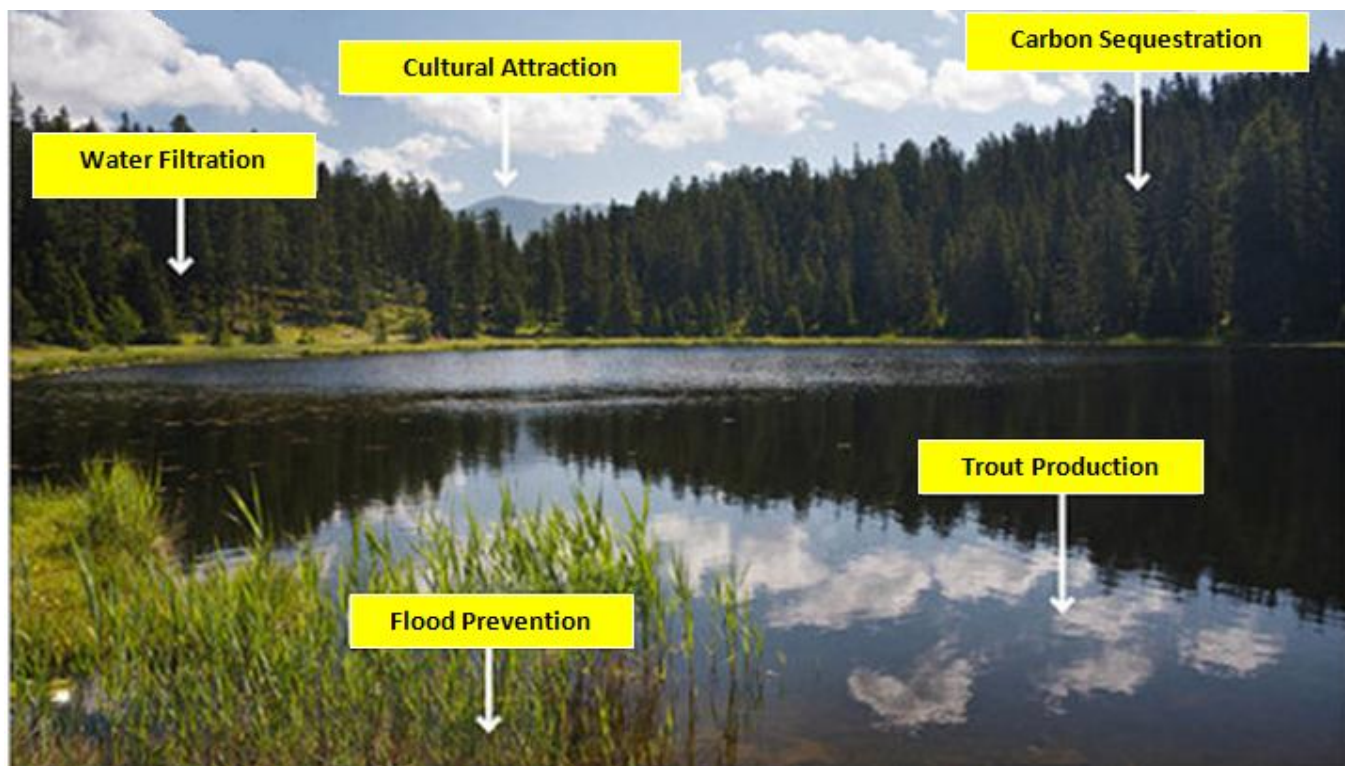


Assessment of InVEST 2.1 Beta: Ecosystem Service Valuation Software

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Adapted from: <http://climateadaptation.tumblr.com/post/4499822904/ecosystem-services-sell-out-or-protection>, 2011.

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Abstract

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) software is a tool used for determining the economic value of an ecosystem service by geographic location. Ecosystem services are goods and services provided by the natural environment, such as carbon sequestration or nutrient retention. Determining where ecosystem services provide the greatest benefit to society is critical information for decision makers in determining where to conserve land and where to allow development or other changes to the natural landscape. The InVEST program provides this information as series of maps and table produced by running a variety of models that account for as many different aspects of the natural environment as possible. Therefore the results of the models are very thorough and can be assumed to be highly accurate; however the amount of data required to run a single model can be so great that it may potentially limit use. Additionally, these models do not run flawlessly; the InVEST program requires substantial improvements before it can be utilized successfully by anyone outside of the creators.

Introduction

The focus of this research was utilizing and analyzing InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) software. InVEST is an ArcGIS extension which can be used to map the values of good and services as provided by an ecosystem. It was designed to lead decision makers to informed conclusions of ecosystem trade-offs in terms of land development and land conservation. This paper will begin by introducing the concept of ecosystem services and InVEST. From that point the focus will shift to an analysis of the InVEST software, through a summary of results and challenges experienced in running models. Finally, this paper will discuss a brief review of the related literature which will include various studies that have used InVEST, overall shortcomings with InVEST and who should use InVEST.

Ecosystem Services

The concept of ecosystem services is the process of identifying and then assigning monetary value to services provided by the natural environment. Traditionally, natural commodities have included timber, fiber and other raw tangible materials. In the new terms of ecosystem services, this list has grown to include “clean air, climate regulation, flood buffering, and other non-material benefits” (Gomen-Baggethun and Ruiz-Perez, 2011, 615).

This system of valuation creates economic incentives for conservation; ecosystem services are viewed as natural capital stock, providing goods and services for society. When a forest or other natural land use is seen as providing an economically quantifiable service to society the argument for conserving it becomes far stronger, particularly if the economic worth of the air purification, water filtration, etc., provided by the forest is greater than the potential profit from harvesting timber. Quantifying ecosystem services addresses the reality that goods

and services provided by nature are not limitless and are actually quite valuable when one considers the cost of artificially replacing them.

One common process of determining the economic value of an ecosystem service is known as the ecosystem service cascade model, Figure 1. This model is also affected by political and social pressures. The value of a given biophysical structure or process may be in terms of social, aesthetic, production, etc. values.

