Partners with Nature:

Developing Scenarios for Ecosystem Services and Resilience in the Greater Portland Region

by

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Executive Summary

Human life depends on the services provided by healthy ecosystems. Ecosystem services are defined as all of nature's direct and indirect contributions to human wellbeing. Practices and frameworks for working with nature to enhance its flows of services include permaculture, agroecology, ecological forest management, ecological design, and green infrastructure.

Portland-area efforts to manage for flows of ecosystem services include the work of numerous public and private individuals and organizations. These efforts are engaged at multiple geographic scales within and around the Portland urban and peri-urban region. Based on an examination of these efforts, and seeking to better understand the potential to bolster personal, social, and natural resilience through management for ecosystem services, we framed a set of scenario-based questions for exploring the region's potential for three services: carbon sequestration, stormwater interception, and food production.

These questions are:

- What percentage of the region's climate change commitments could be met through biological sequestration?
- What percentage of the city's stormwater management commitments could be met via green infrastructure?
- What percentage of the region's food needs could be satisfied with regional production?

Each question depends on assumptions about social goals and indicators of progress. Each also necessitates a consideration of system boundaries, and involves several types of analysis, not all of which were we able to evaluate within the scope of this project.

For carbon sequestration, we examined current carbon storage and new sequestration potential in stream-side riparian buffers at the scale of The Intertwine Alliance regional boundary, and new sequestration potential in the urban forest canopy within the city of Portland. We did not assess the potential of other forest and land management in the peri-urban Intertwine area. For stormwater interception and infiltration, we examined the additional potential for tree planting in the urban canopy at the scale of the City of Portland combined sewer system, but did not assess the additional potential of other public and private management options such as bioswales, ecoroofs, downspout disconnections, and rain gardens. For food production, we examined the landscape potential to satisfy regional needs from agricultural production in the tri-county Clackamas, Multnomah, Washington area, but did not assess the potential of community gardens or other production from within urban areas. Nor did we consider the availability of farming inputs. Each of these management actions — in riparian zones, the urban canopy, and regional food systems — has significant co-benefits.

Based on plausible scenarios for working with nature, we developed the following estimates: New carbon sequestration in the region's riparian areas and urban forests could sequester 485,472 metric tons of CO_2 per year by 2050, meeting 2.1 percent of Oregon's greenhouse gas reduction targets on a current per capita basis. Stormwater interception by new urban forest canopy could meet 6.3 – 14.8 percent of city's projected infrastructural needs by 2040. We found no specific targets for regional food production to satisfy regional demand, and based on a preliminary analysis of landscape suitability, we estimated that the region could supply current regional consumption for most crop categories, with the exception of meat products. These findings are based on numerous assumptions, which we describe in this paper.

Table 1: Three scenarios of management for ecosystem services

Management activity	Estimated primary benefits
CO_2 sequestration in new Intertwine-region riparian growth and new Portland urban canopy	2.1% of Oregon's 2050 greenhouse gas reduction target, on a current per capita basis
Stormwater interception by new Portland urban canopy	6.3–14.8% of projected infrastructural needs by 2040
Regional food production to meet regional demand	Satisfaction of demand for most crop categories, with the exception of meat products

By definition, these findings are partial and exploratory, and this exercise is as much about framing questions as it is about arriving at quantitative estimates. Each of these scenarios could be re-considered within a participatory or planning context, under differing assumptions or more detailed projections for climate, population, and other anticipated changes. Place-based scenario development can support deliberation on shared goals and the cultivation of practices for working with nature and bolstering resilience.

Introduction

Human life depends on the services provided by healthy ecosystems. As described in the Millennium Ecosystem Assessment, these services include the provisioning of resources such as food, fiber, and raw materials; regulating services such as water filtration, storm buffering, and climate stabilization; supporting services such as soil formation, photosynthesis, and pollination; and cultural services that are spiritual, aesthetic, and recreational (MEA 2003).

Human activities can impede ecosystem functions, thereby reducing flows of services. The impervious pavements of built environments impair watershed function, thereby diminishing services such as fish abundance and provision (Booth et al. 2004). Prioritizing for production or harvest of a single ecosystem commodity, such as food or fiber, can diminish other services such as erosion prevention or soil formation (Franklin 2001; NRC 2010), as well as undermine overall ecosystem resilience (Holling 1995).

Conversely, approaches to working *with* nature can be developed to enable, rehabilitate, and restore ecosystem functions. Designs for on-site stormwater interception and infiltration can effectively reduce the imperviousness of built environments (Condon 2010:140-160; EPA 2012a). Food production techniques can maintain or improve yields while bolstering species richness and abundance, enhancing soil fertility, and increasing carbon sequestration (Pretty et al. 2005; Batary et al. 2010). In the Pacific Northwest, restorative forestry can effectively provide timber harvests while supporting other ecosystem services (Davies 2011). Practices and frameworks for working with nature to improve ecosystem functions, increase flows of services, and bolster the resilience of coupled social-ecological systems include permaculture, agroecology, ecological forest management, ecological design, and green infrastructure (Van der Ryn & Cowan 1995; Holmgren 2002; Martinez 2003; Walker & Salt 2006; Davies 2011; Farley et al. 2011).

Much research has been devoted to economic valuations of un-priced ecosystem services, so as to enable incorporation of these values into the cost-benefit analyses that inform public management decisions (TEEB 2010). Such analyses offer one way of making ecosystem benefits more tangible to decision makers, yet as Millennium Ecosystem Assessment director Walter Reid described in 2011:

> We still don't have enough examples where decision makers — county, state, or federal government officials or corporate CEOs, for example — have used an ecosystem service analysis to come to a decision they wouldn't have come to otherwise (Asquith 2011).

In addition to cost-benefit valuations, other research approaches might support public and stakeholder deliberations of the social, economic, and environmental considerations at the heart of management tradeoffs, or support public engagement in practices for working with nature and cultivating resilience (Allen et al. 2011). Ecotrust's own experiences, including the development of spatial and economic analyses that have been used to facilitate participatory, scenario-based, multi-objective marine planning deliberations (Scholz et al. 2011), lead us to seek to better understand these types of research questions and public engagement processes.

Accordingly, we developed a set of scenarios to explore the potential for meeting social goals through management for ecosystem services across the greater Portland region. The regional context of urban and surrounding peri-urban areas is significant for a variety of reasons. In an urbanizing world, the urban environment is, for a majority of people, the place where interactions with nature begin. Many cities across the United States are exploring the advantages of green infrastructure, such as bioswales, in reducing burdens on aging sewer systems. In addition, a growing interest in local foods has facilitated the development of connections across rural-urban boundaries and jurisdictions.

We focused on three services of significance to the rural-urban context: carbon sequestration, stormwater interception, and food production. Our questions are:

- What percentage of the region's climate change commitments could be met through biological sequestration?
- What percentage of the city's stormwater management commitments could be met via green infrastructure?
- What percentage of the region's food needs could be satisfied with regional production?

Each question requires assumptions about social goals — as well as an examination of the ways in which social goals, indicators, and target metrics are formulated, engaged, monitored, and enforced through formal and informal institutional relationships.

On carbon sequestration, we followed the climate change mitigation goal formulated by the Oregon Governor's Advisory Group, which set greenhouse gas emissions reduction targets to 75 percent below the state's 1990 levels by 2050 (Oregon DOE 2004). Washington and Portland have each developed similar emissions reduction targets, the former of 50 percent below the state's 1990 levels by 2050, and the latter of 80 percent below the city's 1990 levels by 2050.

On stormwater management, we followed the projection of Portland's Bureau of Environmental Services that, in order to keep the city's combined sewage overflows to a minimum and protect water quality in the Willamette River and Columbia Slough, new infrastructure, grey or green, capable of handling an additional 2.2 billion gallons annually by 2040 will be required to accommodate population growth and other factors (BES 2007).

On food, we followed the 2008 Institute of Metropolitan Studies food system report (Martin et al. 2008) and the 2010 Multnomah Food Action Plan (Multnomah County Office of Sustainability 2010), each of which solicited broad input and partnership, in considering social goals for increased consumption of local and regional production. The Multnomah Action Plan recognized that "only a small portion of the food consumed in Multnomah County is grown in our region" and did not include a target for such satisfaction. On a national scale, a 2005 estimate by the W.K. Kellogg Foundation Food and Society Initiative pegged the consumption of "good food" — initially defined as "healthy, fresh, and local" and later as "healthy, fair, green, and affordable" — at two percent and their target at 10 percent (Anderson et al. 2009). In lieu of a clearly formulated social target, we simply evaluated the biophysical suitability of the regional landscape to satisfy current regional consumption.

Based on these assumed social goals and targets, we examined three cases of public-private engagement of management for ecosystem services in the greater Portland urban and peri-urban region that have contributed to meeting these targets:

- The experiences of Washington County district utility Clean Water Services, the Tualatin Soil and Water Conservation District, and other partners in working with private landowners to develop a program for planting trees and shrubs in riparian areas along the Tualatin River;
- The experiences of the City of Portland's Bureau of Environmental Services, Portland Parks & Recreation, Friends of Trees, and other partners in developing programs to steward and extend the urban forest canopy on public and private lands throughout the city, and to manage for stormwater on public and private lands within the combined sewer system boundary; and
- The experiences of Clackamas County's economic development team, supported by Cogan Owens Cogan, Ecotrust, and others in developing programs to support business opportunities in the county's agricultural sector.

The programs led by Clean Water Services and Bureau of Environmental Services have been cited as exemplary of their kind (Ervin et al. 2012). The program led by Clackamas County is, in 2012, newly developing and is a notable example of strategic foodshed planning and engagement.

