caused NEE to become more positive, toward a carbon source, and TES habitat to shrink in area. Thinning and burning treatments did, however, partially mitigate these shifts.

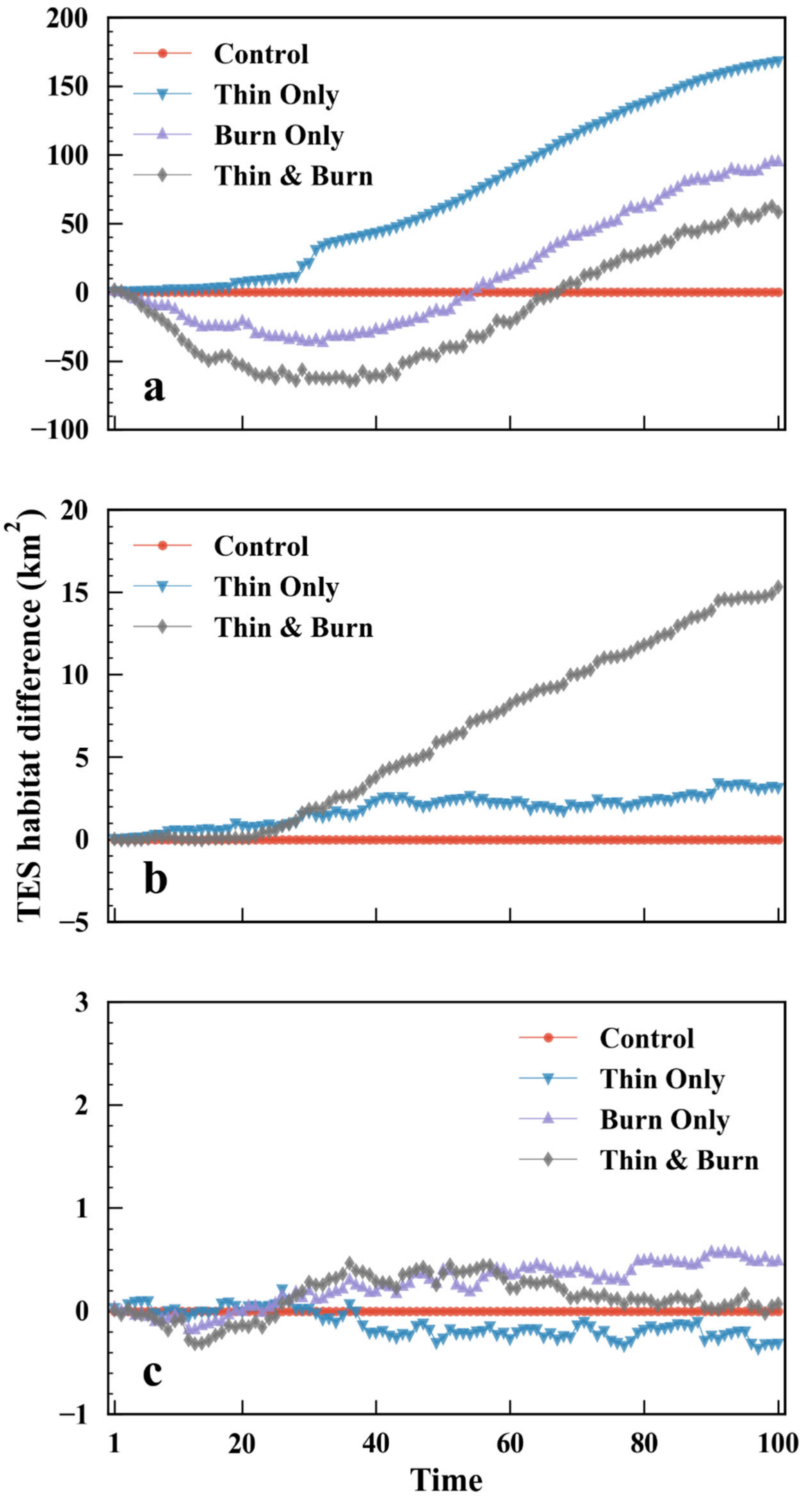

Figure 6. Comparison of time series of TES habitat area deviation from the control experiment under different land-management scenarios at (a) Fort Benning, (b) Camp Navajo, and (c) JBLM. Time is in years since start of the simulations. Notice that the vertical scales for the three sites have different ranges.

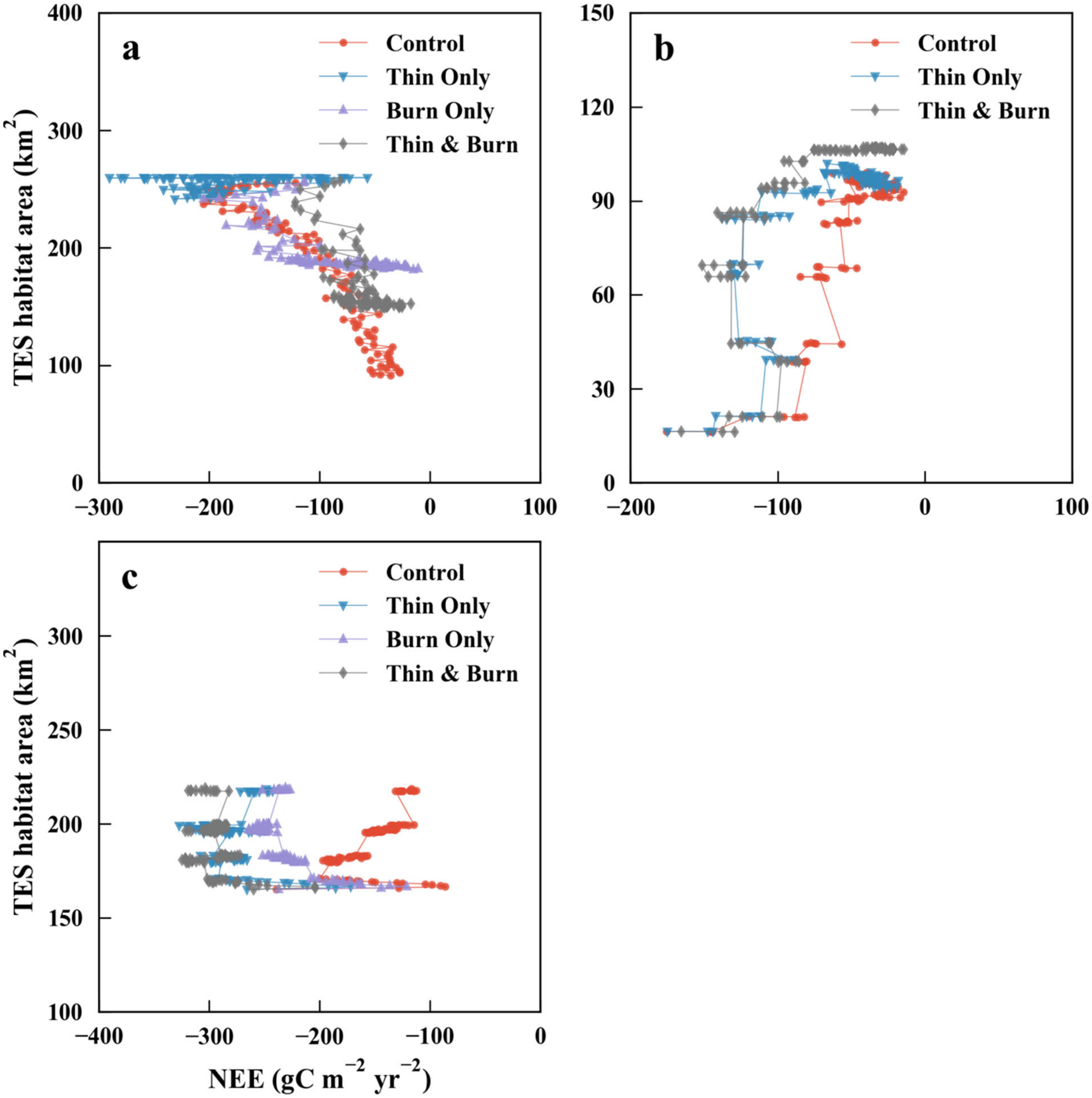

Figure 7. Relationships between NEE and TES habitat area under different land-management scenarios at (a) Fort Benning, (b) Camp Navajo, and (c) JBLM. Notice that the scales for the three sites have different ranges.