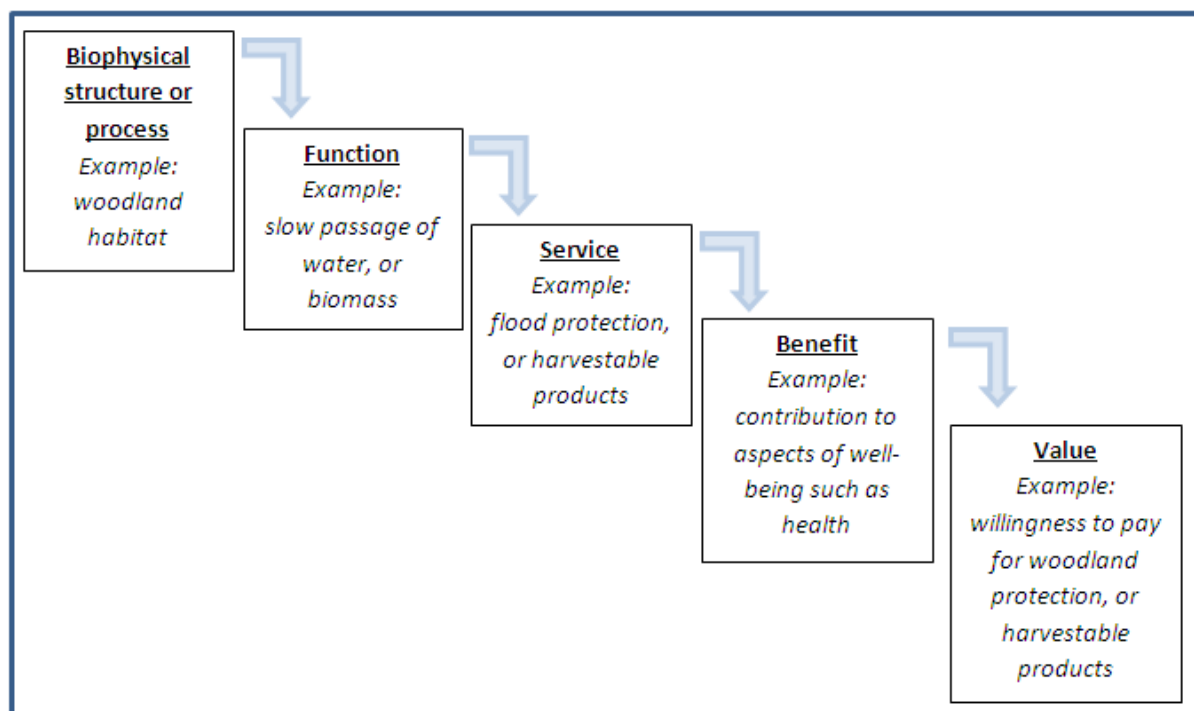


Figure 1: Displays the Ecosystem Cascade Model (Adapted from Potschin and Haines-Young, 2011).

InVEST Software

The purpose of the InVEST software is to determine the economic value of terrestrial, marine and freshwater ecosystem services by geographic location. This software accounts for a variety of factors within an ecosystem by generating models which geographically assign economic values for each factor; models include nutrient retention, carbon sequestration

capabilities, biodiversity and water purification. The results of multiple relevant models are compared to determine at risk and target conservation areas. The process for InVEST use is outlined by Figure 2. The use of multiple models allows decision makers to consider various scenarios while determining where land conservation is most vital.

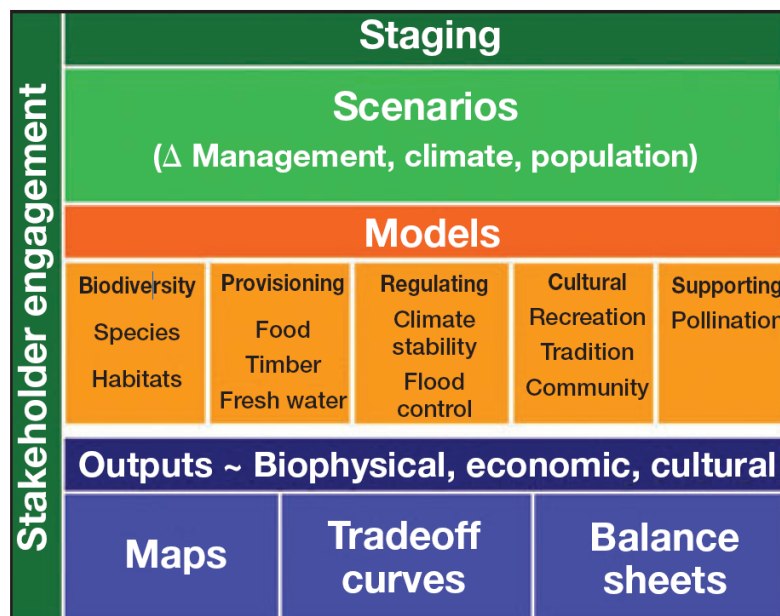


Figure 2: InVEST flowchart of how to compile multiple models for a thorough analysis of an ecosystem service (Tallis *et.al*, 2011).

Methodology: Running Models in InVEST

To assess the practicality and feasibility of utilizing InVEST, our primary objective was to run models in the software using the sample data in an effort to answer one of the sample questions provided by the InVEST documentation. The InVEST program aims to produce results that answer several questions related to ecosystem services, such as... "Where would reforestation achieve the greatest downstream water quality benefits? (Tallis, *et. al*, 2011, 2) The following sections contain the results of running InVEST models and analysis pertaining to the aforementioned question.

Study Area

The study area of the sample data is in the Willamette River Valley, Oregon. The data focuses on three sub-watersheds within the study area, (Figure 3 a). The dominant land covers in this area are forest and agriculture, (Figure 3 b).

