Title
Opportunity assessment for establishing hybrid poplars in California, Oregon and Washington, and Summary of the carbon storage potential for fast growing species (hybrid poplar) in Oregon

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OPPORTUNITY ASSESSMENT FOR ESTABLISHING HYBRID POPLARS IN CALIFORNIA, OREGON AND WASHINGTON

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Arnold Schwarzenegger
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Opportunity Assessment for Establishing Hybrid Poplars in California, Oregon and Washington

PIER PROJECT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission) conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers in California. The Energy Commission awards up to $62 million annually in electricity-related RD&D, and up to $12 million annually for natural gas RD&D.

The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

Opportunity Assessment for Establishing Hybrid Poplars in California, Oregon and Washington is a final report for the West Coast Regional Carbon Sequestration Partnership – Phase II (contract number 500-02-004, work authorization number MR-06-03L. The information from this project contributes to PIER's Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site at www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-5164.

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Abstract

Hybrid poplar (*Populus* spp.), a short rotation woody crop, is of growing interest in the West Coast States of California, Oregon and Washington. This increased interest has been driven in recent years by hybrid poplar's potential as a bioenergy crop or multiple wood products crop in combination with the potential revenue from carbon credits. This report aims to identify eligible lands within the West Coast States for the planting of hybrid poplar crops using a geographic information System (GIS) framework. . The eligible lands will be evaluated for their suitability based on a spatial analysis of environmental variables (datasets) that best predict the growth and productivity of hybrid poplar. The resulting suitability map is then analyzed against current research on the growth and productivity of hybrid poplar under different site conditions, which can then be related to carbon sequestration. The results showed that California has the most eligible land with around 14 million acres, but the majority of these acres would need irrigation. Washington State has the second largest amount of eligible land with 8 million acres, with around 27% of it suitable for planting with limited to no irrigation. Oregon has 5 million acres with nearly one third suitable for limited to no irrigation hybrid poplar plantations. Of these eligible lands the most suitable could produce an average of 3-4 t C/ac.yr, moderate suitability of 2-3 t C/ac.yr, and lands with poor suitability would average 1-2 t C/ac.yr. Revenue from a dedicated bioenergy plantation on a 6 year rotation is estimated to be $737-$976/acre with $86-$325/acre of that being earned from carbon credits. Revenue from a wood products plantation on a 20 year rotation is estimated to be $9,396-$10,989/acre with $425-$1,592/acre of that being earned from carbon credits. This study identifies counties or localities that may have considerable opportunities for hybrid poplar plantations, and can aid project developers in assessing those opportunities.

Executive Summary

Introduction

Hybrid poplar (*Populus* spp.), a short rotation woody crop, is of growing interest in the West Coast States of California, Oregon and Washington. This increased interest has been driven in recent years by hybrid poplar's potential as a bioenergy crop or multiple wood products crop in combination with the potential revenue from carbon credits. This report aims to identify eligible lands within the West Coast States for the planting of hybrid poplar crops using a geographic information System (GIS) framework.

There is interest in hybrid poplars because they are one of the fastest growing tree species in North America. This species is typically established on marginal agricultural lands or conservation reserve lands and as wind breaks, to reduce soil erosion, as riparian buffers, and as crops on marginal lands for generating income from secondary forest products. Over the past 10-15 years there has been increased interest in using these fast growing woody crops for large scale bioenergy crops and multiple wood product crops in combination with carbon credits (Kaster, 2009; Perry *et al.* 2001).

Purpose

The purpose of the report is to identify areas throughout California, Oregon and Washington State (hereafter referred to as the West Coast Region) that are suitable for hybrid poplar plantations, to estimate the potential carbon sequestration, and provide information for project developers interested in the potential for developing large scale hybrid poplar projects for bioenergy or multiple market wood products and carbon sequestration.