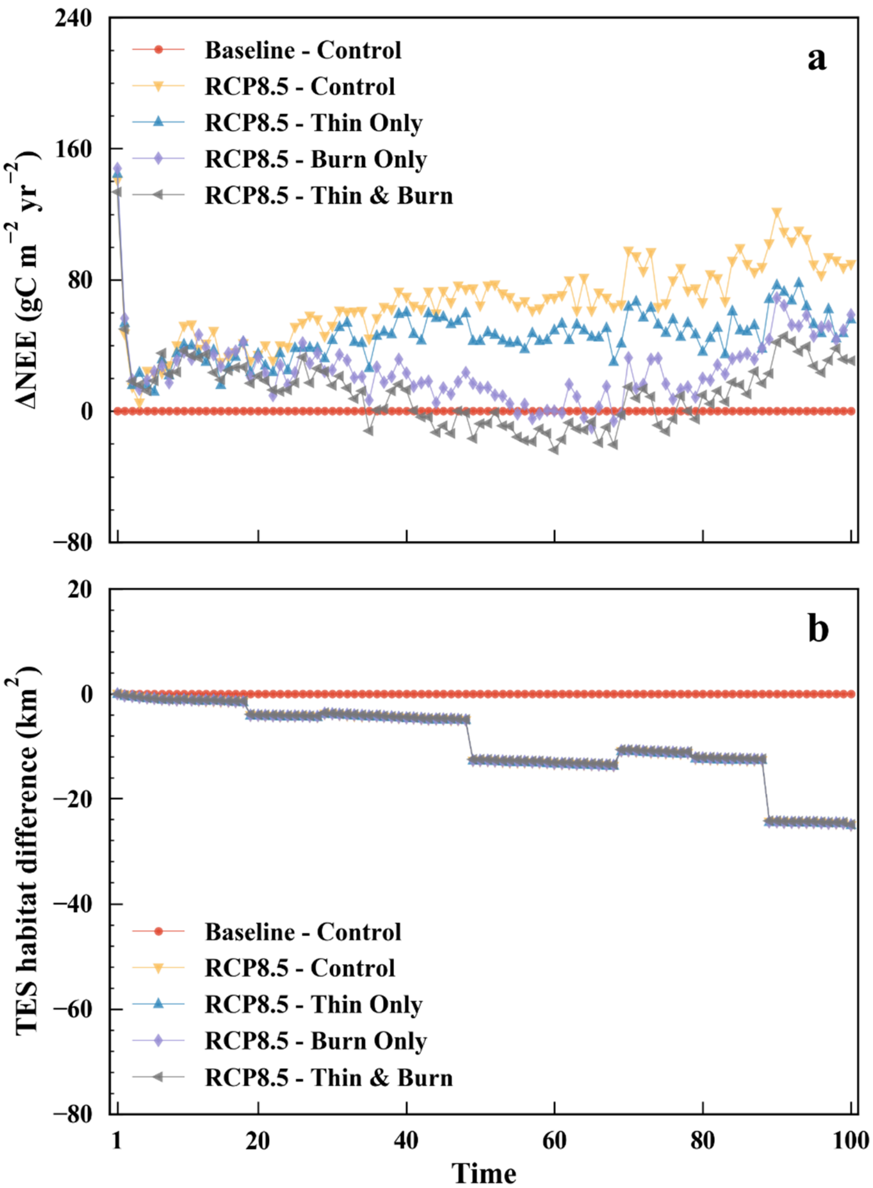

Figure 8. Climate change impacts on NEE and TES habitat at JBLM. In panel (a), the response of NEE compared to the baseline climate, control treatment (no-stand entry) is shown. In panel (b), the response of TES habitat to the same treatments and climate are shown. Time is in years since start of the simulations.

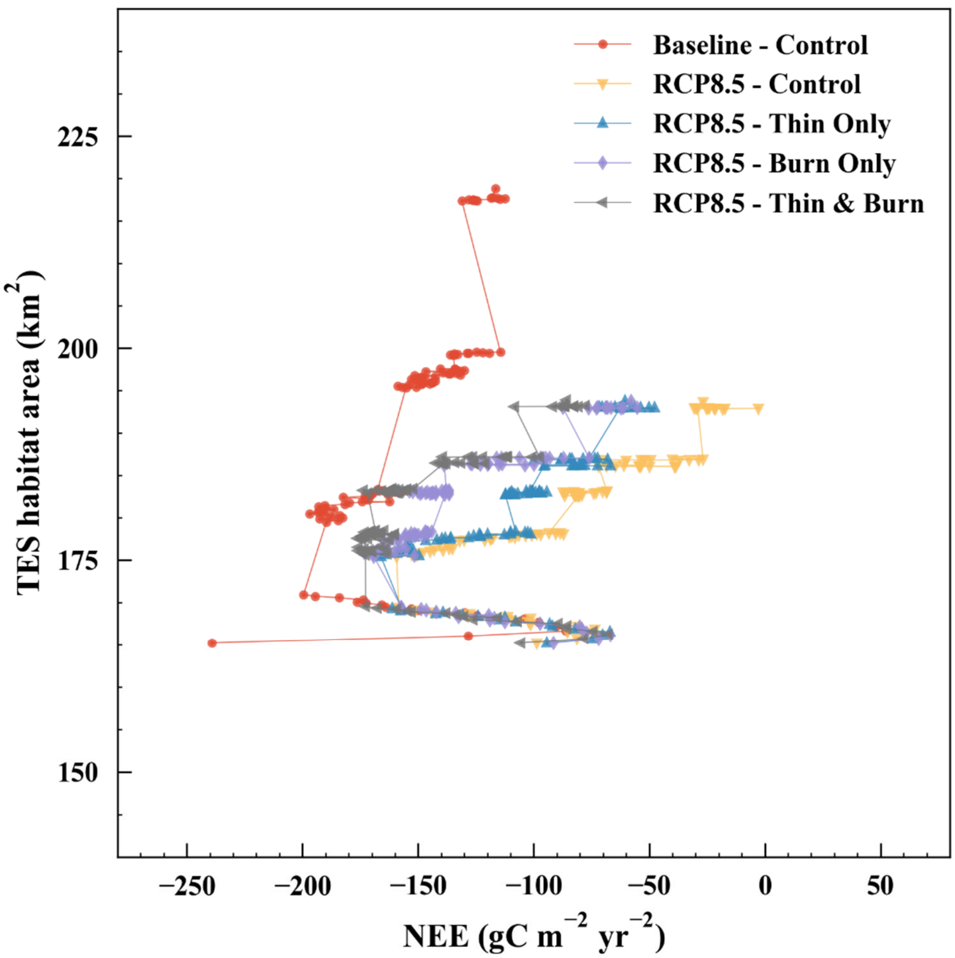

Figure 9. Relationships between NEE and TES habitat area under different land-management scenarios and two climate scenarios at JBLM.

Tradeoffs between carbon uptake and TES habitat in relation to stand thinning and burning treatments existed at all three of our focal research sites. NEE was generally unchanged (at Fort Benning) or increased (at Camp Navajo and JBLM) by thinning and burning treatments (Figure 5) under historical climate conditions. TES habitat varied in response to thinning, from an initial drop followed by an increase over decades after thinning and burning (for RCW at Fort Benning), to a large increase in habitat after two decades (for MSO at Camp Navajo), to virtually no change (for NSO and WGS at JBLM; Figure 6). However, the drivers of these changes varied between sites. This resulted in distinct tradeoffs between NEE and TES habitat under the various management scenarios (Figure 7). However, climate warming changed the outcomes for JBLM. Under the RCP 8.5 warming scenario, JBLM had a significant and sustained loss in both NEE and TES habitat, resulting in a large shift in both relative to historical climate (Figures Figure 8 and Figure 9). Thinning and burning treatments had only minor influence under the warming scenario. Below we discuss the site-specific patterns, the role of stand-entry treatments, and the impact of warming on these outcomes.

The thinning and burning treatments at Fort Benning were employed to achieve mature longleaf pine forests for TES habitat for the RCW. The treatments were effective in this regard, all promoting more mature pine forests over the decades following initiation of the treatments (Figure 6). Because of the relatively minor influence of the treatments on NEE, this resulted in a strong shift on the tradeoff curve toward thinning and burning being a significant benefit to RCW habitat without significant influence on NEE (Figure 7a). Some studies have found restoration treatments in longleaf pine can result in a loss of carbon (Whelan et al. 2013), which was observed here in the thinning-only and thinning and burning treatments. These thinning treatments simultaneously provide wood fiber and increase biodiversity while reducing the risk of catastrophic fires (Krofcheck et al. 2019), so the benefits extend beyond that of simply improved TES habitat.

Thinning and burning treatments are a critical component of avoiding high-severity wildfire in ponderosa pine forests (Allen et al. 2002; Bowman et al. 2013; Hurteau et al. 2016). The danger of wildfire in the ponderosa pine forests of the Southwestern USA is particularly high due to historic land-management practices that have left the stands heavily stocked (Allen et al. 2002). Therefore, maintenance of NEE, TES habitat, and training lands depends on avoidance of such wildfire, necessitating the use of prescribed burning and thinning. The treatments result in more significant NEE for decades (Figure 5), and improved MSO habitat (Figure 6), both of which are consistent with empirical research on similar treatments in ponderosa pine forests (Dore et al. 2010; 2012; Hurteau et al. 2016). The MSO preferably uses older stands (Kolb et al. 2007). The thinning and burning treatments are optimal for species habitat development because they advance the speed at which stands achieve old-growth characteristics, while minimizing forest loss to wildfire (Allen et al. 2002) and drought (Kerhoulas et al. 2013). The influence of thinning and burning treatments in modifying fire severity across the landscape decreased the mean fire severity of locations identified as potential MSO habitat at Camp Navajo (Hurteau et al. 2016).

In contrast to Camp Navajo, the Douglas-fir forests and Garry oak woodlands at JBLM rarely experience wildfire, and so stand entries are more predominately focused on generation of wood fiber while maintaining or expanding TES habitat and training lands. Treatments had large impacts on NEE because thinning focused on 70-180 year-old Douglas-fir cohorts, reducing competition (Laflower et al. 2016). However, treatments had minimal impact on TES habitat at JBLM (Figure 7). This is because the NSO prefers older stands that are not typically entered by the treatments, and because the WGS only lives in the oak woodlands, which occupy a very small fraction the JBLM land area (Laflower et al. 2016).

Climate warming altered the results of thinning and burning at JBLM such that their benefits to NEE and TES habitat are more muted (Figure 8). Increasing temperature resulted in a significant and sustained decrease in NEE (more positive values) with only small improvements due to thinning and burning (Figure 8a). Most studies of western conifers suggest this result is likely; western conifer growth and survival are reduced under conditions of warming and drying (Williams et al. 2013; McDowell et al. 2016; Restaino et al. 2016). TES habitat also declined under warming, and the treatments had little impact on the degree of decline (Figure 8b). These outcomes result from the loss of Douglas-fir survival and expansion of woodlands and shrublands under warming (Laflower et al. 2016). While the expansion of the oak woodlands would benefit one endangered species, the WGS, this increase was small relative to the large loss of TES habitat for the NSO under warming. Thus, warming resulted in a significant shift in the location of the data on the NEE vs. TES habitat curve (Figure 9) such that the benefits accrued from the forests were reduced for both.

Ultimately, thinning and burning treatments were consistently beneficial, or at least not harmful, to NEE and TES habitat at the three chosen locations (Figure 7), and even under climate warming (Figure 9). Tradeoffs in NEE and TES habitat were generally favorable under manipulations but are greatly impacted under climate warming (Figure 8). Warming is likely to greatly increase the likelihood of more severe droughts (Williams et al. 2013), greater insect outbreaks (Raffa et al. 2008), and greater frequency and intensity of wildfires (Westerling et al. 2011). Therefore, the motivation to use pre-emptive thinning and burning treatments to reduce the likelihood of these impacts is all the more important given the future warming scenarios.