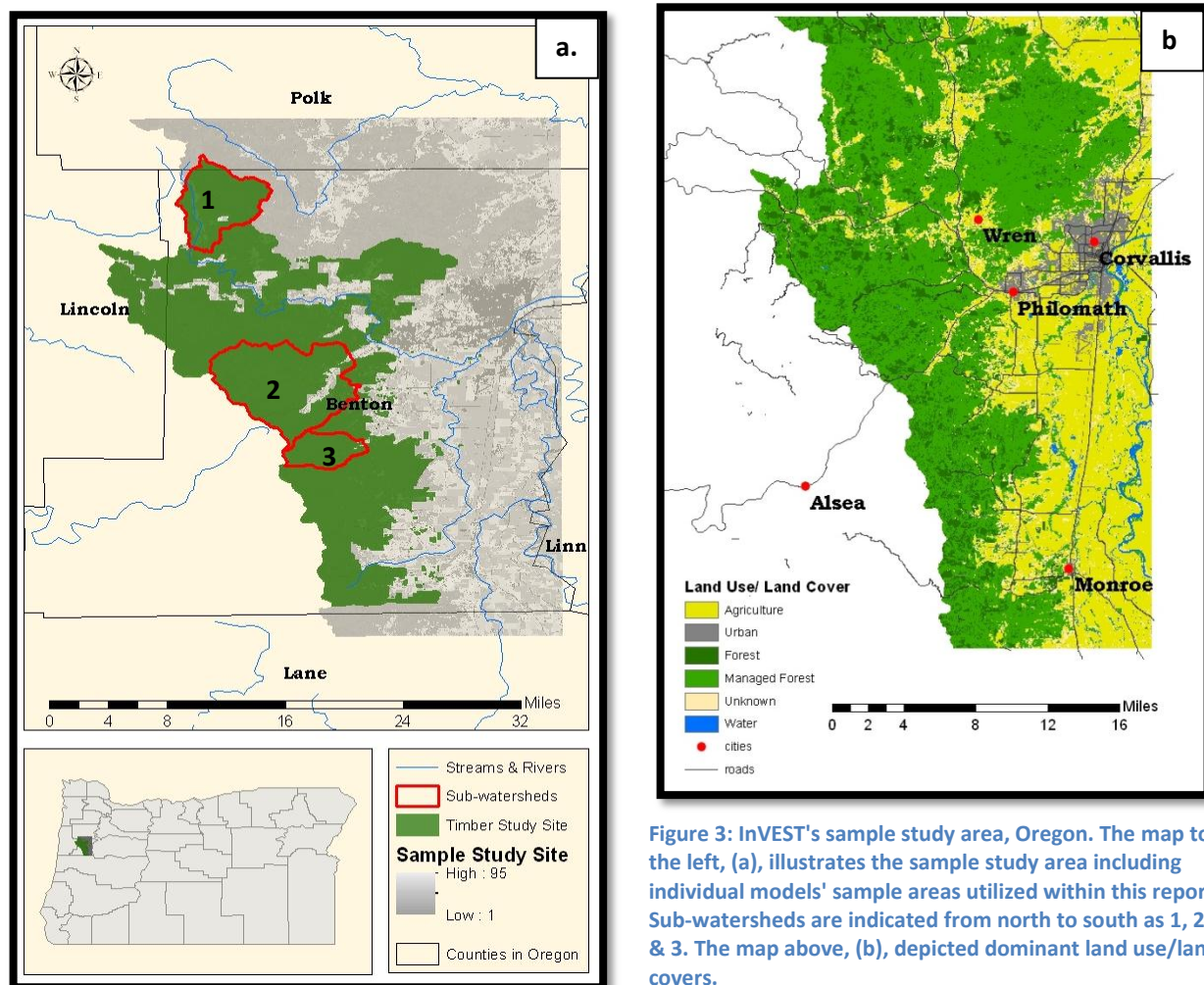


Figure 3: InVEST's sample study area, Oregon. The map to the left, (a), illustrates the sample study area including individual models' sample areas utilized within this report. Sub-watersheds are indicated from north to south as 1, 2, & 3. The map above, (b), depicted dominant land use/land covers.

Managed Timber Production Model

The model is designed to output maps that represent the economic value of the forest parcels as designated by the government, communities, private timber companies, or other regulated entities. The model also accounts for values of timber species types, management and

harvest costs, and harvested timber quantity and rotation time (the frequency of harvest in a specified area).

Inputs of the Managed Timber Production Model

The required input datasets consist of the timber parcels, production table and market discount rate. The timber parcel dataset is a vector set which maps current and expected areas of legal timber harvest. The areas vary in terms of size and proportion of the entire forest. In the attribute table, each area (or parcel) is associated with a harvest level, frequency of harvest and production costs. The production table comprehensive table of timber production which requires parcel identification, area, percent harvested, harvest mass, frequency of harvest, price, maintenance, harvest costs, time period of consistent land cover, immediate or future harvest, volume of harvest wood (converted from mass of harvested wood using the BCEP, or expansion factor, measured in Mg of wood per m³ of wood). The Market Discount rate is an optional parameter. This rate value is not supplied, even in the sample data. It is a user selected value based upon society's preference for instant benefits over future benefits and in this case refers to a company's choice to harvest trees in that year or wait for maturation. InVEST suggests the default for this input as 7% each year. That value is based on government recommendation for environmental projects. (Tallis *et.al* ₃, 2011)

Outputs of the Managed Timber Production Model

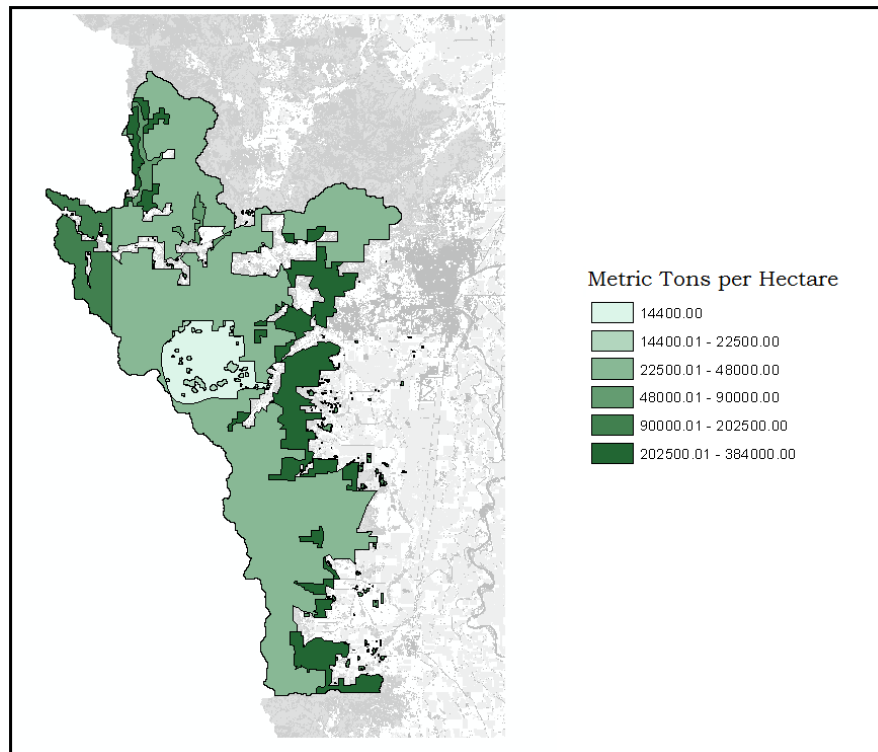


Figure 4: Illustrates biomass harvested from each parcel as measured in metric tons per hectare.