As part of the Westcarb project's terrestrial carbon sequestration component, Winrock International undertook a regional characterization study of areas suitable for hybrid poplar (*Populus Spp.)* afforestation projects in the West Coast Region). The regional characterization study first identified areas eligible for hybrid poplar plantations. "Eligible" is merely an indication that the land could support hybrid polar plantations ecologically and topographically; it does not address current land use, so does not necessarily mean that the area is available. Second, environmental datasets were analyzed to identify suitability classes for the growth and production of hybrid poplar. Suitability classes ranged from "high suitability" to "not suitable," based on factors of climate, soil and slope. Using the suitability map and growth and yield curves for hybrid poplar, the potential yield and carbon sequestration of hybrid poplar on different sites was modeled. This report will be helpful for project developers interested in large scale hybrid poplar plantation. This report is primarily focused on the potential for large scale hybrid poplar afforestation and reforestation projects that would provide carbon credits in combination with revenue from biomass for bioenergy plants, or from multiple market wood products crops that produces things like lumber or veneer.

Project Results

The final suitability map defined 18 different suitability classes ranging from "highly suitable" to "not suitable" using environmental variables of climate, soil and slope (Figure 1). The suitability classes were stratified by areas where irrigation would be needed, limited-no irrigation would be needed and where no irrigation would be needed based on precipitation and evapotranspiration rates.

Results show that most of the prime lands ideal for hybrid poplar, and where no irrigation or limited irrigation would be needed, are located primarily on the western side of the Cascade Mountains in Oregon and Washington State. Washington State has approximately 8 million acres of eligible lands, with 82% needing irrigation, 8% needing limited irrigation and 9% needing no irrigation. Oregon has 5 million acres in total, with 59% needing irrigation, 27% needing limited irrigation, and 13% needing no irrigation. California had the most total land eligible, with 14 million acres. However, 96% of the land would need irrigation, with only 3% needing limited irrigation and less than 1% needing no irrigation. If irrigation is supplied to areas where moisture availability is limited, the amount of highly suitable land throughout the West Coast Region more than doubles.