4.0 Valuing DoD-Specific Ecosystem Services

Valuing DoD-specific ESs is performed by establishing a relationship between ecosystem metrics (which, in our methodology, are derived from natural process model simulations) and economic metrics. Economic valuation assigns quantitative values to FEGS based on ecosystem metrics. The assignment of economic metrics (monetary or unit value) allows for quantification and comparison between FEGS given various land-use scenarios, climate change, and management alternatives. For example, Montgomery et al. (1994) estimates the value of preserving NSO habitat by quantifying the cost of preserving woodland as opposed to using that land for forested products. The opportunity cost of preservation can be applied to the ecosystem metrics (e.g., forested area) derived from our simulations and quantified to establish the benefits of NSO habitat. Established economic techniques are applicable to a wide range of ecosystem metrics making the valuation of DoD-specific benefits a feasible task.

4.1 Valuation Techniques

The economic metrics used to measure FEGS are designed to estimate either market or nonmarket (or a combination of both) values. Economic metrics for goods or services traded in the marketplace (e.g., timber or housing) are quantified using market value metrics. Economic metrics for goods and services not traditionally represented in a market (e.g., TES habitat and spiritual and ceremonial/tribal benefits) are valued using nonmarket valuation techniques. Nonmarket valuation techniques rely on WTP and willingness to accept (WTA) proxies to quantify value. WTP and WTA are defined as the minimal amount of money a benefactor is willing to pay, or to accept, respectively, to allow changes to a bundle of goods. Applied to FEGS, WTP and WTA define what consumers are willing to forego or accept given changes in levels of the FEGS.

Here we describe several valuation techniques that can be employed for FEGS obtained from DoD lands.

4.1.1 Production Function Approaches

The value of inputs to the production of market goods can be estimated via various production function approaches. All production function approaches require producer behavior postulation, response data, and cost and production data. This approach is commonly used when value-added products, such as timber, are derived from ecosystems. The value of changing an environmental good or service (e.g., timber) is assessed through modeling the impacts of changes in inputs (e.g., area of timber-producing land) and resulting production yields. For example, Ma et al. (2016) used the cost per ton of harvested area to derive the impact of changes in forested land to the value of timber products. Similarly, González-Cabán et al. (2003) used a production function approach to estimate the change in value associated with deer hunting in response to prescribed fires. Production function approaches enable measurements of marginal changes in value associated with marketable goods such as timber, big game, fish, and other forest-derived products.

4.1.2 Defensive Expenditure and Replacement Cost Approaches

Both of these methods derive the economic value of an ES by estimating the cost of a substitutable, man-made service. The defensive expenditure approach estimates the change in demand for an ES in response to a change in the environment, serving as a proxy for the value of that service. For example, Abrahams et al. (2000) used the defensive expenditure approach to illustrate the value of water purification systems—such systems are a substitute for water quality. Thus, the cost spent to install and maintain water purification systems is an appropriate proxy for the value of water quality.

Similarly, the replacement cost approach is commonly used to value changes in habitat and the resulting impacts on flora and fauna. The cost of restoring and maintaining TES habitat (e.g., the cost to manage land to enable gopher tortoise habitat) is used as a proxy for the value of that habitat. Coursey (1994) used revealed demand (partially estimated via replacement cost) to calculate expenditures by captive propagation programs to save a single animal; this approach was used to calculate net acreage costs (acreage required to support an animal). The revealed demand approach has also been used by state agencies, such as the Washington State Department of Ecology, to value water management in the form of wetland protection and flood control (Leschine et al. 1997). Similar methods can be used to assess DoD expenditures on environmental and training-land maintenance.

4.1.3 Hedonic Approach

The hedonic approach suggests that the price of a heterogenous good (e.g., land) is a function of the various characteristics composing that good. This is a revealed preference method. In our case, the individual attributes (e.g., size of parcel, soil quality, habitat, proximity to urban areas, etc.) that contribute to the price of land (which can be estimated via regional assessor data or other historic sales data) are valued based on their individual contributions. Thus, given regional land values, the contribution of environmental amenities (such as forested land or proximity to open areas) can be estimated.

The hedonic approach has been used to assess the non-timber value of forests (Scarpa 2000) and the effects of wildfires and floodplains on property values (Hansen et al. 2014, Schultz and Fridgen 2001) to enable insight into land-management and use decisions. Application of the hedonic approach requires data on land prices and land attributes (e.g., soil makeup, habitat type, land use). The hedonic approach can be used to value specific areas of land given changes to that land's attributes (e.g., forest composition, land use).

4.1.4 Travel Cost Method

Observations and market data pertaining to time spent traveling to areas (usually for recreation) are used to estimate the value of an environmental good or service. The travel cost method is a revealed preference method first proposed by Hotelling (1949) to the U.S. National Park Service to value recreational areas. Since then, this method has been used by various researchers to value recreation (e.g., Willis and Garrod 1991, Shrestha et al. 2007, Baerenklau et al 2010) and for environmental education (Hutcheson et al. 2018). This method is applicable to both the valuation of DoD land for public recreation and the value of installation land for training. Estimating the value of installation land for recreation utilizes data pertaining to the distance recreationalists travel to visit a site, frequency of visits, and fees paid to access the site. The travel cost method can also be used to estimate the value of specific land areas to the DoD military trainers. If troops from multiple installations are sent to train at a specific area due to unique or valuable attributes, then the costs to access that training land can be measured in a similar fashion to recreational value.

The travel cost method is particularly useful in assigning values to the creation, elimination, or improvement of a site. This method can be used to deduct the value of changes to ecosystems, such as a change in hydrological flows, changes in water quality or fish-angling values, to approximate value of ESs (Ward 1987, Koteen et al. 2002, Grilli et al. 2017). The travel cost method has been used by agencies to assess values of wildfire management (Englin et al. 2008, Baerenklau et al. 2009) and recreational planning (Marsinko et al. 2002).

4.1.5 Contingent Valuation Method

The contingent valuation method relies on a survey (stated preference) and statistical techniques to analyze responses to survey questions. Interviewees are asked to answer survey questions, stating their preference, which is a monetary WTP for proposed changes in environmental goods or services. Statistical techniques are used to limit bias and the impacts of untruthful response. Contingent valuation has yielded a plethora of useful results (Carson et al. 1996, Smith and Osborne 1996) but is often expensive and requires well-designed and well-executed surveys.

To assess value of land-management, surveys should be composed of questions which center on the participant's WTP for changes to land management. Land managers may be asked their WTP, in monetary terms, for an additional acre of training land. Similarly, the public is asked their WTP for changes to TES habitat, preservation of forested land or unique habitat, and similar ecosystem goods and services. For example, Loomis et al. (1996) used the contingent valuation method to estimate the public's WTP for protection of NSO critical habitat in Oregon. The public's WTP to protect critical habitat was found to range between $49.6 to $99 million annually (in Oregon), and the public's WTP to protect old-growth forest is found to be approximately $28 per acre. The contingent valuation method can be used to assess both the DoD's and the public's value of various land-management options.

4.1.6 Benefit Transfer Methods

Benefit transfer methods are performed via the "transfer" of postulated benefits from completed valuations (study site) to the effort at hand (policy site). These methods are widely utilized in the valuation of ESs because they enable reasonable estimates given tight budget and time constraints. While benefit transfer methods are valid, accuracy relies heavily on similarity between the compared sites (both spatial and socioeconomic charactersistics) (Plummer 2009, Bockstael et al. 2000). Furthermore, the resulting impacts of a change in the valued FEGS should be similar between the study and policy site. For example, if reducing old-growth forest reduces TES habitat in the study site (and the WTP for TES habitat is valued) then in the policy site, WTP should be postulated given similar reductions in TES habitat.

Benefit transfer methods are widely used to value the impacts of forest land management including the effects of timber production in alternative ecosystems (Binder et al. 2017, Deal 2001). The existence of forested land valuations allows for the postulation of DoD FEGS related to forest area, training lands, and TES habitat. Public FEGS related to recreation can be postulated given the existence of extensive recreational valuation efforts (see Rosenberger and Loomis 2001) and aesthetics values (Costanza et al. 2006). When site-specific data is not available, benefit transfer methods can provide reasonable value estimates given compliance to valuation guidelines (NRC 2005).

4.2 Valuing FEGS on DoD Lands

Table 3 in Section 2.4.2 listed the economic metrics corresponding to FEGS obtained from DoD lands. Table 4 lists some of the available approaches and methods that can be employed to value FEGS obtained from DoD lands. The rest of this section explains some of the ways the listed valuation approaches can be used to value the ecosystem metrics associated with the FEGS.

4.2.1 Training Lands

Training lands are FEGS that are associated with DoD foresters, DoD military trainers, and DoD military branches. DoD foresters value the training lands to support troops assigned to the installation. DoD military trainers value the provisioning of training lands across DoD installations to support military-wide training goals. DoD military branches value training lands to meet mission readiness goals. The value of training lands can be measured using the economic

Table 4. Valuation approached associated with FEGS.

FEGS	Ecosystem Metrics	Economic Metrics	Valuation Approaches
training lands	area (km^2), biome, frequency of availability (d/y)	1. Cost of land used for training 2. Value of diverse training conditions 3. Distance and cost to travel to training areas 4. Cost to maintain training areas 5. Value derived from training	Defensive expenditure and replacement cost approaches Travel cost method
harvested products	Harvested quantity (tons)	1. Revenue or cost per ton	Production function approaches
TES habitat	area (km^2), fragmentation	1. Cost of alternative land management 2. Cost of restoring and maintaining habitat 3. Productivity of TES in value contribution to ecosystem 4. Willingness to pay (per km^2) for species preservation	Defensive expenditure and replacement cost approaches Contingent valuation approaches
land for buildings	area (km^2), fragmentation	1. Cost of using land for buildings and residential area 2. Sale price of residential/commercial land in area	Hedonic approach

FEGS	Ecosystem Metrics	Economic Metrics	Valuation Approaches
routes	length (km), frequency of availability (d/y)	1. Cost for unusable routes, cost of alternative routes 2. Damages/costs due to transportation 3. Cost of changing or not using routes, cost of maintenance 4. Cost of TES habitat destruction 5. Changes in transportation costs given changes in environment	Defensive expenditure and replacement cost approaches Contingent valuation approaches Travel cost method
recreation	frequency of access to areas including training areas (d/y)	1. Distance traveled, and dollars spent 2. Willingness to pay (WTP) for access to areas 3. Value attributed to recreation from revenue generating services on land 4. Characteristics of land and contribution to recreational activities	Travel cost method Contingent valuation approaches
the environment	area (km^2), and long-term availability (km^2)	1. WTP for preservation of desired environment 2. Contribution of land to TES habitat, land use, etc.	Contingent valuation approaches
training	area (km^2), biome, frequency of availability (d/y)	1. Value attributed to training (e.g., meeting training goals) 2. Value of obtained skillset in military and post-military professions	Contingent valuation approaches Production function approaches
military readiness	sustained military training capacity (area (km^2), biome, frequency of availability (d/y; y/10y))	1. Value of sustained national production 2. Cost to restore lost national production from compromised national assets	Production function approaches Defensive expenditure and replacement cost approaches Contingent valuation approaches

metrics listed in Table 4. Defensive expenditure and replacement cost approaches and travel cost approach can be used to estimate value of training lands by considering costs of acquiring, using, and maintaining similarly suitable alternative lands if a given training area were to become unavailable or unsuitable.