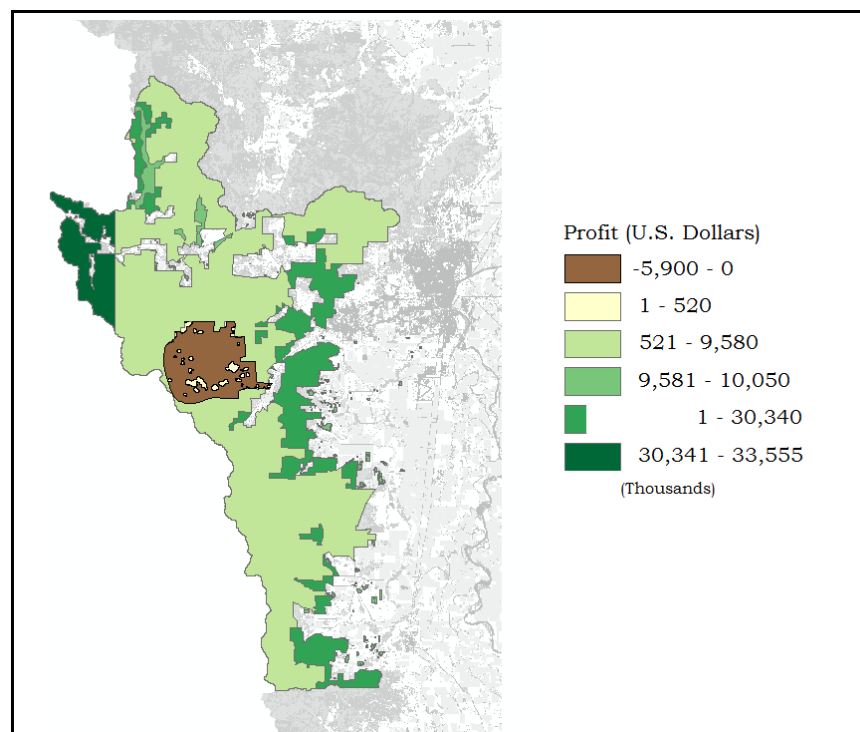


Figure 5: Illustrates profits in U.S. dollars per parcel of harvested timber.
Note: Values are in thousands of dollars.

Discussion of Results of the Managed Timber Production Model

The most profitable parcel is located in the western most section of the study area; the least profitable parcel is located in the center of the study area. In comparing the profits per parcel to the metric tons per hectare of biomass harvested per parcel, greatest quantity removed does not equal highest profit. Despite the parcel in the center of the eastern portion of the study area being the most intensely harvested, it only produced the second highest profits. Conversely in the most profitable parcel, the quantity of timber harvested was only the second greatest in the study area. The variations in quantity harvested as compared to profits are due to variations in production costs, value of tree species, and other factors within the different parcels.

Limitations of the Managed Timber Production Model

Limitations to the model consist of assuming percent of forest harvest, mass of harvest, harvest period, frequency of harvests, related prices and costs remain constant in each parcel over designated periods of time. Some of these concerns can be addressed by running models limiting the length of time used to assess harvests or by consistently updating various components with each analysis run based on current events. Each of these variables can change from year to year and from parcel to parcel. In addition, un-modeled disturbances such as disease, forest fires, or large economic declines can have dramatic effects on harvest levels.

Furthermore, this model only takes into consideration regulated harvested wood. The excluded entities illegally harvesting or harvesting in forested areas where property rights are not enforced or not defined are dealt with in the *Open Access Timber and Non-Timber Products Model*, not currently on the market.

Carbon Storage and Sequestration Model

Storing carbon in timber, biomass, and soil, all within terrestrial ecosystems keep carbon dioxide out of the atmosphere, where it would contribute to climate change; terrestrial ecosystems store more carbon collectively than the atmosphere. Alterations to these systems such as fire, disease, vegetation conversion, and land use change can release large amounts of carbon dioxide which makes managing terrestrial ecosystems vital for regulating climate change (Tallis, *et. al*, 2011).

This model works by assigning each cell a land use/ land cover (LULC). That use/cover is then used to determine how much carbon is being sequestered, for example, a forested cell will sequester more carbon than an developed cell. As so much of this study area is managed forests for timber production (see Figure 3), this model also accounts for timber harvest, including: frequency and product decay rates. The user then has the option of selecting the social value of carbon sequestration only as a forecasted output. The values are market based and derived from carbon credit values.

Inputs of the Carbon Storage and Sequestration Model

The InVEST model utilizes land cover data on timber harvest rates, harvested product degradation rates, and stocks in four carbon pools (aboveground biomass, belowground biomass, soil, and dead organic matter) to estimate the amount of carbon currently stored in a landscape or the amount of carbon sequestered over time (Tallis, *et. al*, 2011). Optional inputs include future scenarios of LULC data, and economic data which include the value of a sequestered ton of carbon, the market discount rate, and the annual rate of change in the price of carbon sequestration.