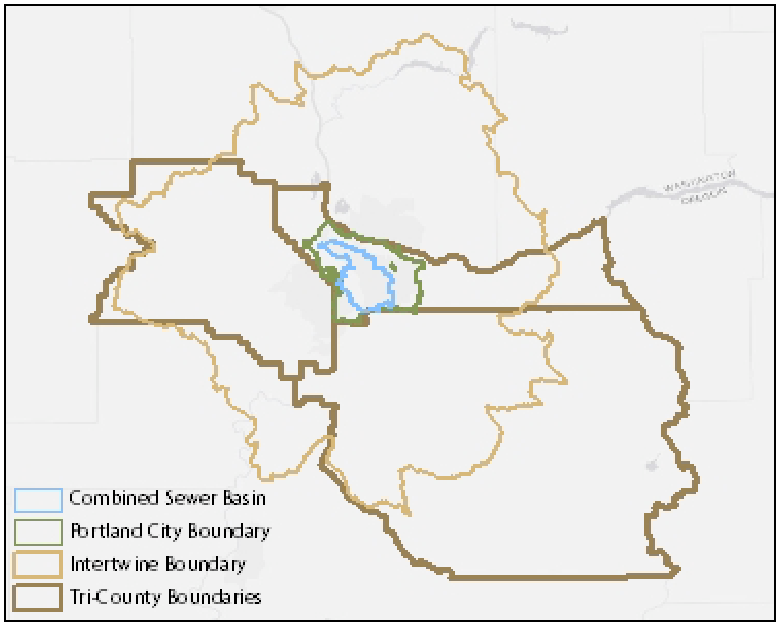
Management for carbon sequestration and stormwater interception each offers potentially significant co-benefits, including reduced stream temperatures in riparian areas and improved air quality in urban areas. Greater satisfaction of regional food consumption, however, does not, in and of itself, ensure improved management for other ecosystem services, such soil fertility, water filtration, or pollination. Accordingly, some researchers have described preferences for local purchasing as a "local trap" (Brown & Purcell 2005; Born & Purcell 2006). We posit that these goals for local and regional food production are best understood as reflecting a resilience perspective, including the propositions that it can bolster agricultural viability against land development and other pressures, improve food security, improve feedback between producers and consumers, increase diversification of agricultural portfolios, support small and mid-sized farm ownership, and increase food system modularity, thereby reducing overall vulnerabilities to the impacts of climate change, resource depletion, and other uncertainties (Vynne et al. 2011; Ecotrust 2012).

Each of these scenarios necessitates a consideration of system boundaries, and involves several types of analyses and land classes, not all of which are we able to evaluate within the scope of this partial and exploratory examination. Our three scenarios are summarized in table 2 and our spatial extents in figure 1.

Table 2: Scenarios of regional potential for three services

	Carbon sequestration	Stormwater interception	Food production
Assumed social goals	Climate change mitigation	Improved water quality in Willamette River and Columbia Slough	Greater satisfaction of regional food consumption
Assumed targets	75% below 1990 levels by 2050 (Oregon DOE 2004)	2.2 billion additional gallons by 2040 (BES 2007)	None (Martin et al. 2008; Multnomah County 2010)
Scenario activities / land classes	(1) Riparian areas (2) Portland urban tree canopy	Portland urban tree canopy	Agricultural lands
Regional experiences and examples	(1) Clean Water Services and partners (2) Bureau of Environmental Services and partners	Bureau of Environmental Services and partners	Clackamas County and partners
Scenario boundaries	(1) Intertwine region (2) City of Portland	Portland combined sewer system	Washington, Multnomah, Clackamas tri-county area
Not included activities/ land classes	Other forest and land management in the peri-urban Intertwine region; other urban canopies in the area	Bioswales, ecoroofs, downspout disconnections, rain gardens, etc.	Community and backyard gardens, etc.
Potential co-benefits	**Ecosystem services:** Filtration of nutrients and pollutants, reduced stream temperatures, etc.	**Ecosystem services:** Improved air quality (reduction in respiratory illness), reduced urban heat island effect (reduced energy use), etc.	**Resilience:** Improved agricultural viability, improved food security, increased diversification of agricultural portfolios, etc.

Figure 1: Spatial extents of four activities in three scenarios



Carbon Sequestration

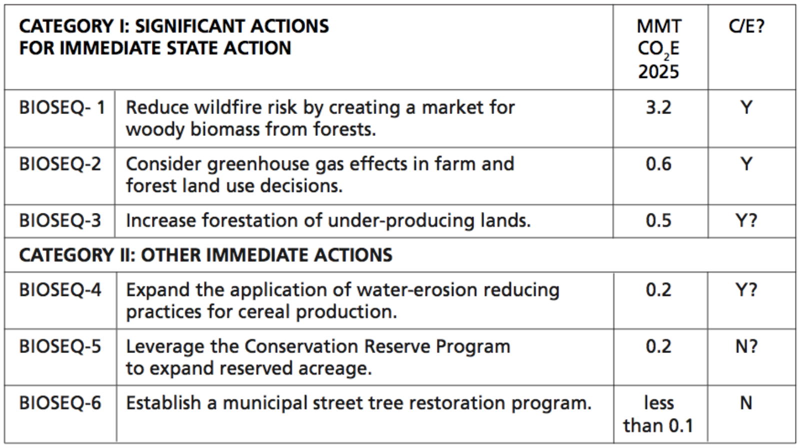
Background

Within the United States, Oregon has been a leader in developing programs for climate change mitigation. In 1993, Portland was the first city in the country to adopt a greenhouse gas reduction plan (Brooks 2005); and in 1997, Oregon enacted the country's first carbon regulations (Ecosystem Marketplace 2012). More recently, government-led working groups in Oregon, Washington, and Portland have all developed greenhouse gas reduction targets, based on 1990 baselines, of 75, 50, and 80 percent by 2050, respectively.

In order to understand potential contributions of forestland management to meeting these commitments, we examined tree planting as a carbon sequestration strategy in two land types in the urban and peri-urban Portland region: riparian areas and the city of Portland's urban canopy. For riparian areas, we selected The Intertwine Alliance Regional Conservation Strategy area as our spatial extent, as this boundary describes an area with significant potential for ecosystem service co-benefits, including reduced stream temperatures from riparian vegetation and citizen access to streams, parks, and natural areas. We are not able to evaluate the potential for new carbon sequestration in the region's forestlands, because this assessment would require knowledge about current management strategies for each ownership or management parcel.

Biological sequestration was listed as one of seven recommended action categories in the Oregon Strategy for Greenhouse Gas Reductions (Oregon DOE 2004). Each of the six activities in the Biological Sequestration Measures to Mitigate Greenhouse Gases section was ranked as having high or low significance (Oregon DOE 2004:91; figure 2). The two actions we examined in this paper are most similar to BIOSEQ-5 and BIOSEQ-6: "leverage the Conservation Reserve Program to expand reserved acreage" and "establish a municipal street tree restoration program." These two activities were evaluated as least significant among the six measures. However, they are both relevant to the Portland regional urban context and open to examination with available data.

Figure 2: Biological Sequestration Measures to Mitigate Greenhouse Gases and Evaluation of Cost Effectiveness (C/E) (Oregon DOE 2004:91)



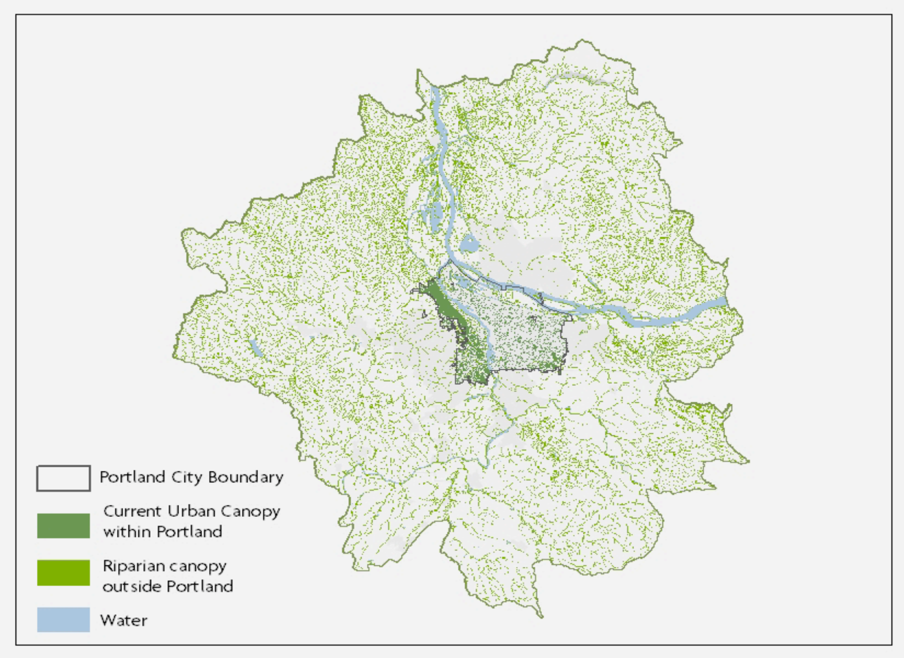
CATEGORY I: SIGNIFICANT ACTIONS FOR IMMEDIATE STATE ACTION		MMT CO_2E 2025	C/E?
BIOSEQ- 1	Reduce wildfire risk by creating a market for woody biomass from forests.	3.2	Y
BIOSEQ-2	Consider greenhouse gas effects in farm and forest land use decisions.	0.6	Y
BIOSEQ-3	Increase forestation of under-producing lands.	0.5	Y?
CATEGORY II: OTHER IMMEDIATE ACTIONS			
BIOSEQ-4	Expand the application of water-erosion reducing practices for cereal production.	0.2	Y?
BIOSEQ-5	Leverage the Conservation Reserve Program to expand reserved acreage.	0.2	N?
BIOSEQ-6	Establish a municipal street tree restoration program.	less than 0.1	N

The U.S. Department of Agriculture (USDA) Conservation Reserve Program provides multi-year payments to agricultural landowners that establish long-term, vegetative covers on eligible farmland. In the Tualatin basin, Clean Water Services led the development of an Enhanced Conservation Reserve Program as part of meeting Oregon Department of Environmental Quality regulations for stream temperatures through riparian planting, with carbon sequestration as a co-benefit. The rural portion of the program was developed with "extensive farmer input" (Oregon DEQ 2007) and managed by the Tualatin Soil and Water Conservation District, whose board was made up entirely of farmers and small woodland owners (Cochran & Logue 2011). From 2004 to 2008, the project engaged rural and urban landowners in planting 31 miles of stream front (Cochran & Logue 2011).