4.2.2 Harvested Products

Harvested products are associated with timber extractors, resource-dependent businesses, and DoD foresters. While DoD foresters may obtain revenue from timber sales or other resources, timber extractors and resource-dependent businesses may obtain profit by selling the harvested products on the market. These values can be estimated by employing production function approaches (e.g., Ma et al. 2016).

4.2.3 TES Habitat

TES habitat are associated with DoD foresters, DoD wildlife biologists, as well as (non-hunting) recreational, inspirational, learning, and non-use beneficiaries. DoD foresters are primarily concerned with protecting existing TES habitat while providing required training areas with suitable species composition. DoD wildlife biologists may be actively engaged in understanding, maintaining, and improving TES habitat. Defensive expenditure and replacement cost approaches and contingent valuation approaches can be used to estimate value of the TES habitat.

There are no markets associated with recreational, inspirational, learning, and non-use benefits. Benefits derived for these uses can be estimated using nonmarket, contingent valuation approaches. Reaves et al. (1999) used various experimental surveys to estimate values to the public from restoring longleaf pine for enabling RCW habitat in southeastern United States.

Values associated with inspirational benefits may be difficult to estimate because sites or monuments that are spiritually or ceremonially valued cannot be replaced. Not only do markets not exist for these benefits, simulated markets are also difficult to formulate. At DoD installations, these sites are identified on an ongoing basis and protected. Values associated with learning benefits may be estimated using defensive expenditure and replacement cost approaches (e.g., alternative site with similar characteristics can plausibly be used instead of the DoD installation site).

4.2.4 Land for Buildings

Benefits from land used for buildings on the DoD installations accrue to DoD property owners. We do not expect DoD buildings to be on the open market. These buildings may be used to provide military and civilian housing, installation administration, equipment storage, and other installation-related use. Therefore, hedonic valuation based on desired characteristics of the buildings (e.g., floor area needed, height requirements, proximity to TES habitat) may be more suitable for valuing this benefit.

4.2.5 Routes

Benefits of routes accrue to DoD transporters of goods and people. Within the installation, routes may facilitate efficient troop and equipment movements for training. Defensive expenditure and replacement cost and travel cost approaches can be used to value routes by estimating the costs of proving alternatives to unusable or damaged routes. Value of a route may also be assessed using contingent valuation approaches based on the route's potential impacts to TES habitat.

4.2.6 Recreation

Benefits from recreation on DoD lands can be related to both use (e.g., big game hunting, fishing) and non-use (e.g., experiencing and viewing the environment). We do not expect use benefits to be derived on the open market. Therefore, travel cost method and contingent valuation approaches can be used to value recreation benefits on a DoD installation.

4.2.7 The Environment

Non-use benefits to the public may also accrue from the desire to preserve certain environments (e.g., forested areas, tree-lined vistas) in addition to TES habitat. These benefits can be valued using contingent valuation approaches.

4.2.8 Training

Benefits of training accrue to the DoD soldiers. Training develops skillsets that are valuable in the soldier's military as well as post-military professional career. For example, combat, equipment operation, management, and leadership skills may assist the soldier in pursuing a sustained military career. These skillsets may also be useful in a subsequent civilian profession. These benefits can be valued using contingent valuation approaches (e.g., what is an employer willing to pay for a certain skillset) or production function approaches (e.g., what is the current salary in the employment market for a well-trained leader).

4.2.9 Military Readiness

Citizens of our nation benefit from military readiness that provides assurance that the nation and its assets can be protected and defended from external threats. These threats can manifest at several spatial scales—from local (e.g., an external malicious actor targeting a community) to regional (e.g., compromised power grid due to an external malicious act) and national (e.g., significant loss of economic activity because of external malicious acts). The impacts can also range from relatively short timeframes to medium and longer terms depending on the severity and extent of the impacts. These benefits may be difficult to value, particularly where loss-of-life is involved. However, some economic indicators may be useful—e.g., production function approaches can be used to value continued national production resulting from successfully defending against an external national threat. Similarly, defensive expenditure and replacement cost approaches can be used to estimate the value of existing national assets as the costs incurred to replace them in the event of their loss. National defense may also be valued by estimating the citizens' WTP in terms of taxes that are used toward military readiness.

5.0 Proof-of-Principle Application

This chapter describes how some of the site-specific benefits to both the DoD and the public could be systematically valued using the simulation-valuation methodology described in this report. The proof-of-principle application used the JBLM site. The objectives for this exercise were:

1. Using ecosystem metrics, estimate selected FEGS associated with the DoD (training lands and TES habitat) and the public (harvest, recreation, and the environment) provisioned under various land-management alternatives.
2. Using economic metrics, estimate values of FEGS for the DoD and the public.
3. Compare values derived by the DoD and the public under various land-management scenarios.

Using previously performed terrestrial ecosystem simulations at JBLM (see Chapter 3.0), we defined the DoD FEGS as follows:

1. Mounted training area: the training area for mounted training (e.g., Stryker brigades) consists of open areas (grasslands and scrublands/shrublands).
2. Dismounted training area: the training area for dismounted training (e.g., for tactical small units) consists of forested areas but excludes any protected areas (e.g., TES habitat, ceremonial grounds).
3. TES habitat area: TES habitat consists of habitats of bald eagle, WGS, and NSO.

We defined the public FEGS as follows:

1. Harvest area: harvested area can be within the forest, grassland, scrubland/shrubland, savanna classes.
2. Recreation area: recreation area is defined as all training lands excluding close-in training area F; artillery, south, and central impact areas; and lakes and wetlands.
3. Area of the environment for public, non-use benefits is defined as the combination of TES habitat and ceremonial and spiritual/tribal areas. Ceremonial and spiritual/tribal area was assumed to be fixed in time at the currently identified extent of cultural sites, 3.9 km^2 (*Joint Base Lewis-McChord Draft Land Management Plan* 2017).

5.1 Quantifying FEGS in Ecosystem Metrics

With the DoD and public FEGS described above, an additional step needs to be performed. In this step, the natural system model (LANDIS-II) predictions are connected to each FEGS. In this application, we defined the various FEGS based on LANDIS-II predictions of various modeled species' evolution. To perform this step, geographic data provided by JBLM and descriptions in *Joint Base Lewis-McChord Draft Land Management Plan* (JBLM 2017) were also used. Table 5 and Table 6 list these connections.

Table 5. Ecosystem description of identified FEGS.

FEGS (Provisioned Areas)		Ecological Description
The DoD	Training – Mounted	Grasslands + Scrublands/Shrublands
	Training – Dismounted	(Forests) – (Habitat + Ceremonial)
	Habitat	(Bald Eagle + WGS + NSO)
The Public	Harvest	Harvested forest area
	Recreation	(Training) – (DoD-restricted areas[§] + Lakes/Wetlands)
	The Environment	Habitat + Ceremonial

[§] DoD restricted area consists of Close-in Training Area F and Artillery, South, and Central Impact Areas (*Joint Base Lewis-McChord Draft Land Management Plan*, JBLM 2017).

Table 6. LANDIS-II modeled parameters used to extract FEGS from model simulations.

Provisioned Area Description		LANDIS-II Modeled Parameters
Habitat	Bald Eagle	Forest grid cell within an 800-m buffer along Muck Creek and Nisqually River
	NSO	Forest grid cells with ≥100 years-old Douglas Fir trees
	WGS	Grid cells with Garry Oak within an 800-m buffer adjacent to grassland, shrubland/scrubland, or savanna
Training - Mounted		Grassland, shrubland/scrubland, and savanna grid cells
Training – Dismounted		Forest grid cells excluding habitat and ceremonial areas
Harvest		Grid cells within forest, grassland, shrubland/scrubland, or savanna areas, if removed biomass was larger than zero for the control and thin only treatments or if the removed biomass was larger than the removed biomass by burning only for the thin-and-burn treatment

Note: Areas provisioned for recreation and the environment are derived from those listed in this table and the ceremonial area (which is assumed fixed at 3.9 km^2).

Figure 10 shows the time series of LANDIS-II modeled habitat area under RCP 8.5 future climate scenario for the duration of the simulation. The habitat area at JBLM started near 165 km^2 and gradually increased to nearly 195 km^2 by 2100, an increase of 18%. The land management scenarios did not make significant difference to the provisioned habitat area (also see Figure 6 in Section 3.2). The gradual increase in habitat area is driven by the expansion of forests in grassland/savanna areas, primarily because of expansion of Douglas Fir that resulted in increases in NSO habitat. This behavior of Douglas Fir in Pacific Northwest has been previously documented (Zolbrod and Peterson 1999, Foster and Schaff 2003, Halofsky et al. 2018).