Outputs of the Carbon Storage and Sequestration Model

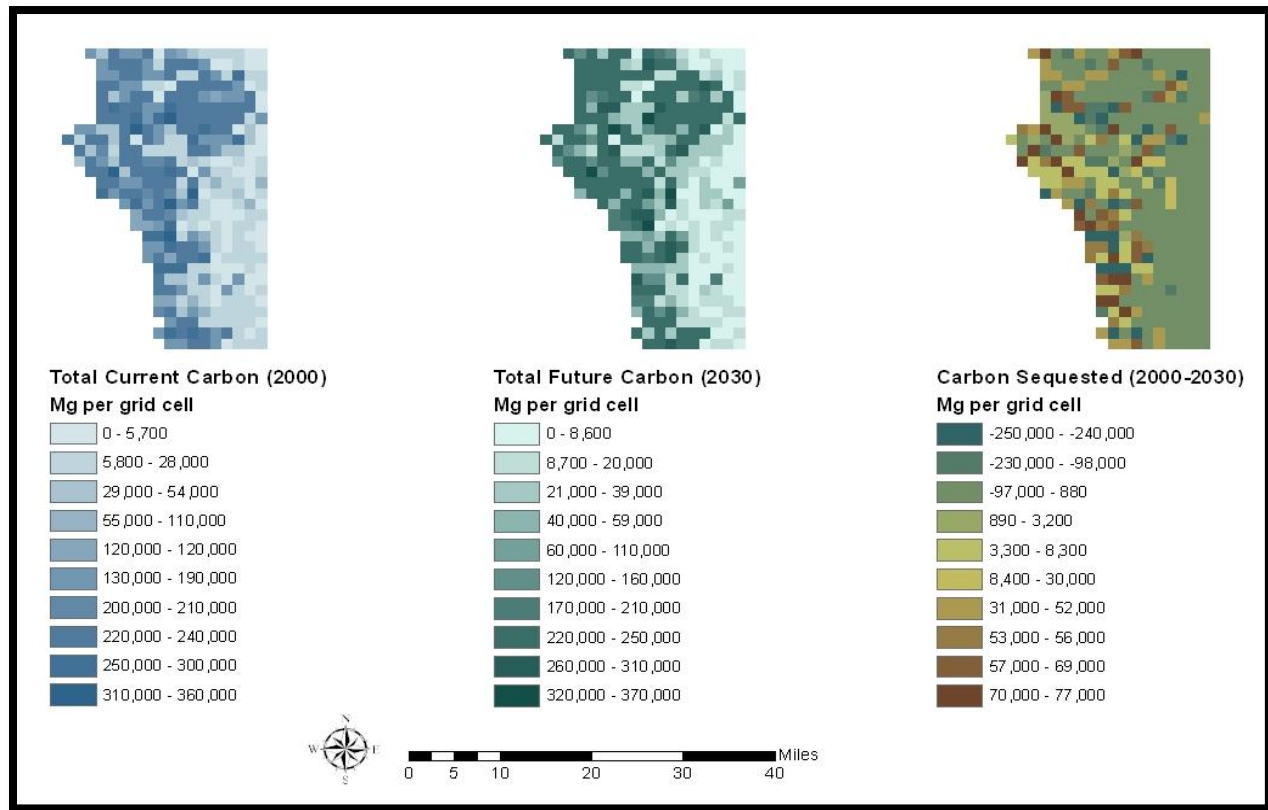


Figure 6: Illustrates the difference between current and projected carbon storage. The map furthest to the right displays the difference in carbon stored between the current and future landscapes i.e. 2000 – 2030.

Discussion of Results of the Carbon Storage and Sequestration Model

The results found from running the carbon storage and sequestration model consisted of the total amount of carbon currently stored in milligrams/2000x2000 meter grid cell. The left-most map in Figure 6 depicts the current sum of all carbon pools per grid cell. The second output, center, received is the projected total amount of carbon stored in milligrams for a future landscape scenario in year 2030. The value depicted is also the sum of all the carbon pools. The final result produces a file that maps the difference in carbon stored between the current landscape and the future landscape. This rate is dependent on the thirty year timeframe of the sample data. Positive values indicate sequestered carbon, whereas negative values indicate

carbon loss per cell. Areas with the largest values, positive or negative, suggest the areas with the largest alteration in LULC or harvest rates. These results do not include the optional output economic valuation of carbon sequestration due to the buggy nature of the Beta software.

Limitations of the Carbon Storage and Sequestration Model

Limitations to the carbon model include an assumed linear adjustment in carbon sequestration over time, an overgeneralized carbon cycle, and constantly changing, thus possibly inaccurate optional discounting rates. Over simplifying the carbon cycle allows the model to run with less information but leads to unrealistic scenarios. Due to the reliance on LULC data, carbon storage estimates are only as detailed as the LULC classification utilized. Finally, the valuation of carbon sequestration can only be forecasted for the future, not for current conditions since it is reliant on the changing value of carbon sequestration.

Water Purification Model: Nutrient Retention

The nutrient retention model is designed to calculate the amount of pollutants that a parcel of land can effectively retain. The pollution can be determined by the user; nitrogen and phosphorous are the two options given within the software but if the necessary data are provided, it is possible for the user to calculate any specific pollutant. This model works by assessing three major attributes of nutrient retention. The first attribute calculated by the model is the average annual runoff per pixel; determined through the hydropower model, which must be run by the user prior to beginning this model. Next, the amount of pollutant per pixel is calculated using coefficients derived in the field by Reckhow *et. al*, 1980, with a “hydrologic sensitivity score” (Tallis, *et. al*, 2011) that accounts for the difference in hydrologic conditions between the field study areas of Reckhow *et. al*, 1980 and the study area of interests. The model

then calculates the amount of nutrients that can possibly be retained by a downstream pixel based on that pixel's land cover type. The model carries out these operations until the downstream pixels flow directly into the stream where the nutrient load is then within the water body and can be calculated. At this point, the output of the model is shown and able to be compared with any data collected in the field to allow for a more precise "hydrologic sensitivity score" (Tallis, et. al, 2011).

Inputs of the Water Purification Model for Nutrient Retention

The Nutrient Retention model of Water Purification utilizes a large number of required inputs in order for the model to run correctly. The required inputs include a digital elevation model, soil depth, precipitation, plant available water content, average annual potential evapotranspiration, LULC, watersheds shapefile, sub-watersheds shapefile, biophysical table, threshold flow accumulation value, water purification valuation table, and a water purification threshold table. The water purification valuation table includes the watershed, total critical annual nutrient loading allowed for nitrogen or phosphorous, the annual cost of water treatment for nutrient removal, the time span of a consistent LULC or of a water treatment plan, and the discount rate over time.