Based on the recommendations of the Oregon Strategy for Greenhouse Gas Reductions and the experiences in the Tualatin basin, we explored the planting of riparian areas within the peri-urban Intertwine region as a plausible scenario. In our analysis, we took carbon sequestration as the primary goal and considered reduced stream temperatures as a potential co-benefit, whereas the Tualatin basin program focused on stream temperatures as the primary goal.

For the urban canopy, we followed City targets for urban forest expansion by land use type set by the 2004 Portland Bureau of Parks and Recreation (PPR) Urban Forestry Management Plan and adopted in subsequent reports (PPR 2007; BPS 2010). Meeting these targets would extend the urban canopy from 24,118 to 30,566 acres, an increase of roughly 26.7 percent in canopy coverage from a current land cover of 26 percent of the city to 33 percent (PPR 2007:24). Civic organizations that have partnered with the City to lead tree-planting efforts include Friends of Trees, the Community Watershed Stewardship Partnership, and the Columbia Slough and Johnson Creek watershed councils, among others (BPS 2010:11).

Figure 3: Current riparian and urban canopies in the Intertwine and Portland areas



Riparian Area Methods and Findings

In order to assess potential carbon sequestration of planted riparian buffers, we calculated two values: (1) current carbon stored within riparian zone vegetation, and (2) carbon storage in five-year increments for possible planting scenarios and various vegetation types. The difference between these two values represents the potential for future carbon sequestration.

In order to calculate these values, we followed these steps:

1. Identify the riparian corridor buffer zones to be analyzed based on Natural Resources Conservation Service-recommended buffer widths for Portland-area mapped streams (Washington County SWCD 1999)
2. Determine the current vegetative cover for the areas within the identified buffer zones and the corresponding current carbon storage value;
3. Describe the future trajectory for each vegetative cover class, based on estimated growth curves; and
4. Estimate the total volume of carbon stored per acre for each different vegetative cover type, using USDA Forest Service Forest Vegetation System (FVS) modeling scenarios and/or estimated growth curves based on Forest Service permanent plot data (Forest Inventory Analysis).

We reviewed the existing literature from the Army Corps of Engineers and the Natural Resources Conservation Service (NRCS) to identify recommended buffer widths for the Portland region. NRCS riparian buffer recommendations vary from 35 to 300 feet on each side of the stream, based on the resources targeted for protection, the local topography, the type of buffer to be planted, and local ecological conditions (Washington County SWCD 1999). General NRCS guidance indicates that a 100-foot buffer will provide for co-benefits such as bank stabilization, reduced sediment load, aquatic habitat, terrestrial habitat, and removal of excess nutrients. Accordingly, we took 100 feet as a maximum buffer and made a further distinction between the types of species we would expect to see growing in each of two zones: smaller hardwoods, such as willow, dogwood, and hawthorn, in the first 30 feet and larger conifers in the 30-100-foot zone. In comparison, the buffers planted by the Clean Water Services-led project averaged roughly 70 feet on each streamside (Cochran & Logue 2011).

We used LiDAR vegetative cover data[*] and average carbon values by age class and species to estimate the carbon stored in riparian areas across the Intertwine region. These maps categorize the landscape into several cover types, based on species groups and canopy heights. Taking height as a proxy for age, we made age class assumptions for each species. For non-forested zones we assumed that current carbon storage was effectively zero. For forested areas, we relied on existing Forest Service regional data to estimate total carbon stored per acre, in metric tons of carbon dioxide equivalent (tCO_2e). We queried the Forest Service Carbon On-Line Estimator (COLE) to summarize per acre carbon totals from above and below ground biomass of standing dead and live trees grouped by species predominance: predominantly coniferous species ("Douglas-fir Group") or predominantly hardwood species ("Alder/Maple Group"). This data provided us with carbon volumes based on age classes ranging from 10–300 years. With the most recently available data (2009), we estimated current carbon storage at 21,053,459 metric tons of CO_2e, across an existing canopy of 114,940 acres.

We then used age class data to establish starting points for carbon storage curves for these forests as they grow. We assumed new tree plantings would take place over a twenty-year period, with a quarter of the plantings in each of four five-year periods. In sum, we estimated 67,117 newly planted acres, and another 72,162 acres in the riparian zone that are considered developed or otherwise not plant-able. We used regression analysis to fit a logarithmic curve to the sampled data points that estimate the carbon stored in any given age class over time. We assumed no harvesting or cutting of the trees and annualized the data to provide an average annual storage of

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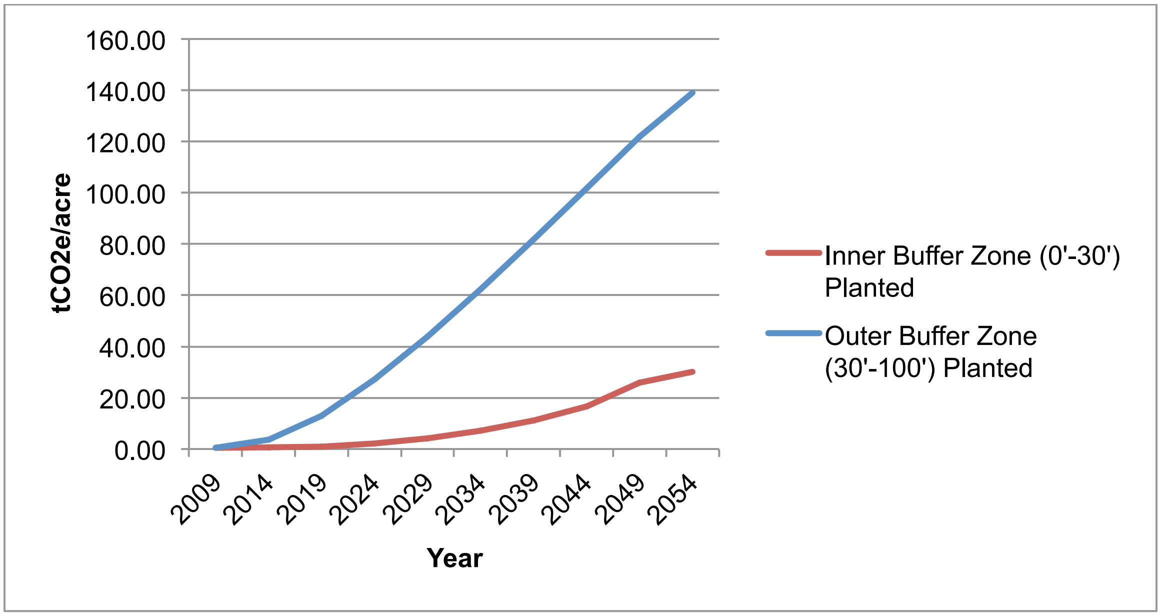
[*] We obtained LiDAR vegetative cover data from The Intertwine Alliance. Land cover classes were derived from 5 meter LiDAR data of various acquisition dates ranging from 2002–2009. The data is being further refined by The Intertwine Alliance, and is considered the best current regional vegetation proxy available.

carbon dioxide equivalent for each age class of coniferous or hardwood species on a per-acre basis. We then applied these numbers to each pixel within the riparian buffer zones (30 and 100 feet) to calculate potential carbon storage scenarios. In order to avoid double counting of riparian areas, we masked the city of Portland out of our riparian analysis. With this conservative approach, we implicitly assumed that plantings on public lands in urban riparian areas would be accounted for in urban canopy expansion targets and implicitly discounted potential plantings on private lands in urban riparian areas. Cumulative trends for carbon stored in newly planted riparian areas are shown in figure 4 and annual carbon sequestration in figure 5.

Figure 4: Estimated cumulative carbon storage potential in newly planted Intertwine-region riparian zones



Urban Area Methods and Findings

The inventory in the report on Portland’s Urban Canopy (PPR 2007) was based on a field sample of park and street trees, followed by a comparison with a 2002 satellite image, to arrive at a full urban forest canopy coverage, estimated through the i-Tree software (Karps personal communication). The report listed totals for street trees and park trees as 236,521 and 1,233,790, respectively (PPR table 3-1); figures for trees on private (residential and commercial/industrial) lands were not included. We extrapolated from the report, as well as from High Resolution Landcover data that was unavailable at the time of its publication*, to derive a total estimate of Portland’s urban tree population.

We examined three methods of extrapolating a figure for private trees, as follows:

1. Based on final inventory numbers for public (park and street) trees of 1,470,311 (PPR table 3-1) and public canopy cover of 11,404 acres (PPR table 3-7), we estimated canopy coverage at 31.4 square meters per tree. Assuming similar canopy coverage per tree for private trees and based on private canopy acreage of 12,714 acres (PPR table 3-7), we estimated the private tree population at 1,639,208. An alternative figure of 36 meters of canopy coverage per tree

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* We obtained 2007 High Resolution Landcover data for existing tree canopy from Portland Bureau of Environmental Services. Data was developed by Metro from Metro Photo Consortiums 2007 six inch color infrared orthophotos. The classification was performed using radiometric, texture, and geometry based classification methods at a cell size of 3x3 feet.

(for street trees), cited in the report on Portland's Green Infrastructure (Entrix 2010:3-3), would instead put the total private tree population at 1,429,215.

2. Based on the estimate of total urban forest carbon storage of 1,534,208,970 pounds (PPR table 5-5), and total park and street tree carbon storage of 562,639,777 and 158,438,439 pounds, respectively (PPR table 5-2), we derived total carbon storage for private trees. Based on the assumption that carbon storage for private trees falls within the range between 456 pounds per tree for park trees and 670 pounds per tree for street trees (PPR table 5-2), we estimated the total number of private trees from 1,213,628 to 1,783,181.
3. Based on High Resolution Landcover data for high structure vegetation unavailable to either the PPR or Entrix reports, we estimated the total urban canopy at 27,229 acres, versus the estimate of 24,118 by PPR (table 3-7). Using the low and high figures of 31.4 and 36 square meters per tree, we calculated the total number of trees and, subtracting the PPR figures for public trees, estimated the total number of private trees at between 1,590,574 and 2,038,984.