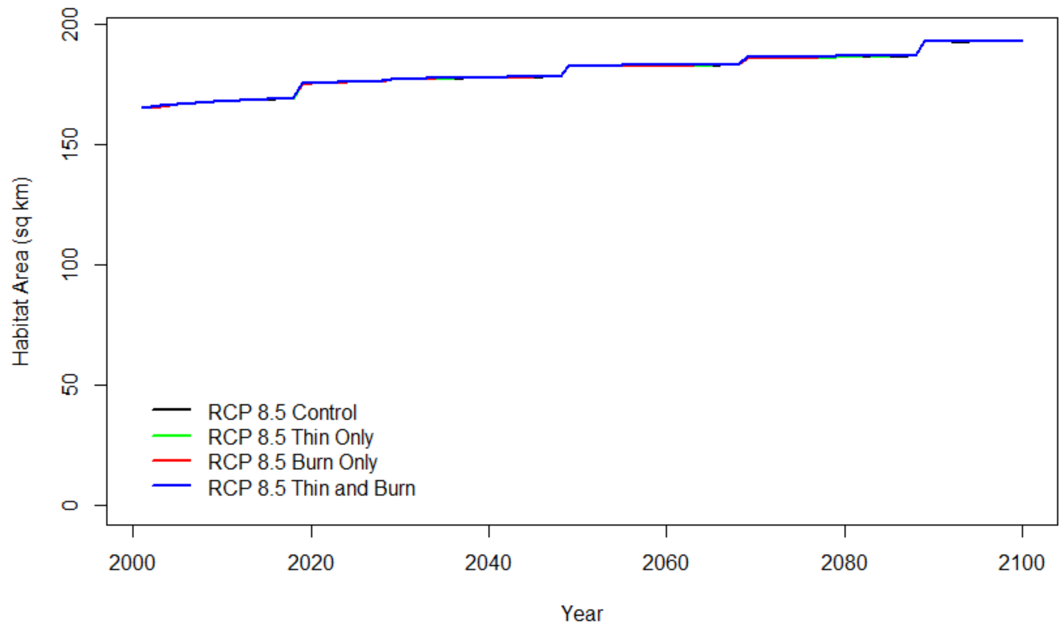

Figure 10. LANDIS-II modeled habitat area for the control and the three land management scenarios under the RCP 8.5 climate scenario.

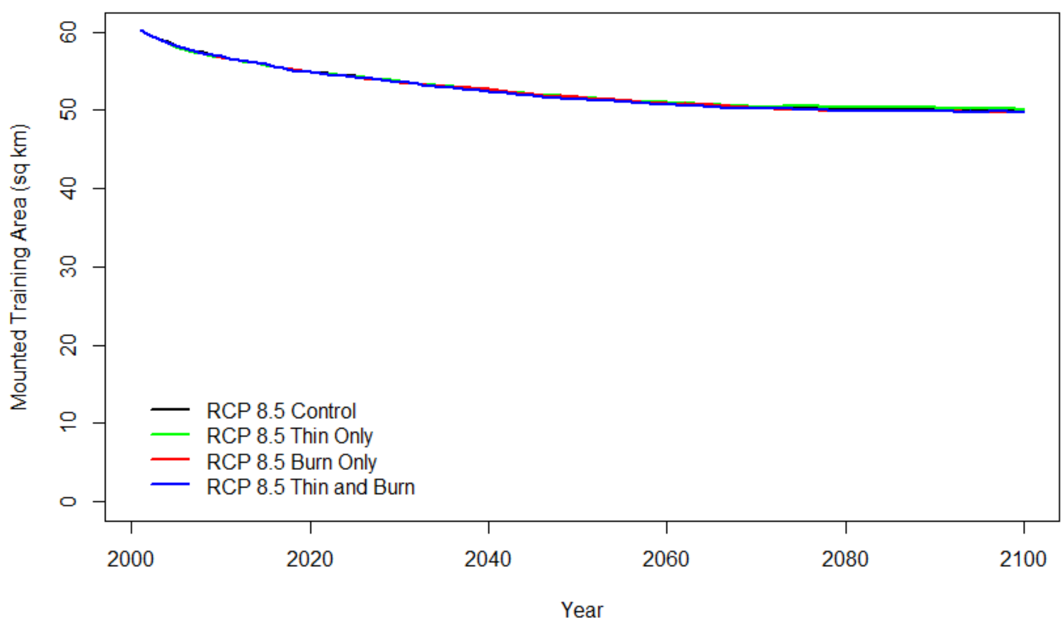

Figure 11. Mounted training area extracted from LANDIS-II simulations for the three land management scenarios under the RCP 8.5 climate scenario.

Figure 11 shows the time series of mounted training area extracted from the LANDIS-II simulations. Under all land management scenarios, a steady decline was observed, with the differences in land management scenarios becoming noticeable after about 2070. The loss of mounted training areas over the 100-year simulations was about 17%. Because the Douglas Fir was simulated to be encroaching in grasslands, shrublands/scrublands, and savanna, most of the loss of mounted training area was likely because of forest expansion.

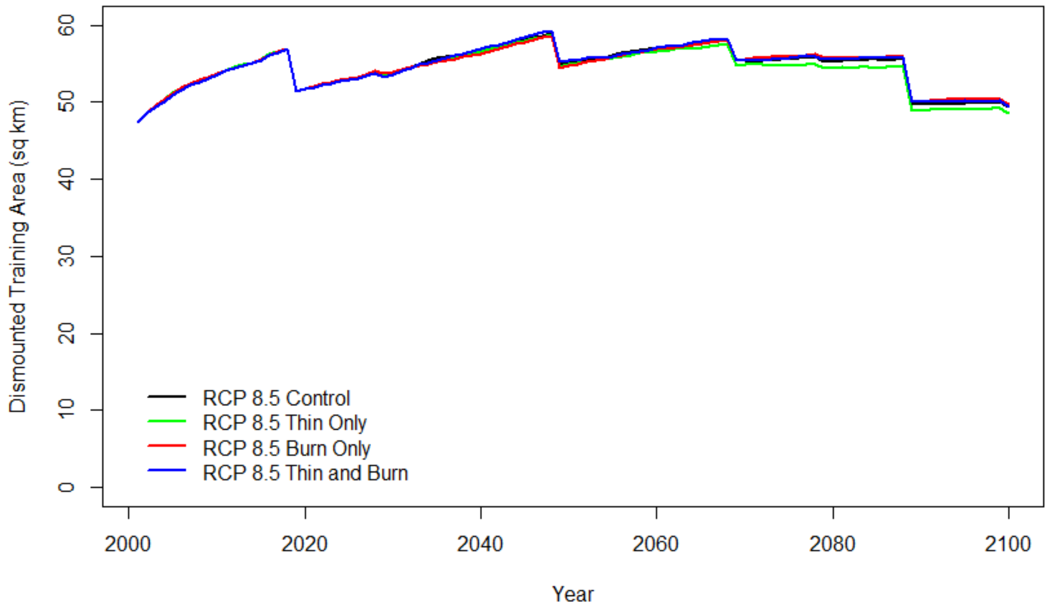

Figure 12. Dismounted training area extracted from LANDIS-II simulations for the three land management scenarios under the RCP 8.5 climate scenario.

Figure 12 shows the time series of dismounted training area extracted from the LANDIS-II simulations. As was the case for mounted training areas, land management seemed to make only minor differences which started becoming noticeable in about 2070. The most noticeable feature of the dismounted training area evolution is the periodic and abrupt, relatively large declines. Notice the existing LANDIS-II simulations do not explicitly model the effects of training. The timing of the abrupt declines in dismounted training areas seem to correspond to the timing of the increase in habitat (Figure 10). The amount of change in the dismounted training area and habitat also seems comparable. While we need to more closely examine the model simulations to explain these features, the two parameters are closely related by definition, i.e., forested habitat area is assumed not used for dismounted training. Therefore, future research may need to refine the definitions of both the habitat areas (in consultation with DoD wildlife biologists) and training areas (DoD foresters and DoD military trainers).

Early in the LANDIS-II simulations (the first two decades), the rate of increase of dismounted training area was quite rapid (about 10 km^2 over 20 years, a 22% increase). However, the rate of rise following the abrupt declines seemed to gradually reduce, with almost no gain seen following the abrupt decline in the 2070s. At this point in our research, we do not know if the declining recovery rates of dismounted training area are related to ecosystem drivers or climate drivers. This issue should be investigated further in future research.

As described above, the proof-of-principle application of our methodology was limited to the following FEGS: training area, habitat area, harvest area, recreation area, and non-use environment area. At this point in our research, additional data and analyses are needed to estimate the remaining ecosystem metrics related to these FEGS (e.g., biome and frequency of availability of training areas, harvested quantity, fragmentation in habitat areas, frequency of access to recreations areas). Nevertheless, we have demonstrated how DoD and public FEGS can be estimated from natural process simulation models. The additional data and analyses required to completely characterize FEGS in ecosystem metrics are described in Chapter 6.0.

5.2 Quantifying FEGS in Economic Metrics

Before values of ESs obtained from JBLM lands can be estimated, the FEGS need to be quantified using economic metrics. We have identified the economic metrics related to FEGS (see Table 3 in Section 2.4.2). At this point in our research, we have limited valuation data related to FEGS used in the proof-of-principle application. These data are from a meta-analysis of valuation studies performed by Richardson and Loomis (2009) and are summarized in Table 7**Error! Reference source not found.**.

Table 7. Currently-available valuation data for FEGS.

FEGS		DoD Installation	Average Annual WTP (2006$)
TES[§]	Bald Eagle	Fort Benning, Camp Navajo, JBLM	$39 per household
	Owl	Camp Navajo, JBLM	$65 per household
	Striped Shiner	Fort Benning	$8 per household
	Washington State anadromous fish populations	JBLM	$241 per household
	Woodpecker	Fort Benning	$16 per household
Old-growth Forest		Fort Benning, Camp Navajo, JBLM	$28 per acre[†]
Critical Habitat		Fort Benning, Camp Navajo, JBLM	$49.6 million to $99 million statewide[†]

[§] The TES values in this table are synthesized from a meta-analysis performed by Richardson and Loomis (2009). Note that some species are aquatic.

[†] The reported range of values is from Loomis et al. (1996) and represents the WTP of the residents of Oregon.

The benefit transfer method[4] is used to apply the values collected by Richardson and Loomis (2009). While this method is subject to potential inaccuracies, attention to locational differences, site characteristics, and proper empirical technique can enhance the viability of benefit transfer applications (Plummer, 2009). More research is required to determine if any location and species adjustments (to the values included in **Error! Reference source not found.**) are required to enable application to JBLM. A preliminary calculation can be performed as shown in Table 8.