Outputs of the Water Purification Model for Nutrient Retention

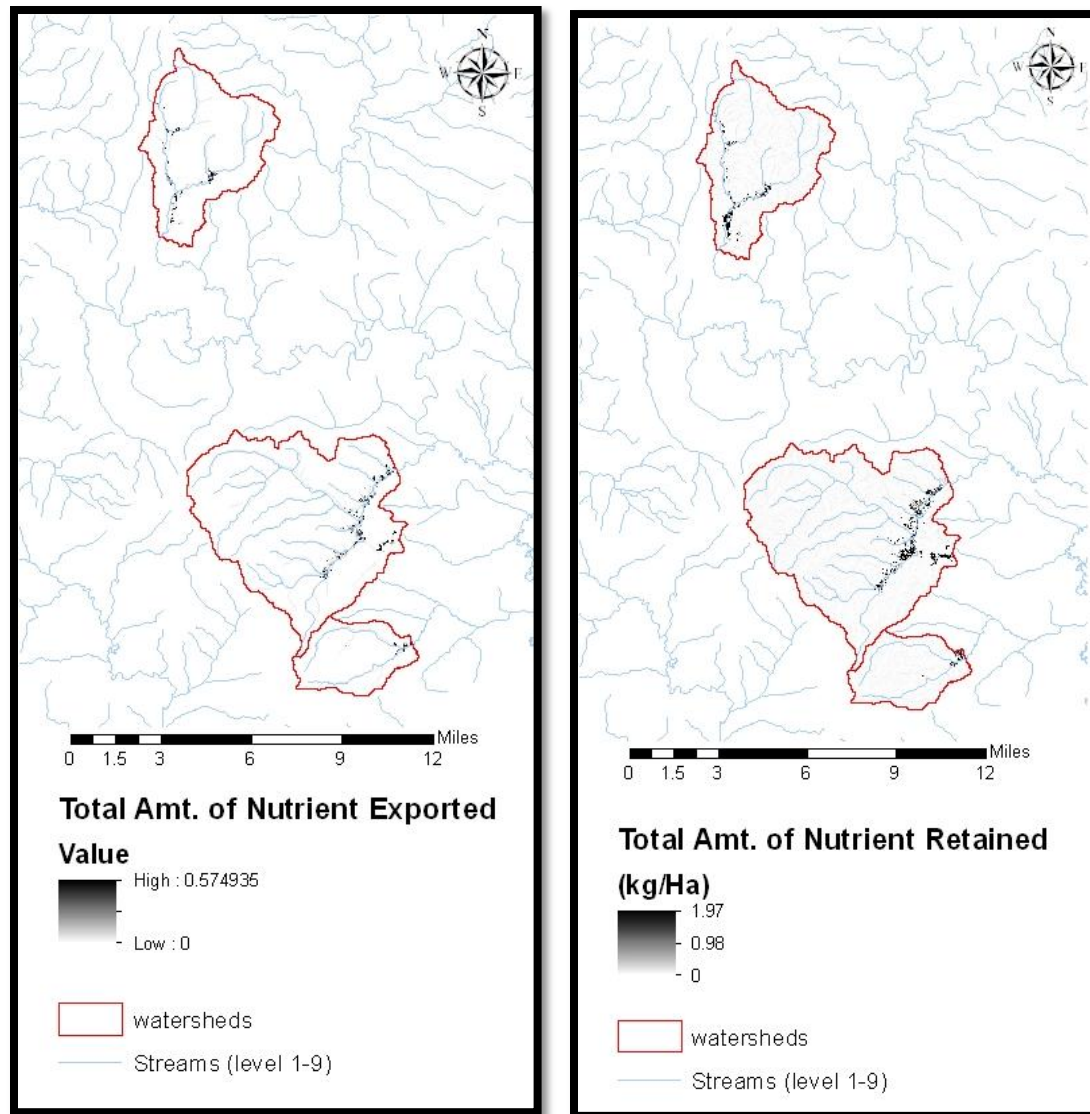


Figure 7: Illustrated on the left is the total amount of nutrients in kilograms per hectare exported into the stream per sub-watershed. Illustrated on the right is the total amount of nutrients in kilograms per hectare retained into the stream per sub-watershed.

Discussion of Results of the Water Purification Model for Nutrient Retention

The resulting outputs if properly utilized will give insight into the dynamics of pollutant loading, transport and filtration within the watershed. Total and mean amounts of nutrient retained by each watershed as well as exported by each watershed are both valuable results to have, again if properly utilized. Figure 7 (above) illustrates the total amount of phosphorus

retained and exported within each sub-watershed. Phosphorus is acting as the surrogate for other pollutants due to the limited sample data provided by InVEST. Additional outputs not utilized within this report consist of total adjusted load per sub-watershed, the economic benefit per sub-watershed, and tables containing values for total nutrient export and retention per watershed.

Limitations of the Water Purification Model for Nutrient Retention

The water quality (nutrient retention) model was designed for watersheds with excess runoff hydrology and may be less applicable for locations where hydrology is determined by rainfall. Second, this model was only designed to assess one pollutant per run which makes the user have to run multiple models or select one pollutant as a surrogate for predicting loadings of other pollutants. The model does not address chemical or biological interactions and will only model pollutants that are susceptible to export through surface or subsurface flows. Additionally, this model may provide incorrect marginal costs for pollutant removal due to the complexity of treatment processes and the lack of a constant for marginal costs. Finally, the inputs for this model are very detailed and complex making it challenging to find and execute each layer properly.

Sedimentation Retention Model

The sediment retention model is designed to assess a parcel of lands ability to retain its sediment. The model is designed to take into account the data on features of each land parcel. The particular features of focus within the model are the land geomorphology, climate, vegetation and management practices (Tallis, *et. al*, 2011). This model was designed to assist decision makers in the estimation of sediment retention and transportation in the context of

human infrastructural damage, this being bridges, hydropower dams and farming lands (Tallis, *et. al*, 2011). All of these examples are affected by sedimentation in different ways yet all are interrelated. In order to most effectively help planners, the model can be set to calculate the areas where the sediment load would increase due to a land use change upstream. This is easily done with varying input values of a desired land feature. The resulting output will generate a scenario with a change in sediment retention values dependent on the selected input changes.

Inputs of the Sediment Retention Model

An extensive amount of data is required to run this model; including a digital elevation model, LULC, watershed shapefile, and a sub-watershed shapefile. The other required inputs are more complicated. The model requires a rainfall erosivity index, which is a raster dataset that contains the erosivity index values by cell. The index is dependent on the length and amount of rainfall in the study area.