Given these three ranges — 1,429,215 to 1,639,208; 1,213,628 to 1,783,181; and 1,590,574 to 2,038,984 — and our need to simplify this analysis, we followed our first method above to establish 1,639,208 as our working estimate of private trees. Adding in public trees as inventoried by PPR we calculated 3,109,519 as the current total for all trees in Portland's urban canopy. Based on current and target acreages shown in PPR table 3-7, we calculated the targets for total target and total additional trees, as shown in table 3. The assumptions described above are significant, and these figures should be understood as estimates for the purpose of the current analysis.

Table 3: Estimated tree inventory for Portland's urban canopy

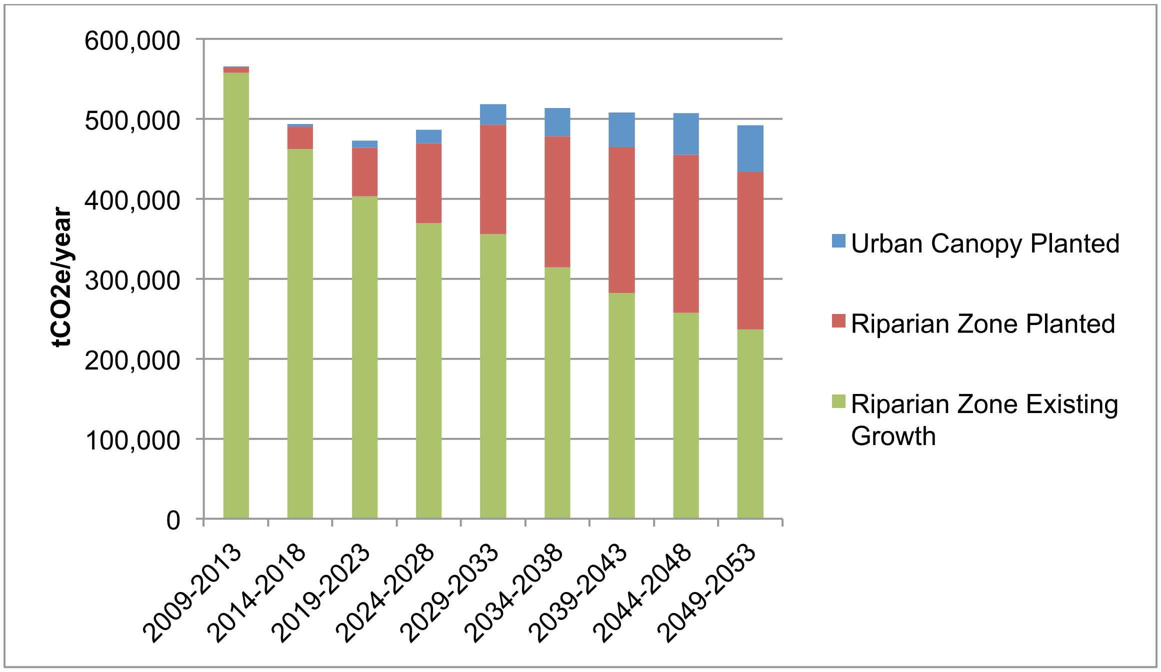
Public trees	1,470,311
Private trees	1,639,208
Total trees	3,109,519
Total target trees	3,940,856
Total additional trees	**831,337**

According to the USDA Forest Service Center for Urban Forest Research (CUFR), the CUFR Tree Carbon Calculator is the only tool approved for calculating carbon credits under the Climate Action Reserve Urban Forestry Protocol v1.1 (USDA 2012b), and we used this tool to calculate carbon sequestration in urban trees. CUFR is also the developer of the STRATUM (Street Tree Resource Assessment Tool for Urban Forest Managers) model, which powers the i-Tree Streets tool.

We calculated carbon sequestration rates by species and age class for the top ten most "important" street and park tree species, as defined in Portland's Urban Canopy Report (PPR 2007:17). The top ten species represent 47.2 percent of the current street tree population and 86.7 percent of the current park tree population. To estimate carbon sequestration rates for species not included in these top ten lists, we averaged the lowest five carbon sequestration rates of the top ten for each of these two categories and used this conservative figure as an estimate for the rest of the population. Based on this method, we derived an average carbon sequestration rate for new street trees of 5.4 pounds of carbon per year, from the first period after all trees have been planted up to 2050, and a single carbon sequestration rate of 8.2 pounds of carbon per year in 2050. These figures are conservative as compared with the sequestration rate of 46 pounds of carbon per year listed for street trees in PPR table 5-2. Based on this method, we derived a current urban canopy carbon stock of 2,507,682 metric tons, which is similar to the 2,551,215 metric tons listed in PPR table 5-5.

We assumed that new street and park trees would follow the same species percentages as the current population and assumed that species percentages for new private trees would be similar to that of street trees. In using the CUFR tool to create growth curves, we implicitly assumed that all trees would grow as urban trees rather than natural forests. Based on the target expansion of park trees from 28 to 30 percent of developed parks and open spaces, a City of Portland urban land environment (ULE) class, we calculated the target number of new park trees at 88,128, and therefore the target number of new street and private trees at 743,209. With these land class figures and age class totals, we then fit regression curves to create a carbon storage curve in five-year increments. We assumed an ambitious program of new tree plantings that would begin in 2012 and take place over a twenty-year period, with a quarter of the plantings in each of four five-year periods. We implicitly assumed stewardship and replacement of current trees at rates to maintain canopy coverage, in addition to the targeted canopy expansion. Annual carbon sequestration totals for riparian and urban areas are shown in figure 5.

Figure 5: Estimated potential for annual Intertwine-region riparian forest and Portland urban tree carbon sequestration rates



We normalized these findings on a per capita basis for the Intertwine-region population, which is currently reported as 2.1 million (The Intertwine Alliance 2012), in relation to Oregon's greenhouse gas reduction 2050 target of 41.86 million tCO_2e (Oregon DOE 2004; Oregon DOE 2010). In the 2010 census, Oregon's population numbered 3,831,074, which equates to a per capita emissions reduction target of 10.93 tCO_2e. Our findings are summarized in table 4.

Table 4: Estimated carbon sequestration potential from Intertwine-region riparian growth and Portland urban tree plantings

Riparian acres	254,220
New urban trees	831,337
Riparian CO_2 sequestration in growth of current stock (tCO_2e in 2050)	236,985
Riparian CO_2 sequestration in new plantings (tCO_2e in 2050)	196,374
Urban forest new CO_2 sequestration (tCO_2e in 2050)	52,113
Total CO_2 sequestration in new riparian growth and new urban canopy (tCO_2e in 2050)	**485,472**
Normalized per person in relation to target of 75% below Ore. 1990 emissions	**2.1%**

These two management actions in riparian areas and the urban canopy relate most closely to action numbers BIOSEQ-5 and BIOSEQ-6 in the Biological Sequestration Measures to Mitigate Greenhouse Gases section of the Oregon Strategy for Greenhouse Gas Reductions (figure 2, above; Oregon DOE 2004:91). Our finding of nearly 500,000 metric tons a year for the Intertwine and Portland areas is approximately double the statewide estimate for these two management strategies.

Valuation

Both the riparian and urban activities described in our scenario may be eligible for the sale of carbon credits. In order to qualify, these activities would have to meet specific standards as being “additional” to what would be required under current law as well as to business as usual management. We limit our analysis to street trees in the urban canopy, as an example of how valuations might be estimated.

We analyzed two market scenarios for the sale of carbon credits generated by urban street tree planting, 1) the voluntary market following the Climate Action Reserve (CAR) Urban Forest Project Protocol v1.1 (CAR 2010); and 2) the regulated market in California following the California Air Resources Board AB32 documentation for “Compliance Offset Protocol Urban Forest Projects” (California EPA 2011).

According to both protocols, offset projects are eligible on municipal, educational, or utility properties, but not on private lands. According to both protocols, municipalities that are interested in developing carbon offset projects can calculate the amount of carbon their tree planting programs will sequester above a baseline of “common practice,” which is defined as maintaining a stable tree population. Thus, as long as a municipality increases the total number of trees over time, it may be eligible for carbon offset credits for planting and maintenance activities. For each tree planted above this net zero threshold, the municipality must calculate the amount of carbon sequestered in that tree every year. From that amount it must subtract the amount of greenhouse gas emitted by vehicles and equipment used in planting and maintaining trees. In both protocols, municipalities that do not have records of these maintenance emissions may be able to use a default value of 4.17 kg CO_2e/tree planted/year, and we use this figure in our calculations.

The two protocols differ in their methods for calculating the additional carbon sequestered in planted trees above the baseline. The Climate Action Reserve Urban Forest Protocol v1.1 allows municipalities to calculate carbon stocks using the Forest Service CUFR Tree Carbon Calculator. Using this tool, we evaluated the additional annual carbon stored in 250,434 new street trees in five-year increments. We then subtracted the default emissions value of 4.17 kg CO_2e/tree planted/year to come up with an annual carbon credit total.

To determine an appropriate price for the sale of these voluntary credits (CRTs), we relied on an Amerex pricing report (dated Feb. 7, 2012), which quoted a 2012 price of \$8.75 per Climate Reserve Tonne (CRT) for forestry projects following the CAR system (Amerex 2012). The carbon credits, in metric tons of CO_2e, and annual revenue generated under these assumptions are shown in the table 5.

Table 5: Estimated revenue from sale of voluntary credits under Climate Action Reserve Urban Forest Protocol v1.1

Years	Additional annualized CO_2 from street tree planting (tCO_2e)	Annualized revenue
2012–2016	-52	(\$457.59)
2017–2021	431	\$3,768.71
2022–2026	1,521	\$13,307.55
2027–2031	3,235	\$28,310.15
2032–2036	5,615	\$49,130.86
2037–2041	8,042	\$70,369.35
2042–2046	10,405	\$91,039.94
2047–2052	12,637	\$110,574.65

The AB32 Regulations require a different approach for calculating carbon stored in trees and provide equations for numerous commonly planted species as well as a default value for a typical “hardwood” and “softwood” species (California EPA 2001:38). Since not all species types to be planted in Portland are represented on this table and to simplify our calculations, we assumed planting of hardwood and softwood street trees would follow current hardwood/softwood ratios for street trees within the city, and we calculated additional annual carbon sequestration using equations found within the protocol. We then subtracted the default emissions value of 4.17 kg CO_2e/tree planted/year to come up with an annual carbon credit total for five-year increments.