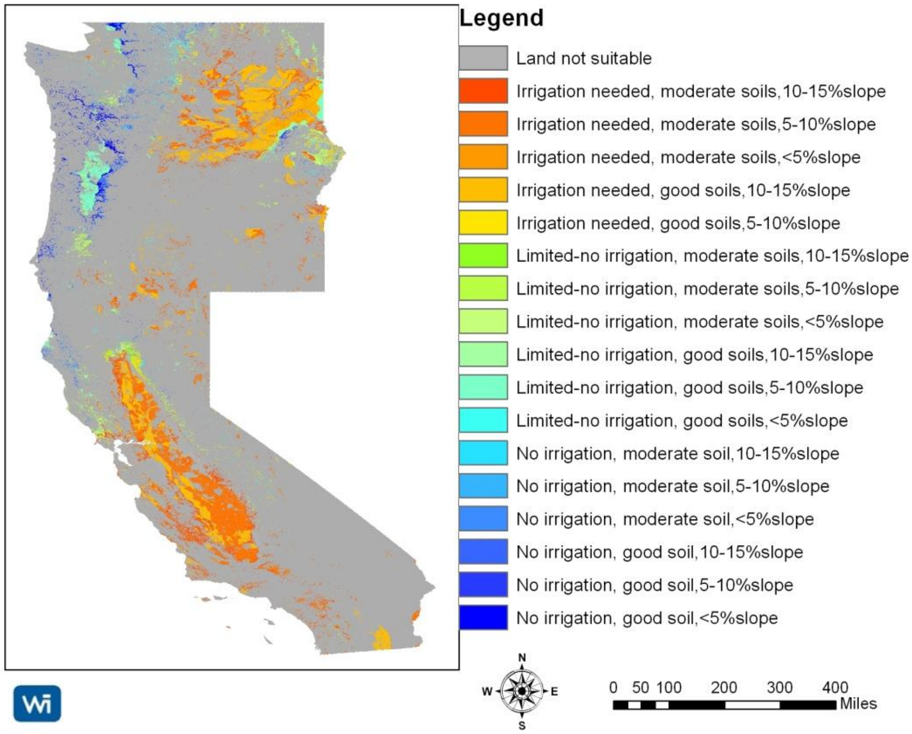

Figure 1. Final suitability map for the entire West Coast Region

Using the suitability map and published literature for hybrid poplar, growth and yield was estimated, and subsequently carbon sequestration. Growth and yield of hybrid poplar averages from 8-11 green tons/ac.yr of above ground biomass on highly suitable sites with ample water, 6-8 green tons/ac.yr on moderate sites, and 4-6 green tons/ac.yr on poor to moderate sites. This growth and yield relates to approximately 3-4 t C/ac.yr on highly suitable sites, 2-3 t C/ac.yr on moderate sites, and 1-2 t C/ac.yr on poor to moderate sites (Figure 2). Carbon sequestration per year was modeled with irrigation (Figure 2 A), and without irrigation (Figure 2 B). These results indicated that over 6 year rotation approximately 20 t C/ac could be achieved, and Over a 20 year rotation 81 t C/ac.

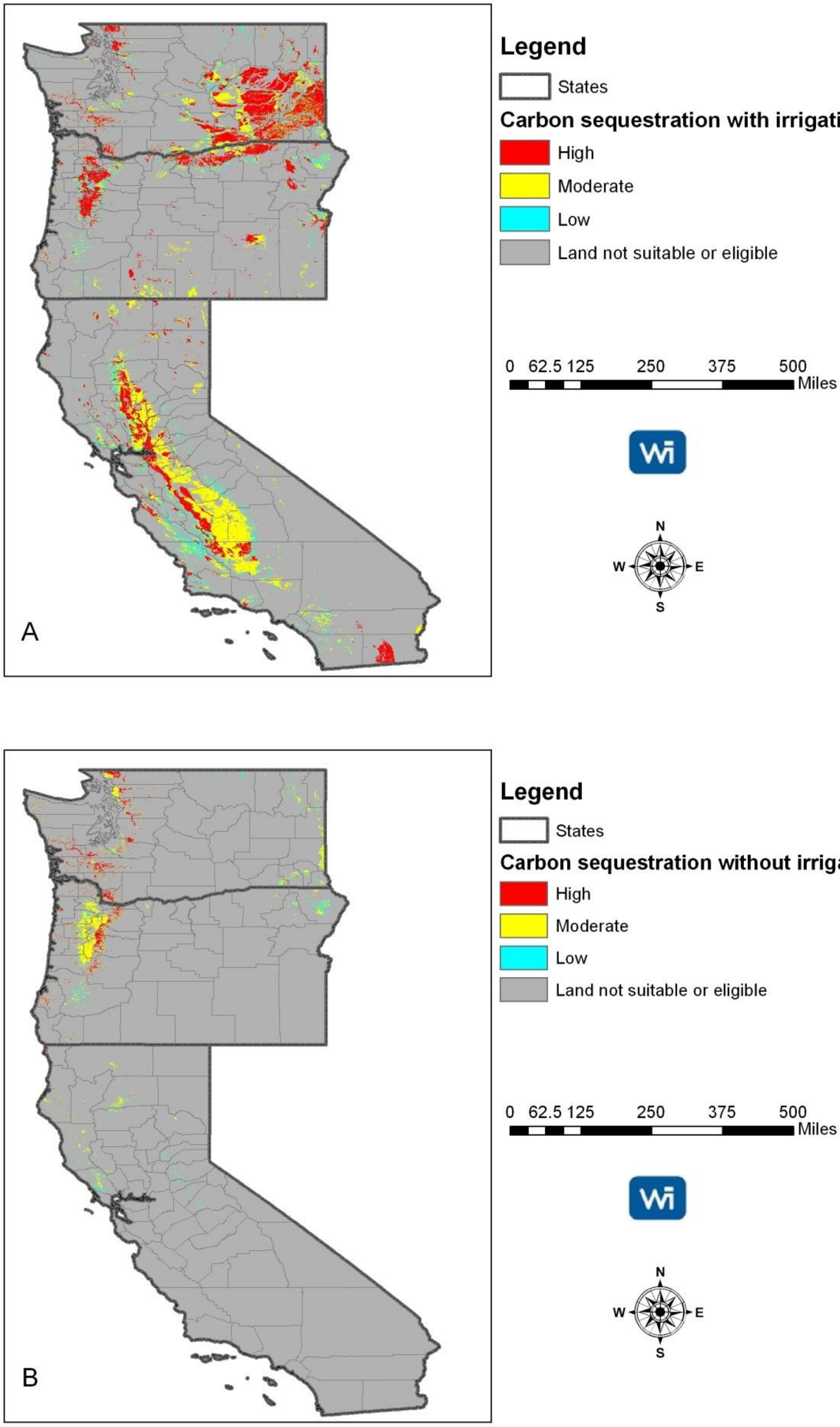

Figure 2. Potential carbon sequestration across the West Coast Region with irrigation (A) and without irrigation (B) based on the suitability map.