A soil erodibility raster dataset accounts for the tendency of soil to runoff with rainwater. The biophysical table provides details about the LULC, and includes codes, descriptions, etc. A threshold flow accumulation dataset accounts for how many cells the rainwater flows through before it becomes part of the stream. The slope threshold dataset contains values that describe the slope management and the slope stabilization of a cell. The sediment valuation table consists of economic valuation data in each reservoir within the study area. Finally, the sediment threshold table contains information regarding the amount of time land cover will remain constant, water volume, and annual sediment loading allowed.

Outputs of the Sediment Retention Model

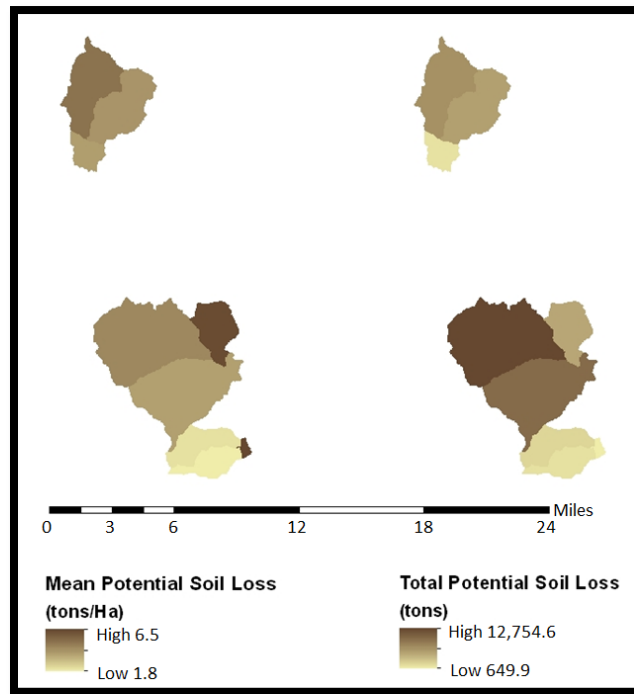


Figure 8: Illustrates the mean and total potential soil loss per sub-watershed in ton and tons per hectare.

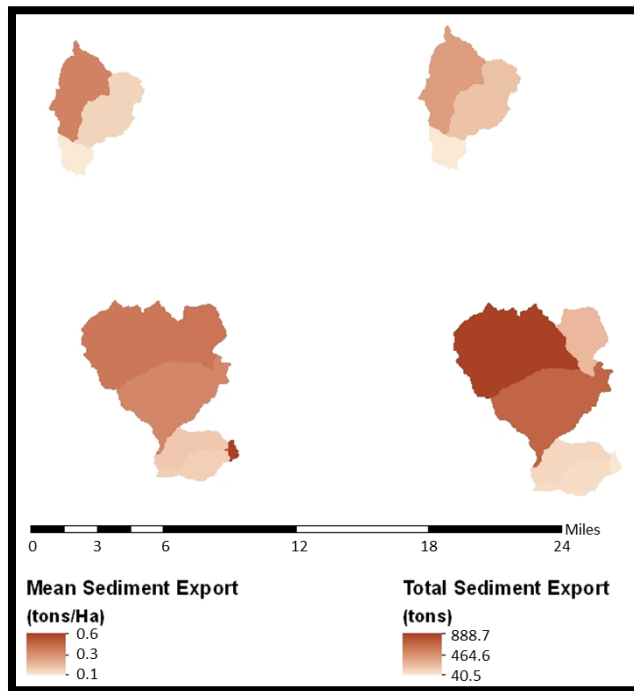


Figure 9: Illustrates the mean and total sediment exported from each sub-watershed in tons and tons per hectare.

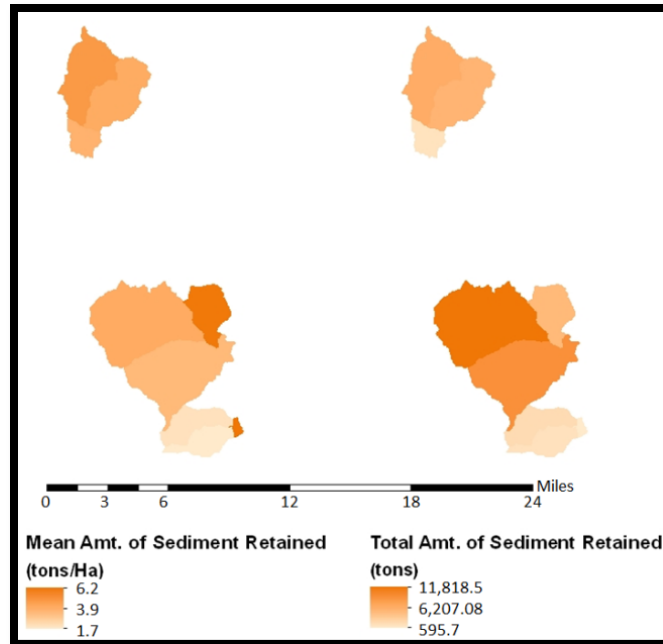


Figure 10: Illustrates the mean and total amount of sediment retained from sediment originating upstream in tons and tons per hectare, averaged across pixels in each sub-watershed. Note: Does not include sediment originating from the pixel itself.

Discussion of Results of the Sediment Retention Model

Even though the output is simply given as tons of sediment loss per hectare, it can be inferred by the user where the most beneficial location for land management practices would be. These results can be applied to aspects outside of the originally desired application. In this case, the volume of sediment lost will be used as one of the several parameters in this study that will help to calculate the overall health of a water body. Sediment loads are an important aspect of stream health as they have the potential to devastate the water it flows into. Not only does sediment loss effectively strip the land of a valuable resource, it can cloud the water making it less penetrable to light, directly effecting the subaquatic vegetation which provides habitat, oxygen and food to the local aquatic biota. When the sediment settles, it has the potential to bury the aquatic life that resides on the stream bed.

Limitations of the Sediment Retention Model

The equation used to calculate the erosional rates has only been tested in the great plains of America and therefore cannot be assumed accurate for mountainous regions where the slopes of the land are much different. This model assess soil loss on flat land features and not on features such as stream banks, gullies and many others found throughout the world. A less substantial yet still important factor in the lack of accuracy for this model is how the varying attributes to soil erosion are calculate individually. Some attributes may interact with others, positively or negatively, affecting the actual erosional rates that might be found in the field. By assessing the attributes individually, the output of this model may differ from actual results. The design of this model is not to give the user an accurate volume of sediment eroded but rather to show the user how the erosional volume might change in conjunction with changes in land use cover.