The values listed for TES (**Error! Reference source not found.**, Column 3 and Table 8, Column 2) were taken from Richardson and Loomis (2009). The TES values are per household—i.e., a household's WTP for preservation of a species. According to the 2010 Census, the states of Oregon and Washington had 1,518,938 and 2,620,076 households, respectively. Because the value for Oregon's critical habitat was reported on a statewide basis, it was scaled to Washington

[4] The benefit transfer method is used to assign existing economic values to a different location or ecosystem. Accurate benefit transfers require close attention to locational differences and similarity of site characteristics.

state assuming that the citizens of the two states value critical habitat similarly on a per-household basis (Table 8). The difference in valuation of critical habitat from 2006 to 2010 was implicitly assumed to be negligible. The TES values were assumed to transfer from Oregon to Washington with no change and the total annual value of TES were estimated by scaling the per-household value with the number of 2010 households (Table 8).

Table 8. Preliminary valuation of certain FEGS at JBLM.

FEGS	Average Annual WTP (2006$)	JBLM Annual Value (2006$)†
TES – Bald Eagle	$39 per household	Less than $102 million
TES - Owl	$65 per household	Less than $170 million
Old-growth Forest	$28 per acre	$1.1 million to $1.3 million
Critical Habitat§	$86 million to $171 million statewide	Less than $86 million to $171 million

§ Because critical habitat value in **Error! Reference source not found.** applies to the whole state of Oregon, it was scaled for the state of Washington using the two states' 2006 populations. The underlying assumption is that the residents of the two states value critical habitat similarly on a per capita basis.

† The annual values for TES and critical habitat at JBLM would be less than the corresponding statewide values as stated in Column 3. Further research is needed to determine how JBLM's share of statewide value should be determined.

Because the values reported for TES and critical habitat are on a statewide basis, they need to be scaled to JBLM. At this point in our research, we do not have sufficient data or comparison of various scaling approaches to estimate value of these FEGS at JBLM. Therefore, Table 8, Column 3 generally notes that the JBLM annual values would be less than the corresponding statewide values. The value of old-growth forest (which provides NSO habitat), in contrast to TES and critical habitat values, was reported on a per unit area basis. Therefore, assuming that old-growth forest at JBLM is valued similarly to old-growth forest in Oregon, JBLM-specific value of old-growth forest (age ≥100 years) was calculated between $1.1 million in 2000 to $1.3 million in 2100 (2006 dollars). The increase in value of old-growth forest is a result of expansion of forests into grasslands/savanna at JBLM under the RCP 8.5 climate scenario.

Other relevant valuation data are not available. For example, economic metrics associated with training lands are (1) cost of training lands, (2) value of diverse training conditions, (3) distance and cost to travel to training areas, (4) cost to maintain training lands, and (5) value derived from training. While land value in adjacent areas could be used to estimate cost of training lands, we need to elicit information from JBLM staff regarding the other economic metrics. For example, value of diverse training conditions on maintained training lands could support a certain number of troops. The cost of training a certain number of troops at JBLM would need to be elicited from JBLM staff.

Harvested quantity is the economic metric associated with harvested products. To estimate harvested quantity (e.g., on an annual basis), harvest duration and frequency (e.g., number of days per year, time between harvests), harvest rules (e.g., harvested species age and percentage), and restrictions (e.g., TES habitat or other DoD restrictions) are also needed. Similar data gaps also exist for recreation and non-use environmental areas. These gaps are further described in Chapter 6.0.

Filling the data gaps and performing additional analyses is therefore necessary to more completely value FEGS obtained from DoD installation lands. We also note that the proof-of-principle application addressed a small subset of FEGS and only those in the terrestrial environment. These issues are also discussed in Chapter 6.0.

5.3 Preliminary Results

The differences among land management alternatives at JBLM seem to be minimal in terms of provisioning TES habitat and training areas. While climate warming had a significant effect on TES habitat provisioning (see Chapter 3.0), forested area showed increase, primarily because of expansion of Douglas Fir into grasslands and savanna, even under the RCP 8.5 future climate scenario. Because of this forest expansion, mounted training area that primarily uses open spaces has the potential to decrease by 17% over 100 years. Dismounted training area showed an interesting increasing tendency in the first 50 years by the rate of increase seemed to slow and eventually decline in the next 50 years. Habitat area showed a steady increase of about 18% over 100 years.

Using limited valuation data, a limited set of FEGS were valued (Table 8). However, this limited valuation exercise demonstrated that the simulation-valuation methodology is viable. Using site-specific valuation data in the methodology would increase the accuracy and reduce the uncertainties in valuation, allowing for development of foundational datasets for robust tradeoff analyses and decision-making.

While these results are preliminary and the reader must be cautioned that the LANDIS-II simulations did not explicitly account for effects of training on succession of various species, JBLM has an opportunity to maintain timber harvests both as a revenue stream and as an option to maintain availability of mounted training area without significantly impacting TES habitat.

6.0 Implications for Future Research and Benefits

The results from this research suggest that the simulation-valuation methodology is a viable approach for consistently estimating the benefits from DoD installation operations. Leveraging FEGS-CS for beneficiary and benefits identification revealed that military-unique ESs need to be explicitly accounted for in greater detail. This report presents an attempt at identifying military-unique ESs.

The inclusion of natural process models to characterize and quantify ESs allows not only explicit accounting of ESs from DoD installation operations, but also explicit accounting of spatio-temporal ecological and terrestrial processes. Because the models are mechanistic, they also enable scenario analyses (e.g., climate change scenarios, land management options, future installation changes) allowing a range of alternatives to be examined.

The valuation of ESs are possible with well-established economic techniques. These include both market and non-market valuation approaches. Using these techniques, a range of benefits can be consistently valued providing a common base to assess tradeoffs among various alternatives and scenarios.

6.1 Identified Gaps and Recommendations

Gaps in both methods and data were identified during this project. These gaps and potential solutions to filling these gaps are described below.

6.1.1 DoD-Specific FEGS-CS Gaps

The DoD-specific FEGS-CS matrix described in Chapter 2.0 is limited to the terrestrial environment only. DoD installations also provide benefits from the aquatic and the atmospheric environments. Moreover, even at the scale of DoD installation areas, significant interactions among the terrestrial, aquatic, and atmospheric environments exist. These interactions have the potential to complicate the characterization of ESs. However, some of the interactions may also be critical to accurately quantifying FEGS in ecosystem metrics. To enable more comprehensive accounting of ESs and the benefits that accrue from them, the simulation-valuation methodology should be expanded to include aquatic and atmospheric ESs also.

The DoD-specific FEGS-CS matrix introduced some new beneficiary classes and subclasses. These new classes may require refinements to more precisely define the benefits they obtain from the environment. Future research should also ensure that any potential double-counting of benefits to the newly-defined beneficiaries are properly recognized and minimized in valuation.

6.1.2 Natural Process Model Gaps

The natural process model used in this project did not explicitly account for the effects of military training on habitat areas and any associated feedbacks on ESs. Explicitly accounting for the effects of military training on various ecosystems (e.g., potential habitat fragmentation, potential soil and/or water contamination) can account for feedback effects on evolution of accrued value both to the DoD and to the public. In future work, more representative natural process models should be employed.

The predictions from natural process model used in the study were only available at annual timesteps. Therefore, no seasonal characterization of ESs could be attempted (e.g., frequency and duration of harvests, frequency and duration of recreational access, characterization of season-specific training areas). In future work, DoD and public activities that have a seasonal component should be included in the natural process models.

The inclusion of natural process models to characterize all three environmental classes—aquatic, terrestrial, and atmospheric—has the potential to complicate the ES simulations because of myriad of interactions these models may need to represent. It may be possible to develop and employ reduced-form models that adequately capture the interactions without making the computations intractable.

As in any natural process modeling, the models employed in the simulation-valuation methodology contain several sources of uncertainty. Some of these arise form natural variations (e.g., imprecisely known future climatic conditions) and some arise from our incomplete knowledge of the natural system and processes (e.g., inaccurately known species interactions under climate change). Future research should explicitly characterize known sources of uncertainty to provide a measure of confidence in the predictions of ESs' provisioning.

6.1.3 Valuation Gaps

The valuation of ESs on DoD lands depends on (1) accurate characterization and quantification of ecosystem and economic metrics related to FEGS and (2) identification of economic value by careful application of market and non-market valuation techniques. As described earlier, training can cause fragmentation of previously contiguous habitat and result in feedback effects on provisioned training area. Therefore, while some of the ecosystem metrics can be readily obtained from natural process models (e.g., TES habitat area), some require additional information from DoD installations (e.g., fragmentation caused by training, frequency of harvests, routes used for training, number of troops assigned).

There are some gaps in intermediate data that are required to estimate economic metrics from ecosystem metrics. For example, the area of training lands needs to be represented as quantifiable metrics such as training areas to support a specified number of dismounted troops, a specified number of field artillery officers, or a stryker brigade.

Quantification of ESs in economic metrics also has gaps (e.g., DoD costs to maintain training areas/routes, restoring habitat, using alternative routes). Some valuation-related data exist (e.g., market value of harvested goods, sale price of residential/commercial land, WTP for habitat/species preservation, salaries paid to well-trained leaders) and some need to be obtained from site-specific surveys (e.g., WTP to access DoD lands for recreation, citizens' WTP for military readiness).

Future research should focus on compiling existing valuation data and validating these data for site-specific use. Valuation data that do not exist will need to be elicited from well-designed and well-executed surveys.

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Appendix A

Federally and State-Listed Species at Selected DoD Installations

Our simulation-valuation framework includes three U.S. Department of Defense (DoD) installations: Fort Benning (Georgia), Camp Navajo (Arizona), and Joint Base Lewis-McChord (JBLM; Washington). A listing of federally and state-protected flora and fauna is presented in Table A.1. This list provides general guidance regarding threatened and endangered species (TES) on each site, providing insight into species that have the potential to affect training at the selected DoD installations. Note that a majority of Fort Benning resides in Georgia although a small part in located in Alabama (a list of federally protected species which reside in Alabama is not included). The state of Arizona does not have its own endangered species list or list of protected areas. JBLM houses approximately 90% of the rare South Puget Sound prairie ecosystem (total remaining acreage is about 9,300 acres). The South Puget Sound prairie ecosystem is critical to the support of several endangered species including; the Taylor's checkerspot butterfly (*Euphydryas editha taylori*), streaked horned lark *(Eremophila alpestris)*, and Mazama pocket gopher *(Thomomys mazama)*. The Western bluebird *(Sialia mexicana)* is a species of growing concern although not federally listed. JBLM engages in the Sentinal Landscapes Partnership[5] to ease land use restrictions caused by endangered species. Mixed forest areas and ponderosa pine provide habitat for the threatened (Washington State) Western gray squirrel (*Sciurus griseu*) (WAC 220-200-100).