The financial analysis of large scale hybrid poplar plantations showed that a dedicated biomass energy crop could earn estimated revenue of $737-$976/ac with $86-$325/ac of that being earned from carbon credits. For a multiple market wood product crop the revenue over a 20 year rotation is estimated to be $9,396-$10,989/ac with $425 - $1,592/ac of that being earned from carbon credits.

The results from this study will be useful to project developers interested in identifying counties or locales that would be productive for investing in and establishing hybrid poplar crops. Project developers identifying areas for investment will be able to use this study to gauge the level of investment and resources need to establish a hybrid poplar plantation. This study should be used to identify counties or local regions where more detailed spatial analysis can be done.

1.0 Introduction

1.1. Background and overview

Fast growing woody crops have traditionally been used as shelter belts for protecting agricultural crops, to reduce wind and water erosion, and on marginal agricultural land for generating secondary forest products (Perry *et al.* 2001). Poplars (*Populus* spp.) have long been known as one of the fastest growing North American trees species, and as such have been selectively bred and hybridized to increase their potential as a short rotation woody crop. The popularity of hybrid poplar has been a result of their fast growth and adaptability to different environments. However, growing hybrid poplars as a short rotation woody crop involves intensive management more similar to agriculture than forestry with significant investment (Agri-Food Canada, 2009).

In the last 10-15 years there has been increased interest in hybrid poplar crops for both financial revenue as a bioenergy crop or multiple wood products crop, and for their environmental benefits to reduce erosion, improve local water quality in riparian areas, and more recently to mitigate global greenhouse gas emissions (Boswell *et al.* 2008; Kaster, 2009; Perry *et al.*, 2001; Pinno, 2008). Because of this, the establishment of afforestation hybrid poplar crops on marginal agricultural lands is of considerable interest in the West Coast states of California, Oregon and Washington (Boswell *et al.*, 2008; Shock *et al.* 2002; Washington State Univ. 2000). However, given the variability of climates in these states, and the fact that much of the area has limited water resources, special care needs to be taken when deciding where hybrid poplar can be grown in large scale afforestation projects.

To support the regional interest in hybrid poplar afforestation, knowledge is required about suitable locations that are capable of, but are not presently involved in growing trees. This type of analysis is best undertaken using a GIS framework, where environmental data sets are analyzed and decisions made concerning the relative productivity of an area.

1.2. Project objectives

The purpose of this study is to develop a regional characterization map that shows areas eligible for establishing hybrid poplar plantations across the three West Coast states of CA, OR, and WA and evaluates the suitability of these areas based on environmental factors that affect growth and productivity. Using the regional characterization maps this study aims to project potential carbon sequestration of hybrid poplar plantation under different suitability conditions, and to inform project developers on large scale hybrid poplar plantations for bioenergy, and multiple wood product crops. This will be accomplished in three main steps:

a. Create a suitability map for all eligible lands in the West Coast Region that could support hybrid poplar plantations.
b. Compare the suitability map to current published literature on the growth and yield of hybrid poplar under different site conditions. Relate this information to potential carbon sequestration.
c. Assess the economic feasibility of multiple market wood products, bioenergy and carbon sequestration projects.

2.0 Methods

Spatial datasets were used to identify areas that are eligible for hybrid poplar plantations, and to analyze environmental variables that are important to the growth and productivity of hybrid poplar (Figure 3, Table 1). Using expert knowledge and primary literature, the environmental datasets were grouped into suitability classes, ranging from “not suitable,” to “highly suitable” (Table 2). By overlaying these spatial datasets and implementing a Boolean Logic analysis the final suitability map was created (Tegelmark, 1998; Malczewski, 2002; Joss *et al.* 2008).