To determine an appropriate price for CCOs (California Carbon Offsets), we relied on the most current bid price on the Karbone pricing report (Feb. 28, 2012), \$10/CCO (Karbone 2012). The total revenue generated under this method is provided in table 6.

Table 6: Estimated revenue from sale of voluntary credits under AB32 Compliance Offset Protocol Urban Forest Projects

Years	Additional annualized CO_2 from street tree planting (tCO_2e)	Annualized revenue
2012–2016	217	\$2,172.96
2017–2021	2,002	\$20,021.46
2022–2026	5,536	\$55,364.03
2027–2031	11,125	\$111,254.48
2032–2036	18,707	\$187,071.55
2037–2041	26,428	\$264,284.85
2042–2046	34,563	\$345,629.73
2047–2052	42,423	\$424,228.86

Co-benefits

Trees provide numerous ecosystem services, and the riparian and urban activities described here would, in addition to carbon sequestration, offer multiple benefits.

In riparian areas, potential co-benefits include stream bank stabilization, reduction of stream temperatures, filtration of nutrients and pollutants, and habitat for animals. The need to reduce stream temperatures provided the regulatory impetus to the Tualatin basin experiences described above. Although completing an analysis of the additional stream temperature benefits of the riparian activities in our scenario is beyond the scope of this paper, we describe here some basic calculations. Taking the annual thermal credits achieved in the Tualatin example and calculating on a per-acre basis, we found that, based on variable factors such as stream width, riparian activities offered temperature reductions that were evaluated between a range of 0.28 and 1.01 million kilocalories per acre (Cochran & Logue 2011). Extrapolating from this range to our scenario acreage for The Intertwine Alliance boundary, we estimated that total temperature reductions across 67,117 acres of new plantings would be in the range of between 18,793 and 67,788 million kilocalories per day. For comparison, the Tualatin basin partners sought to offset 895 million kcal/day from the Rock Creek and Durham advanced wastewater treatment facilities (Cochran & Logue 2011).

In urban areas, potential co-benefits of tree planting include food for people and habitat for animals. Studies specific to the Portland region have found:

- Improved air quality: 300g of pollutants removed per urban tree, per year — carbon monoxide (18g/year), nitrogen dioxide (32.4g/year), ozone (129.6g/year), PM10 (93.6g/year), and sulfur dioxide (25.2g/year) (Entrix 2010:3-3).
- Reduced respiratory illness: 18 percent reduction, based on pollutants removed by urban trees and shrubs (Entrix 2010:3-3).
- Reduced summer temperatures: 0.65°F reduction in peak summer temperatures, with a 10% increase in vegetation (Entrix 2010:4.5).
- Reduced energy demand: 11 kWh/year reduction in annual energy demand per yard tree, for houses using air conditioning in two summer months (Entrix 2010:4-7).
- Increased home values: over $8,500 average additional value to the sale price for a street tree, based on July 2006 – April 2007 home sales in eastside Portland (Donovan & Butry 2010).

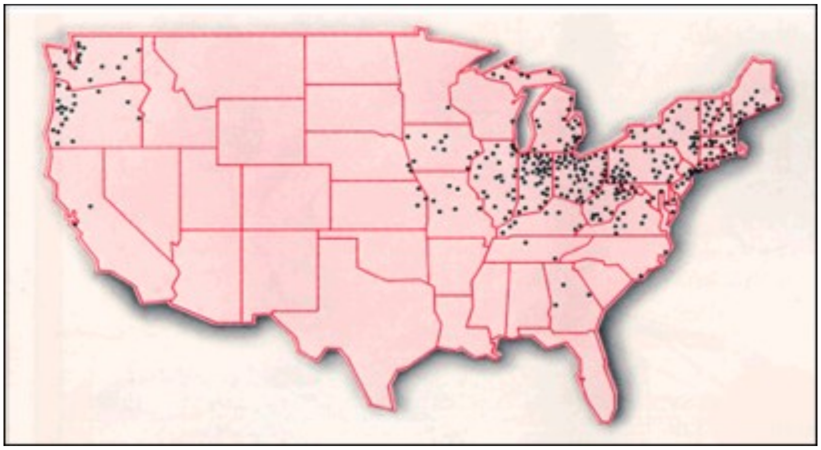
In addition, studies of urban trees, parks and natural areas outside the Portland region have found: improved mental and emotional health (Ulrich 1984; Weinstein et al. 2009), improved community cohesion and lower crime (Kuo 2003; Sullivan et al. 2004), and increased pedestrian use (Moudon et al. 1997).

Stormwater Interception

Background

Portland's stormwater management commitments are fundamentally driven by hydrology and infrastructure. The city receives an average of 37 inches of rainfall every year, 80 to 90 percent of it in small, infrequent storms that can burden the city's combined sewer system (City of Portland 2006). The combined sewer system serves roughly 34 percent of the city's land area, and this area drains an estimated 8.6–8.9 billion gallons of stormwater annually (BES 2007:8; Vizzini personal communication). The U.S. Environmental Protection Agency estimates that combined sewer systems serve 772 communities containing about 40 million people around the country (EPA 2012b), as shown in figure 6.

Figure 6: EPA map of combined sewer systems around the U.S.



In the 1970s, an estimated 10 billion gallons of stormwater and sewage overflowed into the Willamette River and Columbia Slough each year (BES 2011a:62). By 2011, with the completion of the $1.4 billion "big pipe" suite of projects, this overflow had been reduced to minimal levels. Meanwhile, infrastructure costs have contributed to escalating water bills, and the stormwater utility user fee for a typical Portland household has gone up an average of 11 percent annually since the late 1970s (BES 2011a:17).

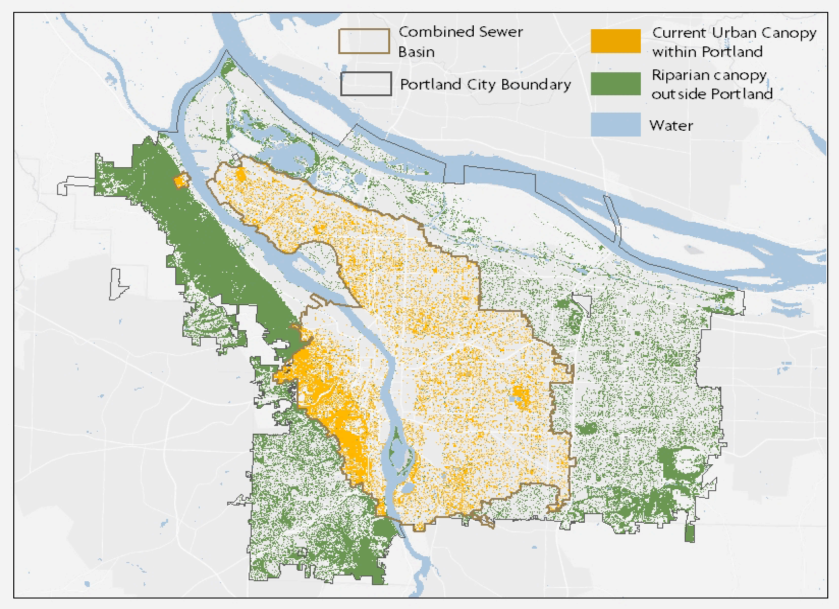
Population growth and increasing density will increase the burden on the city's combined sewer area. The Portland Metro regional government projects that by 2035 the city's population will increase 44 to 57 percent, to between 345,000 and 376,000 (BPS 2011:2); and Portland's Bureau of Environmental Services estimates that by 2040 an additional burden of 2.2 billion gallons will be placed on the combined sewer system (BES 2007:8). In order to keep combined sewer overflows to a minimum and maintain federal Clean Water Act compliance, this additional burden will need to be handled through additional grey or green infrastructure. We are not aware of the extent to which the potential adoption of living building systems such as grey-water reuse was factored into BES projections; such non-traditional grey infrastructure could also mitigate the projected stormwater burden.

Additional green infrastructure that might be developed to meet or alleviate this projected stormwater commitment include bioswale, ecoroof, and rain garden installations, tree plantings, and downspout disconnections. The effectiveness of each of these types of green infrastructure depends on factors of both hydrological-infrastructural suitability and social engagement and acceptance. Hydrological-infrastructural factors involve questions such as: What locations are suitable for what types of infrastructure and how might they perform there? Social factors involve questions such as: How do perceptions of green infrastructure and rates of adoption vary by neighborhood, land ownership, or other demographics? What types of engagement or incentives have been successful in promoting acceptance, adoption, and stewardship?

Programs led by Portland's Bureau of Environmental Services have been successful in implementing green infrastructure, engaging private landowner participation, and providing utility ratepayers with a lower-cost alternative to grey solutions. According to 2006 BES projections and recent estimates, roughly from 31 to 37 percent of current (2011) combined sewer area stormwater runoff is accommodated through green infrastructure interception and infiltration (BES 2007:8; Kurtz personal communication; Vizzini personal communication). The 1996–2011 BES downspout disconnection program worked with private landowners to partially or fully disconnect downspouts on over 56,000 properties and keep 1.2 billion gallons of annual stormwater runoff out of the combined sewer system. With a program investment of $10.6 million, the downspout disconnection program reduced grey infrastructure requirements by an estimated $240 million (BES 2011b). Another program, Tabor to the River, used a combination of grey and green infrastructures to achieve an estimated $63 million in savings over grey-only solutions (Bacchieri 2011). A Portland State University researcher-led evaluation of the Tabor to the River program found BES stormwater outreach and education efforts "effective" (Shandas et al. 2010).