Table A.1 was compiled from TES listings obtained from the three selected DoD installations.

Table A.1. Threatened and endangered species found near selected DoD installations.

Species	Status	Location	Habitat Requirements
American Alligator (*Alligator mississippiensis*)	T(S/A)	Fort Benning	Slow moving freshwater, swamps, marshes and lakes.
Bald Eagle (*Haliaeetus leucocephalus)*	P	Fort Benning, Camp Navajo, JBLM	Contiguous U.S., aquatic habitats and riparian forests.
Bocaccio Rockfish *(Sebastes paucispinis*)	E	JBLM	Outer Puget Sound, Washington coast.
Bull Trout (*Salvelinus confluentus*)	T	JBJM	Colder, clean water and complex habitats in Pacific Northwest.
Canary Rockfish (*Sebastes pinniger)*	T	JBJM	Outer Puget Sound, Washington coast.
Georgia Rockcress (*Arabis georgiana*)	E	Fort Benning	Hardwood slopes, river banks and rocky bluffs in Alabama and Georgia.
Gopher Tortoise *(Gopherus polyphemus)*	T	Fort Benning	Coastal plains (sandy soils) and Longleaf pines.
Humpback Whale (*Megaptera novaeangliae*)	E	JBJM	Pacific Coast, Oceanic.

[5] The Sentinel Landscapes Partnership is a working agreement between Departments of Agriculture, Defense and the Interior and various local stakeholders to promote compatible land uses such that training needs as well as stakeholder needs are met (Sentinel Landscapes 2019).

Species	Status	Location	Habitat Requirements
Marbled murrelet (*Brachyramphus marmoratus*)	T	JBJM	Inland nesting in old-growth forests with large trees, multiple canopy layers and moderate high canopy closure.
Mazama Pocket Gopher *(Thomomys mazama)*	T	JBJM	Prairie, well-drained soils.
Mexican Spotted Owl (*Strix occidentalis*)	T	Camp Navajo	Ponderosa Pine and Gamble Oak forests.
Northern spotted owl *(Strix occidentalis caurina)*	T	JBJM	Multilayered, multi-specie old forests with moderate to high canopy closure (≥60%), ground covered in accumulated debris and open spaces sufficient for flying.
Oregon Spotted Frog (*Rana pretiosa*)	T	JBJM	Perennial bodies of water, large areas of wetland.
Red-cockaded woodpecker (*Picoides borealis*)	E	Fort Benning	Mature Longleaf (*Pinus palustris*) pine (greater than 60 years old).
Relict Trillium (*Trillium reliquum*)	E	Fort Benning	Moist hardwood forests in Alabama, Georgia, and South Carolina.
Steelhead *(Oncorhynchus (=Salmo) mykiss)*	E	JBJM	Gravel-bottomed, fast flowing freshwater and ocean access.
Steller Sea Lion *(Eumetopias jubatus)*	E	JBJM	Ocean, Pacific coast waters and shores.
Streaked horned lark *(Eremophila alpestris)*	T	JBJM	Prairie, large open spaces.
Southern Resident Killer Whale (*Orcinus orca)*	E	JBJM	Pacific Coast, Oceanic.
Taylor's checkerspot Butterfly (*Euphydryas editha taylori*)	E	JBJM	Northwest grass land prairie's and grass/oak woodlands.
Water Howellia (*Howellia aquatilis)*	T	JBJM	Wetlands, lowlands bordering forested areas.
Wood Stork (*Mycteria americana*)	T	Fort Benning	Brackish forested wetlands.
Western gray squirrel *(Sciurus griseus)*	T	JBJM	Oak woodlands and coniferous forests in the Western United States.
Yelloweye Rockfish (*Sebastes ruberrimus)*	T	JBJM	Outer Puget Sound, Washington coast.
State-Listed Species			
Alligator Snapping Turtle (*Macroclemys temminckii*)	T	Fort Benning	Rivers and streams that flow to the Gulf of Mexico.
Barbour's Map Turtle (*Grapthmys barbouri*)	T	Fort Benning	River systems in southeast Alabama, southwest Georgia and the Florida Panhandle.
Blue Stripe Shiner (*Cyprinella callitenia*)	T	Fort Benning	Small to medium streams with rocky substrates as well as small pools.
Croomia (*Croomia pauciflora*)	T	Fort Benning	Moist deciduous forests in ravines and river bluffs.
Georgia Oak (*Quercus georgiana*)	E	Fort Benning	Sandstone and granite outcroppings at 160 to 1640 ft altitude.
Ground Dove *(Columbina passerina*)	SP	Fort Benning	Bushy shrub cover and thickets in the Southern United States.
Indian Olive (*Nestronia umbellule*)	T	Fort Benning	Upland woods mixed with hardwood-pine canopy.
Lax Water-Milfoil (*Myriophyllum laxum*)	T	Fort Benning	Sand-bottomed creeks in Atlantic white cedar forests, spring-fed ponds and the Fall Line sandhill ponds.
Northern spotted owl (*Strix occidentalis caurina*)	E	JBJM	
Pickering's Morning-Glory (*Stylisma pickeringii pickeringii*)	T	Fort Benning	Sandy soils along the Fall Line and Coastal Plan rivers. Alongside roadsides and co-habitat with turkey oak and longleaf pine.

Species	Status	Location	Habitat Requirements
Southeastern Pocket Gopher (*Geomys pinetis*)	SP	Fort Benning	Lose sandy soils and ground cover.
Sweet Pitcherplant (*Sarracenia Rubra*)	E	Fort Benning	Wet, boggy area in the U.S. Southwest.

Legend: E = Endangered; T = Threatened; P = Federally Protected; SP = State Protected; S/A = similarity of appearance. (Alabama no longer lists species as threatened or endangered. The state designates a species as SP if it is protected under state regulations.)

Appendix B

Final Ecosystem Goods and Services Classification System

An abbreviated form of the Final Ecosystem Goods and Services Classification System (FEGS-CS) list of beneficiary categories and environmental classes is shown in Table B.1. FEGS are denoted by a code of the form XY.AABB, where X denotes the environmental class, Y denotes the environmental subclass, AA denotes the beneficiary category, and BB denotes the beneficiary subcategory. Therefore, FEGS denoted by the code 11.0101 refers to potential benefits from river and streams (XY=11) to a beneficiary in the agricultural beneficiary category (AA=01), specifically an irrigator (BB=01). For the full FEGS matrix, see the appendices in Landers and Nahlik (2013).

Table B.1. Abbreviated FEGS-CS beneficiary-environment relationship.

Beneficiary Category	Beneficiary Description	Environmental Subclasses (XY)														
		11	12	13	14	15	16	21	22	23	24	25	26	27	28	31
XY.01 Agricultural																
XY.0101																
XY.0102																
XY.0103																
XY.0104																
XY.0105																
XY.0106																
XY.0107																
XY.02 Commercial/Industrial																
XY.0201																
XY.0202																
XY.0203																
XY.0204																
XY.0205																
XY.0206																
XY.0207																
XY.0208																
XY.03 Government, Municipal, and Residential																
XY.0301																
XY.0302																
XY.0303																
XY.0304																
XY.04 Commercial/Military Transportation																
XY.0401																
XY.0402																
XY.05 Subsistence																
XY.0501																
XY.0502																
XY.0503																
XY.0504																
XY.06 Recreational																
XY.0601																
XY.0602																
XY.0603																
XY.0604																
XY.0605																
XY.0606																

Beneficiary Category	Beneficiary Description	Environmental Subclasses (XY)														
		11	12	13	14	15	16	21	22	23	24	25	26	27	28	31
XY.07 Inspirational																
XY.0701																
XY.0702																
XY.08 Learning																
XY.0801																
XY.0802																
XY.09 Non-Use																
XY.0901																
XY.0902																
XY.10 Humanity																
XY.1001																

The beneficiaries identified to derive benefits from U.S. Department of Defense lands are described below. These descriptions generally follow the FEGS-CS descriptions as closely as possible; however, we needed to modify the definitions where more specificity was needed to clearly describe the beneficiary and the derived benefit. Newly added beneficiary subcategories are explicitly identified.

B.1 DoD foresters

In FEGS-CS, the beneficiary subcategory "foresters" (XY.0107) is described as follows (Landers and Nahlik, 2013).

> "Foresters introduce tree cultivars and nurture those cultivars as they grow into trees, which are harvested. The rotation for the tree crops may be as short as 10 years or many decades."

While periodic harvesting may be allowed on DoD lands, DoD installation lands are usually managed to meet installation requirements for providing training areas with suitable species composition, preserving habitat for TES or state-listed species, and providing lands for installation uses other than training. Therefore, in the DoD-specific simulation-valuation framework, the beneficiary subcategory "DoD foresters" (XY.0107) is used to refer to the DoD land managers that develop and implement land management actions within an installation.

B.2 DoD wildlife biologists

In FEGS-CS, the beneficiary category "agricultural" (XY.0108) does not provide a subcategory pertaining to wildlife, particularly the management of TES habitat. Maintenance of suitable TES habitat is a desired outcome of installation management. We define "DoD wildlife biologists" (XY.0108) as DoD personnel who are primarily interested in preserving TES and state-listed species given training needs and restrictions. DoD wildlife biologist contribute to DoD foresters' (XY.0107) mission through monitoring, documentation, and analysis of training land and TES habitat availability.

B.3 Timber extractors

In FEGS-CS, the beneficiary subcategory "timber, fiber, and ornamental extractors" (XY.0202) is described as follows (Landers and Nahlik, 2013).

> "Timber, fiber, and ornamental extractors rely on the environment for products used or sold commercially. Only non-cultivated, renewable material (i.e., NOT oil, ore, gems, etc.) are considered FEGS."

The primary purpose of DoD forest management is to meet the needs of installation training; timber extraction is secondary. DoD foresters manage training land by allotting contracts to cut, extract and use timber from installation lands. Timber extraction benefits installations by enabling better land management through prescribed thinning. The extractors benefit by the revenue stream derived from both extraction and use of timber. We focus on the extraction of timber by the extractors and define the FEGS-CS subcategory as "timber extractors" (XY.0202).