Culminating Results and Discussion

Where would reforestation achieve the greatest downstream water quality benefits?

After assessing the results of InVEST, (Figures 4-10), it can be concluded that the reforestation efforts would have the greatest positive impact in sub-watershed 2. Sub-watershed 2 contains that region in which the smallest amount of biomass is harvested, (Figure 4) and timber production is least profitable (Figure 5). While all three of the sub-watersheds are comparable in terms of carbon sequestration, (Figure 6), sub-watershed 2 contains the greatest total potential for soil loss (Figure 8), and is exposed to the greatest amount of nutrients (Figure 7). Figures 9 and 10 show that sub-watershed 2 exports and retains the greatest amount of nutrients; reforestaion of this area would help in retaining more and exporting less.

General Limitations of the InVEST Software

Assumptions and simplifications are the largest limitations to all models within InVEST and to models in general. The multifaceted intricate patterns among ecosystem services may be lost in over generalization.

Another potential limitation of InVEST is the amount of data required to run some of the models. Although the large amount of inputs required ensure accuracy as the software accounts for a range of influences, much of the data is very specific, and would be very time consuming and expensive to attain. In fact this constraint was cited in a UN report as problem, which stated “...this is a data-intensive undertaking, and whilst customisable tools for mapping ecosystem service values such as InVEST13 exist, they require significant parameterisation for local application.” (UNEP-WCMC, 2011, 58). Additionally, this constraint limits individual use InVEST, as well as which geographic location models may be run for.

The NCP community is extremely well connected to government and large non-governmental organizations such as the United Nations Environment Programme, World Wildlife Foundation and the Nature Conservancy. InVEST was built by a team of experts in a broad range of disciplines and employed in academia, government and non-profit sectors. The number of contributing authors listed on every study where InVEST is utilized emphasizes the point that it requires a broad spectrum of backgrounds to successfully run and interpret results of InVEST. The specificity and customization that InVEST allows, requires extensive resources to apply the full potential of the tool. The data needs are specific and may often require the generation of new data to complete a specified analysis, therefore, many InVEST projects require substantial organizational and financial support and a tremendous amount of research.

Thorough interpretation of the results is enhanced by the talents and knowledge of experts in multiple fields, for example, economics, ecology, and climatology.

The vast quantity of complications encountered throughout this research due to constant errors in the software limited the ability to run through several of the models. Despite use of the sample data set provided by InVEST, and despite following the instructions of the InVEST documentation, each model ran invariably resulting in at least one error message before producing results. In fact, many models are not included in this report as results were not ever achieved.

A final limiting factor of InVEST is the additional software requirement; InVEST assumes ownership of ArcGIS, a costly software suite. Therefore, an organization lacking ArcGIS or utilizing a different GIS software may not be able to use InVEST.

Applying InVEST to the Real World

Where and by whom has InVEST been used?

Based on the exploration of the sample data provided, it would appear that for effective use of InVEST, significant time, information and expertise beyond what may be gathered from the documentation is required. Additionally, it seems all successful InVEST studies have had the contributions a NCP researcher. For example, the study area of the provided InVEST sample data is located within the Willamette River Valley in Oregon. This sample area is situated within a more extensive study area of a previous InVEST study conducted by Nelson *et al* in 2009. The study named ten contributing authors, many of whom are key NCP researchers and contributing authors to the InVEST documentation.

Researchers associated with the Natural Capital Project (NCP), the creating organization of InVEST, have published almost all of the studies that use InVEST as an analytical tool. Heather Tallis, Gretchen Daily and Erik Nelson have been listed as primary or secondary authors in most of the studies that used InVEST. Tallis is the Lead Scientist for the NCP and the chief editor of the InVEST documentation, Daily is one of five directors of the NCP and Nelson was a contributing author for the InVEST documentation. Throughout these studies, InVEST has typically been applied to the Pacific Northwest of contiguous United States.

Research in the Eastern Arc Mountains of Tanzania, used InVEST for a 2011 study, and none of the core InVEST individuals worked on the project. However several of the authors of Fischer *et al*, 2011 previously worked with many of the key NCP researchers on the earlier Nelson *et al*, 2009 paper. A detailed assessment of all of the available documentation of studies using InVEST for analytics reveals no more than one degree of separation between the core NCP researchers and any study.

Alternatives to InVEST

InVEST may be the most comprehensive and detailed spatial ecosystem services assessment tool available. That said, it is extremely complex, and requires highly specific data that may be costly to create. Governments, large NGOs and the NCP team all have the funding and resources necessary to effectively utilize InVEST. For smaller projects that need to be completed quickly or remotely, there are other alternatives. MARXAN was developed at the University of Queensland in Australia. It is an example of a conservation planning software which can be applied to ecosystem service analysis. Heather Tallis has published multiple studies using MARXAN outputs including, *Linking Terrestrial and Marine Conservation Planning*

and Threats Analysis in 2008 and her dissertation, *Human impacts on the coupling of terrestrial and marine ecosystems* in 2006. Many key NCP individuals have also published research using MARXAN. Unlike InVEST, MARXAN does not have a graphical user interface, which means it can interface with a multitude of GIS packages, both commercial and open source. MARXAN generalizes data to greater extent than InVEST resulting in easier application across broader study areas.

Conclusion

InVEST has the potential to develop in to a very powerful and useful tool. The valuation component of InVEST is a fairly new concept that has had incredible implications to the conservation world. However, this component of each model tends to be the most frequent to malfunction; until this is fixed InVEST cannot realize its full potential. It is vital for conservationist to continue pushing the idea of ecosystem services. Further development of technologies will strengthen the conservation argument; identifying services provided by natural systems as economic benefits translates in to a concept better understood, and accepted, by the general public.

Use of the current Beta release of InVEST 2.1 to answer the specified research question was moderately successful, the final results had the potential to be much more thorough through the use of additional models and deeper analysis. The results of this sample study are not comprehensive enough to be applied in a real world setting with real world implications. The findings of this paper are that researchers outside of the NCP network would be limited in their effective use of the current InVEST software package and their application of results.

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