In order to explore the potential to meet projected 2040 stormwater commitments through green infrastructure, we examined two scenarios for one type of green infrastructure: tree plantings. In these two scenarios, we (1) assumed a proportional increase in trees inside and outside the combined sewer boundary; and (2) as a comparison, assumed a weighted increase in trees to favor inside the boundary. The current urban canopy is shown in relation to the city's combined sewer area in figure 7.

Figure 7: Current urban canopy, inside and outside the combined sewer boundary



Methods and Findings

We based these canopy expansion scenarios on the potential 26.7 percent canopy acreage increase described in the report on Portland's Urban Forest Canopy (PPR 2007:24), and to get a more precise view of the canopy, utilized High Resolution Landcover data that was unavailable to PPR at the time. According to this data, the current canopy covers 27,229 acres, and with a 26.7 percent increase, we calculated an additional 7,270 acres.

In the first scenario, we assumed a proportional increase in canopy acreage inside and outside the combined sewer boundary. The High Resolution Landcover data shows this ratio of current canopy as 70.1 percent outside to 29.9 percent inside. Therefore, an analysis of additional stormwater interception based on these figures is similar to, but more conservative than, a proportional scenario based simply on acreage, in which the combined sewer area representation would be roughly 34 percent.

Based on two parameters, square meters per tree and interception per tree, we bracketed this scenario into four estimates of potential performance. For square meters per tree, we used the two estimates discussed in the carbon section: 36 and 31.4 square meters. For interception per tree, we used estimates of 572 and 1,162 gallons. The former is the 2007 PPR estimate, developed with the STRATUM model, of annual interception per tree for street trees. The report on Portland's Green Infrastructure found the 572 gallon figure to be conservative and estimated interception at 1,162 gallons annually (Entrix 2010:4-4). For comparison, the USDA Forest Service Center for Urban Forest Research Tree Guides provide other interception ranges. The guide for the Temperate Interior West estimated annual interception at from 142 gallons for a small yard or street tree to 1,390 gallons for a large one (Vargas et al. 2007:31), and the geographically overlapping guide for Western Washington and Oregon estimated interception at from 169 gallons for a small yard tree to 449 gallons for a large one (McPherson et al. 2002:28). For the stormwater analysis, we did not distinguish between species types or interception rates for street and park trees. We compared each estimate to the 2040 target projection of 2.2 billion gallons of additional infrastructure capacity, as shown in table 7.

Table 7: Estimated additional stormwater interception in 2040 through proportional urban canopy expansion

	Additional stormwater interception, assuming proportional increase of trees (outside-inside)			
	Assuming 572 gals. /36 sq. m. per tree)	Assuming 572 gals. /31.4 sq. m. per tree)	Assuming 1162 gals. /36 sq. m. per tree)	Assuming 1162 gals. /31.4 sq. m. per tree)
Outside combined sewer area (million gals.)	327.8	375.8	665.9	763.4
Inside combined sewer area (million gals.)	**139.7**	**160.2**	**283.8**	**325.4**
Total (million gals.)	467.4	536.0	949.7	1,088.8
As a percentage of 2040 target	**6.3%**	**7.3%**	**12.9%**	**14.8%**

In addition to carbon sequestration and stormwater interception, tree planting serves numerous social goals. For example, proximity to trees and parks has been found to improve air quality and increase home values (Entrix 2010:3-2; Donovan & Butry 2010). Thus, the draft Portland Plan lists among its 2035 objectives that tree canopy be more "equitably distributed" around the city (BPS 2011:63). Nevertheless, there are reasons to believe that our inside-outside proportional increase scenario may be overly conservative for calculations of potential stormwater interception. One factor is that current parklands are heavily weighted to the outside and are targeted with only 10.6 percent of the overall canopy increase, compared with greater increases for other land classes. In its evaluation of the City's Grey to Green imitative, the Portland's Green Infrastructure report assumed that 75 percent of new plantings would be inside the boundary (Entrix 2010:4-3). Therefore, we follow suit with a similar scenario for assumed canopy expansion targets: 75 percent within the combined sewer area. Such a scenario is strictly plausible, as our High Resolution Landcover analysis shows stocking potential to accommodate the increase, yet it is improbable and serves merely to describe an upper boundary for potential stormwater interception through newly planted trees. We show this weighted increase scenario side by side with the proportional increase scenario in table 8.

Table 8: Estimated additional stormwater interception in 2040 through proportional and weighted urban canopy expansion

	Additional stormwater interception							
	Assuming proportional increase (of trees outside-inside)				Assuming weighted increase (75% of new trees inside)			
	Assuming 572 gals. /36 sq. m. per tree)	Assuming 572 gals. /31.4 sq. m. per tree)	Assuming 1162 gals. /36 sq. m. per tree)	Assuming 1162 gals. /31.4 sq. m. per tree)	Assuming 572 gals. /36 sq. m. per tree)	Assuming 572 gals. /31.4 sq. m. per tree)	Assuming 1162 gals. /36 sq. m. per tree)	Assuming 1162 gals. /31.4 sq. m. per tree)
Outside combined sewer area (million gals.)	327.8	375.8	665.9	763.4	116.9	134.0	237.4	272.2
Inside combined sewer area (million gals.)	**139.7**	**160.2**	**283.8**	**325.4**	**350.6**	**401.9**	**712.2**	**816.5**
Total (million gals.)	467.4	536.0	949.7	1,088.8	467.4	535.9	949.6	1,088.7
As a percentage of 2040 target	**6.3%**	**7.3%**	**12.9%**	**14.8%**	**15.9%**	**18.3%**	**32.4%**	**37.1%**

Co-benefits

In addition to the co-benefits of tree planting described in the carbon sequestration section, using green infrastructure for stormwater management can reduce energy use by reducing the need to pump and treat stormwater. Based on a study of 2006–07 data for energy use of City of Portland operations by fuel type, the electricity consumed in stormwater management accounted for 17 percent of the City's total 948,486 million BTU energy use, and was the City's single most energy intensive activity by fuel type (Diesner & Williams-Rajee 2011). Thus, the benefits of green infrastructure for stormwater management can be evaluated, not only in terms of capital costs, but also in terms of potential savings on operations costs.

Food Production

Background

Throughout the 20th-century trend of food system industrialization, Americans developed social, political, and economic relationships that treated food as a mere commodity, akin to any other. Local planners seldom considered food systems within their purview, and federal approaches to urban issues were generally considered separately from those for rural areas (Pothukuch & Kaufman 1999; Gardner 2002; Sustainability Institute 2003).

In Portland, a dedicated focus on building rural-urban connections emerged among food system activists in the 1990s, with organizational leaders that included Portland Farmers Market, Food Alliance, Portland Chapter of the Chefs Collaborative, New Seasons Market, Burgerville, Kaiser Permanente, Ecotrust, and many others (Halweil 2004). The Portland-Multnomah Food Policy Council began its work in 2002.

In 2009, based on data from visionPDX surveys and other sources, the City concluded, "demand for (local food and urban agricultural) services is outstripping current supply" (BPS 2009). In 2010, the Multnomah Food Initiative and Action Plan brought together dozens of food activists and organizations around a set of principles, goals, and indicators for local food, healthy eating, social equity, and economic vitality (Multnomah County Office of Sustainability 2010). And in

2011, Clackamas County representatives initiated a process of local foodshed business development through an Agricultural Investment Plan.

Although diverse public and private individuals and organizations have embraced the social goal of greater regional food self-reliance, no Portland-area plan offers specific targets for regional satisfaction of regional demand. As such we perform this analysis purely as a landscape suitability exercise, in order to develop a baseline understanding of Portland-area foodshed potential.

A foodshed is a geographic region that provides food for a particular population, through formal and informal institutional relationships (Hemenway 2006). Since 2005, Ecotrust has developed a range of approaches to foodshed analysis. These analyses allow us to address questions such as: Could X region feed itself? What are the fewest number of proximate farmland acres required to feed X town or city?

Methods and findings

This analysis builds on Ecotrust's 2007 analysis of California's Ventura County, in support of the nonprofit Ag Futures Alliance (Mertens et al. 2007), as well as on recent work with the Institute of Metropolitan Studies at Portland State University, work with Clackamas County Economic Development and Business Services, and discussions with Multnomah County representatives. We selected the tri-county Clackamas-Multnomah-Washington area as our system boundary, and we selected the current 265,869 acres zoned for agriculture (i.e. "exclusive farm use" under state land use designations) within the tri-county area as our food production zone.

Our approach is based on matching potential production to current or potential consumption. In order to make this match, we calculated demand for specific food products as demand for the inputs of these products, which are generalized into broad crop categories. For example, we calculated demand for dairy products as demand for the inputs: grain, alfalfa hay, alfalfa or other silage, and pasture (Reed, 2004). Then we evaluated the landscape's capacity to support such demand in terms of these generalized crop categories.

Specifically, our process was as follows:

1. Based on the 2010 USDA National Farmland Mapping Program crop data layer (CDL) 30-meter data, we mapped and analyzed crops at the landscape-level for the tri-county area. We grouped 55 CDL classes into broad crop categories, following the crop definitions used in the Clackamas County Agricultural Investment Plan outreach survey, with slight variations. These categories are: grain, berries and grapes, hay, nuts, oil seeds, tree fruit, vegetables, pasture, and sod and grasses. Crops that cannot be grown in the study region, such as rice and citrus, we assigned to a category called "other." These groupings are shown in table 9.
2. Based on 2008 USDA Economic Research Service food consumption data (Putnam et al. 2000), we classified U.S. food consumption into the same broad categories, and based on 2010 population data, we calculated total demand by crop category for the 1,641,036 people in the tri-county region.
3. Based on average crop yield estimates from a variety of sources (British Columbia Ministry of Agriculture, Food and Fisheries 2001; North Willamette Research and Extension Center 2005; OAIN 2010; Sugar Knowledge International 2012) and on USDA CDL data for current numbers of acres of each crop category in production in the tri-county area, we calculated total potential regional productivity for each crop category.

4. Based on our totals for regional demand and productivity per crop category, we calculated the extent to which current potential regional production could meet current demand.
5. Based on USDA soil data, we developed a cost surface to distinguish among types of agricultural lands. When production fell short of demand for any crop category, we used a cost-distance analysis to assign additional production to currently fallow or pasture acres, based on proximity to current acres of the same crop category, and ran this analysis until demand was satisfied. This method results in a clustering of croplands.