B.4 Resource-dependent businesses

In FEGS-CS, the beneficiary subcategory "resource-dependent businesses" (XY.0206) is described as follows (Landers and Nahlik, 2013).

> "Without the environment, this beneficiary would not have the opportunity for businesses, including marinas, stables, and ecotourism (e.g., rafting companies, hot air balloon companies, beach resorts, hot springs, ice hotels) - but not farm or forest land."

Resources found on DoD property provide opportunities for non-DoD businesses; these opportunities may relate to the direct use of DoD land (e.g. recreational companies which use DoD land for ecotourism) or the intermediate us of DoD land-based resources (e.g. timber manufacturing). "Resource-dependent businesses" are members of the public who benefit from resources found on DoD land.

B.5 DoD property owners

In FEGS-CS, the beneficiary subcategory "residential property owners" (XY.0303) is described as follows (Landers and Nahlik, 2013).

> "While changes in property value are not a FEGS, residential property owners are affected by the environment in which their property resides."

On DoD installations, residential property may be present (e.g., barracks for housing troops, residences for military and administrative staff and families), but are likely to be owned by the DoD installation. There may also be other kinds of buildings (e.g., offices, storage facilities) which are also likely to be owned by the DoD installation. Public ownership of residential or other buildings on a DoD installation is assumed to be unlikely. For the purpose of this report, "residential property owners" are limited to DoD-specific benefactors and thus referred to as "DoD property owners" (XY.0303). "DoD property owners" are DoD personnel who benefit from available land for residential and building purposes.

B.6 DoD military trainers

In FEGS-CS, the beneficiary subcategory "military/coast guard" (XY.0304) is described as follows (Landers and Nahlik, 2013).

> "The Military/Coast Guard relies on the environment for the placement of infrastructure (e.g., ports, bases, etc.) or conditions for training activities."

In the DoD-specific simulation-valuation framework, the beneficiary subcategory "DoD military trainers" (XY.0304) refers to the DoD installations' (1) training managers that develop and implement troop training plans and (2) infrastructure managers that develop and implement building plans. This subcategory refers to DoD benefactors who plan and oversee installation needs in alignment with the overarching goals of the DoD. Such goals include management across installations and foresight in planning. This includes furthering the installation's mission to train troops for mission readiness through infrastructure placement on selected/suitable DoD installations.

B.7 DoD military branches

FEGS-CS does not provide a subcategory for benefits accrued to DoD military branches. In the DoD-specific simulation-valuation framework, we define "DoD military branches" (XY.0305) as a beneficiary subcategory. "DoD military branches" invest in the training of troops and development and testing of new military equipment on installation lands. The primary benefits the "DoD military branches" obtain is mission readiness.

B.8 DoD transporters of goods

In FEGS-CS, the beneficiary subcategory "transporters of goods" (XY.0401) is described as follows (Landers and Nahlik, 2013).

> "This beneficiary uses the environment as a media to transport goods - specifically, via boats (e.g., barges), airplanes, and overland/off-road vehicles (e.g., quads)."

On DoD installations, two kinds of transportation of goods may occur—supplies shipped into the installation from outside or goods/equipment which are moved within the installation. It is the second of these that is relevant to this study and involves movement of supplies for troop training within the boundaries of the DoD installation. Therefore, in the DoD-specific simulation-valuation framework, the beneficiary subcategory "DoD transporters of goods" (XY.0401) refers to training supply transporters.

B.9 DoD transporters of people

In FEGS-CS, the beneficiary subcategory "transporters of people" (XY.0402) is described as follows (Landers and Nahlik, 2013).

> "This beneficiary uses the environment as a media to transport people - specifically, via boats (e.g., cruise liners, ferries, tour boats), airplanes, and overland/off-road vehicles."

On DoD installations, two kinds of transportation of people may occur—DoD installation staff and military personnel travelling to and from outside of the installation or staff moving within the installation. The movement of troops within the installation for training purposes provides the primary benefit from DoD land holdings at a given installation. Therefore, in the DoD-specific simulation-valuation framework, the beneficiary subcategory "DoD transporters of people" (XY.0402) refers to troop transporters within the base for training purposes.

B.10 Experiencers and viewers

In FEGS-CS, the beneficiary subcategory "experiencers and viewers" (XY.0601) is described as follows (Landers and Nahlik, 2013).

> "This beneficiary views and experiences the environment via an activity, such as scenery gazing, hiking, bird watching, botanizing, ice skating, rock climbing, flying kites, etc. This beneficiary does not have physical contact with water."

Experiencers and viewers are members of the public that derive enjoyment from passive viewing of the environment or though participation in activities within DoD installation boundaries. Many times, "experiencers and viewers" are physically located outside of installation boundaries but derive enjoyment from the environment within the installation boundaries. For example, dramatic landscapes or habitat within DoD installation boundaries provides benefits to members of the public located nearby. DoD installations also grant public access for certain recreational activities; members of the public derive benefit from such activities.

B.11 Hunters

In FEGS-CS, the beneficiary subcategory "hunters" (XY.0603) is described as follows (Landers and Nahlik, 2013).

> "This beneficiary is primarily interested in hunting mammals and fowl (not flora or fungi) recreationally (i.e., not for survival). In aquatic environments, this beneficiary has potential contact with water."

Members of the public who derive benefit from hunting on DoD land are defined as "hunters" (XY.0603). "Hunters" derive benefit from the maintenance of ecosystems and habitat suitable for hunted species. Public benefits may be impacted by installation management and habitat maintenance.

B.12 Spiritual and ceremonial/tribal

In FEGS-CS, the beneficiary subcategory "spiritual and ceremonial participants and participants of celebration" (XY.0701) is described as follows (Landers and Nahlik, 2013).

> "This beneficiary uses the environment for spiritual, ceremonial, or celebratory purposes, such as harvest festivals, seafood festivals, Native American observances, religious rites (i.e., baptisms, weddings), personal growth, etc."

In the DoD-specific valuation-simulation framework, we shorten the sub-beneficiary name to "spiritual and ceremonial/tribal" (XY.0701). Many DoD installations are in areas where tribal celebrations have historically taken place. DoD installations may also include environmental goods pertinent to spiritual and ceremonial livelihood (i.e. flora and fauna of ceremonial importance, "first-foods"[1] and significant religious locations). Installation management may influence the availability and accessibility and environmental goods which benefit tribal members.

B.13 Educators and students

In FEGS-CS, the beneficiary subcategory "educators and students" (XY.0801) is described as follows (Landers and Nahlik, 2013).

> "This beneficiary includes both formal and self-taught educators and students. All parts of the environment are of interest."

Educators and students are members of the public who derive benefit from accessing and learning from environments within DoD installation boundaries. Management, by DoD personnel, affects the availability and accessibility of educational habitat.

B.14 Non-DoD researchers

In FEGS-CS, the beneficiary subcategory "researchers" (XY.0802) is described as follows (Landers and Nahlik, 2013).

> "Researchers are interested in the environment for academic and applied purposes and as a group do not discriminate over which parts of the environment are of interest."

In the DoD-specific simulation-valuation framework, the beneficiary subcategory "researchers" is modified to "non-DoD researchers" (XY.0802). "Non-DoD researchers" are members of the public who are interested in research pertaining to ecosystems and the environment within the boundaries of DoD installations. Such beneficiaries derive benefit from access to various environments within the installation.

B.15 DoD researchers

In FEGS-CS, the beneficiary category "learning" (XY.08) does not provide a subcategory for DoD-specific research. In the DoD-specific simulation-valuation framework, we include the subcategory "DoD researchers" (XY.0803).

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[1] "First foods" refer to the food which tribal members traditionally relied on to both survive and perform ceremonies. Traditional foods include both seasonal and non-seasonal foods such as berries, roots, hoofed-game, and salmon. "First foods" are historically celebrated to remain an important part of tribal culture.

While “non-DoD researchers” (XY.0802) are primarily interested in the availability of DoD installation lands for the purpose of academic and applied research, “DoD researchers” are interested in the use of installation resources for DoD-specific research and innovation. For example, an installation may provide suitable habitat for the development and testing of novel un-manned military equipment. “DoD researchers” benefit from access to suitable environments and areas in which they can conduct DoD-specific research.

B.16 DoD soldiers

In FEGS-CS, the beneficiary categories “government, municipal, and residential” (XY.03) and “learning” (XY.08) do not provide a subcategory for benefits that accrue to soldiers that train on installation lands. In the DoD-specific simulation-valuation framework, we include the subcategory “DoD soldiers” (XY.0804) in the learning category.

DoD soldiers derive benefits from training at the installation to acquire skills, obtain education, and accumulate experience. The skills, education, and experiences are valuable to the DoD soldiers both in their military and post-military professional careers.

B.17 Non-users—existence

In FEGS-CS, the beneficiary subcategory “people who care (existence)” (XY.0901) is described as follows (Landers and Nahlik, 2013).

> “This non-use beneficiary believes it is important to preserve the environment because of a moral/ethical connection or for fear of unintended consequences.”

“Non-users—existence” are members of the public that value preservation of the environment on DoD installation lands. Such beneficiaries derive benefit from the existence of TES habitat, ecosystems, and wildlife all of which are directly correlated with management of installation lands by DoD personnel. “Non-users—existence” are mainly concerned with maintenance and upkeep of such areas for fear that losing unique habitat can cause potential harm.

B.18 Non-users—bequest

In FEGS-CS, the beneficiary subcategory “people who care (option/bequest)” (XY.0902) is described as follows (Landers and Nahlik, 2013):

> “Option/Bequest non-use beneficiaries consider that they or future generations may visit or rely on the environment. This includes beneficiaries that value the traditional aspects or features of an activity or FEGS.”

“Non-users—option/bequest” are members of the public who derive value from the continued preservation of DoD installation lands, and services on those lands, such that future generations can access and benefit from such lands. This beneficiary is concerned with long-term land management and future resource use.

B.19 Citizens

One of the main benefits that DoD installation provide is military readiness by training troops at levels needed for national defense. FEGS-CS does not provide a beneficiary category for national defense. We added this category, indicated as XY.11. Because national defense benefits all citizens of our nation, we define one beneficiary subcategory within national defense, citizens (XXY.1101). Citizens derive benefits from the provisioning of national defense needs (e.g., soldier training, mission readiness) from installation lands.

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