Table 9: Crosswalk of USDA National Farmland Mapping Program crop data layer to our broad crop categories

CDL value	Crop name	Crop category
21	Barley	Grain
23	Spring Wheat	Grain
24	Winter Wheat	Grain
27	Rye	Grain
28	Oats	Grain
69	Grapes	Berries and grapes
221	Strawberries	Berries and grapes
229	Pumpkins	Berries and grapes
242	Blueberries	Berries and grapes
250	Cranberries	Berries and grapes
37	Other Hay	Hay
58	Clover/Wildflowers	Hay
205	Triticale	Hay
224	Vetch	Hay
36	Alfalfa	Hay
76	Walnuts	Nuts
71	Other Tree Nuts	Nuts
31	Canola	Oil seeds
34	Rape Seed	Oil seeds
38	Camelina	Oil seeds
66	Cherries	Tree fruit
68	Apples	Tree fruit
73	Other Tree Fruits	Tree fruit
210	Prunes	Tree fruit
220	Plums	Tree fruit
1	Corn	Vegetables
5	Soybeans	Vegetables
12	Sweet Corn	Vegetables
14	Mint	Vegetables
35	Mustard	Vegetables
41	Sugarbeets	Vegetables
42	Dry Beans	Vegetables
43	Potatoes	Vegetables
47	Misc. Vegetables & Fruits	Vegetables
49	Onions	Vegetables
53	Peas	Vegetables
56	Hops	Vegetables
57	Herbs	Vegetables
208	Garlic	Vegetables
214	Broccoli	Vegetables
216	Peppers	Vegetables
219	Greens	Vegetables
222	Squash	Vegetables
243	Cabbage	Vegetables
244	Cauliflower	Vegetables
246	Radishes	Vegetables

247	Turnips	Vegetables
62	Pasture/Grass	Pasture
181	Pasture/Hay	Pasture
61	Fallow/Idle Cropland	Other
131	Barren	Other
44	Other Crops	Other
171	Grassland Herbaceous	Other
59	Sod/Grass Seed	Sod and grasses

Primary assumptions of the current analysis:

- We assumed all cows were pasture-raised. As described above for dairy, all beef consumption was calculated as demand for grain, grass and hay, and pasture. We assumed intensely managed stocking densities of 1.7 cattle per acre (see, for example, EatWild 2012), and we assumed that each steer yields an average of 450 edible pounds and takes 2 years to raise (USDA 2012a).
- We did not examine production to satisfy demand for chicken, pork, or other types of meat consumption. Nor did we examine production to satisfy demand classified as other.
- The data we used for consumption was aggregated at a national scale, and we assumed that regional consumption patterns were equivalent.
- We did not calculate availability of agricultural inputs such as fertilizers.

Our results are shown in table 10. We found that, in terms of sheer productive potential, current production of grain, berries and grapes, hay, and nuts could already satisfy regional demand. We estimated that production of oil seeds, tree fruit, and vegetables could meet demand if additional acres were devoted to them, by shifting production from non-edible crops. We found that current pasture lands could support roughly half of current beef consumption.

Table 10: Potential satisfaction of current food demand for the tri-county region

Crop category	Current production (acres, USDA)	Yield (lbs. / acre)	Existing production (lbs.)	Demand (lbs.)	Surplus (or shortfall) (lbs.)	Potential (acres)	Potential (lbs)	Current demand met (%)
Grain	43,379	6,500	281,960,655	276,186,359	5,774,296	43,379	281,960,655	102%
Berries and grapes	3,469	10,200	35,385,202	33,313,031	2,072,171	3,469	35,385,202	106%
Hay	38,869	12,000	466,423,402	305,478,851	160,944,551	25,684	308,204,582	101%
Nuts	6,414	1,500	9,621,469	7,302,610	2,318,859	5,150	7,725,664	106%
Oil seeds	261	5,800	1,515,621	6,441,500	(4,925,879)	1,132	6,568,121	102%
Tree fruit	1,609	12,000	19,305,653	96,000,606	(76,694,953)	7,975	95,695,619	100%
Vegetables	11,501	25,000	287,534,314	729,899,992	(442,365,678)	29,223	730,572,675	100%
Pasture	105,203			218,879*	(113,676)	105,203	n/a	48%
Other	15,426					4,916	n/a	
Sod and grasses	39,738					39,738	n/a	
Total	**265,869**					**265,869**		

* Demand reported in acres

Figure 8: Current tri-county agricultural production, by broad crop categories

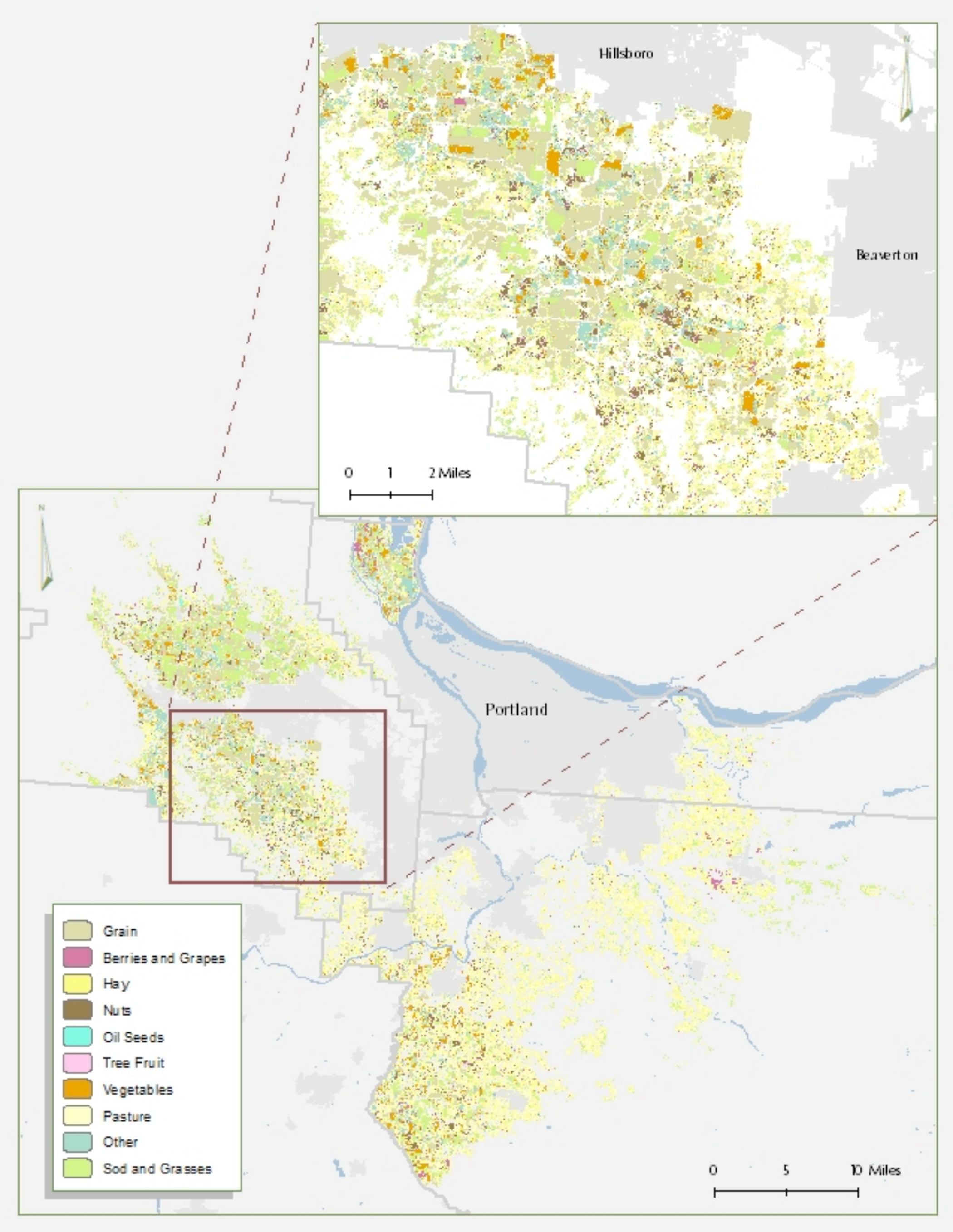
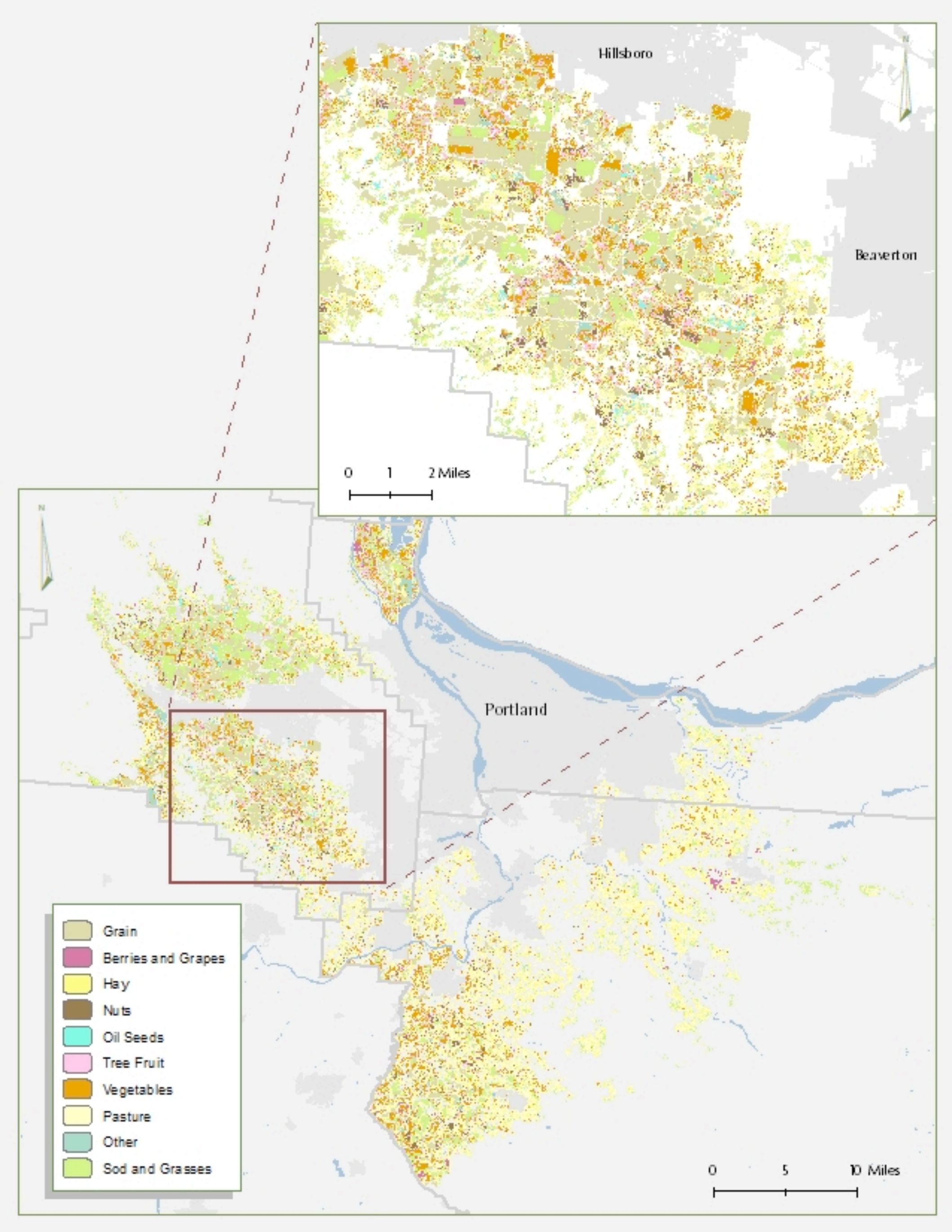


Figure 9: Potential tri-county agricultural production, by broad crop categories



Primary limitations of the current analysis:

- For our Ventura County analysis, we used a more disaggregated set of 42 crop types, which was available for California, rather than the 8 categories examined here. The larger number of crop types provides greater resolution on both suitability of production and capacity to meet demand.
- The CDL dataset, based on Landsat spectral signatures, is best used in mapping large, contiguous acreages, such as Iowan corn. For our Clackamas County work, we verified CDL

data against 2009 and 2011 NRCS aerial imagery, as well as survey data. We were unable to undertake this labor-intensive verification work for the larger tri-county geography.

- In two instances where CDL data were aggregated in a manner inconsistent with our demand categories, we used Oregon Agricultural Information Network (OAIN) data to disaggregate crops types. These two cases enabled us to better distinguish grain from hay and tree fruit from nuts. We then randomly designated these crops to the landscape, based on OAIN proportions.
- For our Ventura County analysis, instead of using crop yield estimates, we estimated landscape productivity through a more spatially precise agro-ecological analysis of factors such as temperature, precipitation, elevation, and slope, which provide greater resolution on productivity potential.
- In this preliminary analysis, we did not examine the suitability or potential to additionally satisfy demand through the use of agricultural lands currently designated as “sod and grasses.”
- In this preliminary analysis, we did not examine how shifts in consumption preferences, water availability, climatic patterns, or other variables might affect our findings.

These limitations are significant, and this current analysis should be understood as a precursor to a more extensive one we hope to be able to undertake in the near future.

Benefits

Food production has been described as an “environmentalist’s paradox.” Virtually alone among the Millennium Ecosystem Assessment’s tally of ecosystem services, food-provisioning services saw substantial 20th century increases, with concomitant benefits for the era’s human wellbeing. At the same time, ecosystem conversion to meet human food demand has often come at the expense of other ecosystem functions, such as those that provide for erosion and pest regulation, as well as a loss of biodiversity (Raudsepp-Hearne et al. 2010).

An increase in regional food consumption does not directly assure better management for ecosystem services. Instead, we posit that regional food system goals are best understood as reflecting a resilience perspective, including the potential to develop institutions and capacities that better support agricultural diversity, rural-urban and multi-sector system feedbacks, social capital formation, self-reliance, economic viability, local ownership, functional redundancies, access to healthy foods, and human interaction with the rest of nature (Vynne et al. 2011; Ecotrust 2012).

Enthusiasm for local foods has outpaced relevant research. A 2010 USDA study concluded, perhaps overstating the case, that “there were few studies on the impact of local food markets on economic development, health, or environmental quality” (Martinez et al. 2010). A further complication is that researchers of food system resilience and food system sustainability may, in some cases, approach their topics differently. For example, a resilience study of European wheat yields found that greater diversity in farm sizes, types, and intensities reduced vulnerabilities to projected climate impacts (Reidsma & Ewert 2008). This is a significant finding but one outside the usual research on “environmental quality.”

Conclusions and Lessons Learned

Ecotrust’s experiences with spatial analysis began in the 1990s with the first maps and characterizations of the status of temperate rain forest and Pacific salmon across their North American range. Since then, we have worked with numerous partners and clients to develop spatial analyses on land and sea, at local and regional scales. Through this work we have developed a suite of spatial toolkits for use in prioritization, visualization, stakeholder engagement, decision support, management planning, economic assessment, and monitoring. Embedded in these toolkits are implicit assumptions about the potential for active management for multiple benefits and the value of working from social and ecological context-based experiences and data.

We began this project as an opportunity to ask "what if" questions: What if management for ecosystem services and resilience were the norm? What would that look like? To what extent could social goals be satisfied? This project has also been an opportunity to apply our toolkits closer to home, in the rural-urban region where we live, and at a time when projects that are taking an explicitly regional approach include The Intertwine Alliance, the Portland Sustainability Institute Climate Prosperity Greenprint, and the Portland Pulse suite of indicators.

We sought to use data specific to the region, though in the food analysis this was not always possible, and to develop plausible scenarios by learning from the examples and experiences of others who have been working in these areas. As we began to develop analyses of carbon sequestration and food production, we found that Portland's Bureau of Environmental Services was asking very similar "what if" questions about stormwater management: Could social goals be achieved through green infrastructure, and at what costs? With their assistance, we incorporated a stormwater analysis. We also explored, but did not incorporate, a biodiversity analysis.

We assumed ambitious tree planting. Based on the successes of Clean Water Services and numerous partners in the Tualatin basin, we envisioned that similar riparian planting could be adopted throughout the Intertwine region. Based on the successes of Portland's Bureau of Environmental Services and numerous partners in managing for Portland's stormwater and caring for the urban forest, we imagined that the city could meet its urban canopy goals within 20 years. While these scenarios are ambitious — some might say extremely ambitious — in other ways our calculations are conservative, as we have described. We found that new carbon sequestration in the region's riparian areas and urban forests could sequester 485,472 metric tons of CO_2 per year by 2050, meeting 2.1 percent of the region's greenhouse gas reduction targets on a current (2010) per capita basis. Stormwater interception by new urban forest canopy could meet 6.3 – 14.8 percent of city's projected infrastructural needs by 2040. On a landscape suitability basis for food production, we found that the region could supply current regional consumption for most crop categories, with the exception of meat products.

Table 11: Three scenarios of management for ecosystem services

Management activity	Estimated primary benefits
CO_2 sequestration in new Intertwine riparian growth and new Portland urban canopy	2.1% of Oregon's 2050 greenhouse gas reduction target, on a current per capita basis
Stormwater interception by new Portland urban canopy	6.3–14.8% of projected infrastructural needs by 2040
Regional food production to meet regional demand	Satisfaction of demand for most crop categories, with the exception of meat products

The most critical assumption is that the initiatives highlighted in this paper — and many others like them — are able to continue to develop and expand successful partnerships for working with nature to achieve social goals. For if any local food scenario is to be plausible, and farmers are to sell more of their products into local markets, then they will depend on a food system of public and private partners to help make such work more viable. And if our carbon and stormwater scenarios are to be plausible, and private landowners are to adopt and effectively maintain expanded riparian and urban tree canopies, as well as rain gardens, bioswales, ecoroofs, and permeable paving, then many types of supportive programs, organizations, and institutions will be necessary.

Among the papers we reviewed throughout this project, several stand out for the way they helped shape our thinking. One is the 2010 national voter survey on perceptions of ecosystem services performed on behalf of The Nature Conservancy (Metz and Weigel 2010). Among its findings and conclusions, the authors cautioned against an exclusive reliance on economic valuation.

> Do highlight other ways of quantifying the benefits of nature, beyond simply dollars. In the poll, voters were far more receptive to me
> thods of calculating the benefits of nature that rely on the number of people benefited, the amounts of beneficial materials generated (like clean air and water), or the number of jobs created.

A second is a 2011 paper published in *Solutions Journal* by Jennifer Allen and coauthors, which emphasized transparent, participatory, and spatially specific practices and methods (Allen et al. 2011).

> [T]he use of participatory geographic information system (GIS) technology, mediated modeling, town meetings, or other approaches can also help participants develop shared learning about a resource and shape a unique place-based approach. … By making all of the values and ethical considerations that influence decision making more explicit, we can better design institutions to mediate when values conflict.

Lastly are a variety of papers that evaluated citizen engagement in and perceptions of urban stormwater and tree planting projects (Dill et al. 2010; Shandas et al. 2010; Netusil et al. 2011), along with a 2010 report by the Center for Neighborhood Technology, which described a vision for engaging citizen science in monitoring and stewardship of these public assets (CNT 2011).

> This study seeks to define procedures and tools through which Portland can implement tree asset management (TAM), and in doing so to integrate its trees — and potentially other grey-to-green infrastructure features — into an infrastructure asset management format that helps the city maximize the benefits of trees, engage the community, and potentially qualify trees for financing on par with conventional infrastructure.

Our hope is that the types of spatially specific, scenario-based analyses described herein can contribute to more transparent, participatory, and broad-based approaches to stewarding for ecosystem services and cultivating resilience.

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