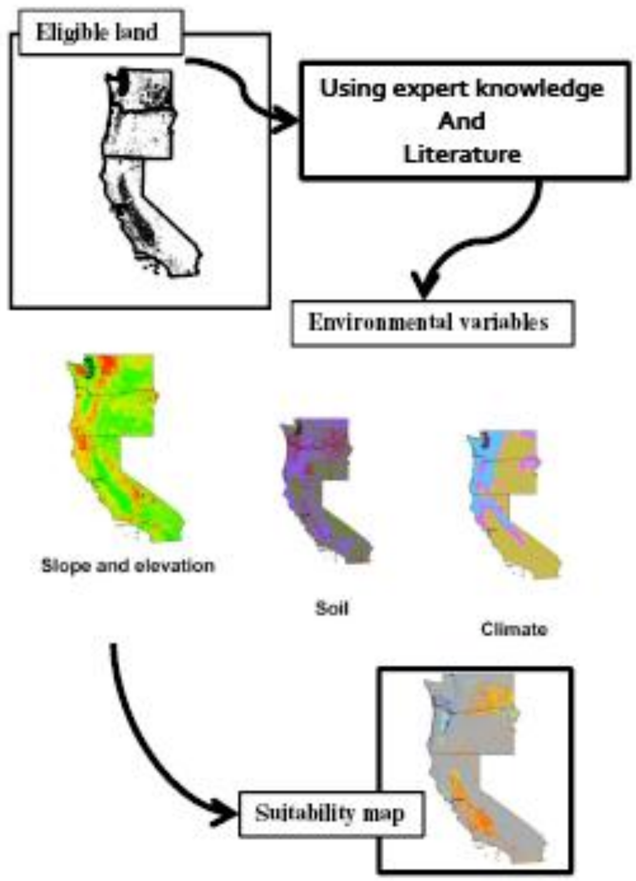

Figure 3. Diagram of the process and datasets used to create the suitability map.

Table 1. GIS data sources used for the regional characterization study

Description	Source
Land eligibility	National Land Cover Database (NLCD) 2001, developed by USGS
Federal lands	Federal lands dataset, developed by USGS
Climate data	PRISM Climate Group, developed by Oregon State University
Soil data	Natural Resource and Conservation Service (NRCS), STATSGO soil data mart maps
Slope and elevation	National Elevation Dataset 30m DEM, developed by USGS

2.1. Land Eligibility

All eligible land in the West Coast Region was identified based on the National Land Cover Dataset from 2001 (NLCD). Based on the NLCD dataset, areas defined as crop land, rangeland and grassland were considered eligible for hybrid poplar plantations. Areas excluded are all forestlands, shrub lands, wetlands, and urban/developed and all areas located on Department of Defense, National Park, Wildlife Refuge or Wilderness land.

2.2. Environmental variables

Environmental variables which were most important for the growth and productivity of hybrid poplar were identified using primary literature and expert knowledge. Climate type was defined by available moisture index (MI) that is estimated as millimeters of rain fall minus evapotranspiration (driven by air temperature) during the growing months of March-August (Table 2). Soils were characterized by available soil water (ASW) that is related to percent silt and clay and is measured as centimeters of water that can be held within 1 meter of soil. A higher percent of silt and clay in the soil indicates a higher ASW. Less than 10cm/m of ASW was considered too poor a soil for hybrid poplar plantings. Slope was characterized into four classes based on percent slope—greater than 15% slope was considered unsuitable for hybrid poplar plantations.

Table 2. Environmental variables and the definition of suitability classes.

Climate (available moisture mm)		
	low suitability	<240mm
	moderate suitability	240-375mm
	high suitability	>375mm
Soil (available soil water cm/m)		
	not suitable	<10cm/m
	low suitability	10-20cm/m
	high suitability	>20cm/m
Slope		
	not suitable	>15%
	low suitability	10-15%
	moderate suitability	5-10%
	high suitability	<5%

2.2.1. Climate type

It is well recognized that at large regional scales climate is a dominant factor defining the growth and productivity of hybrid poplar (Ung *et al*., 2001; Hogg *et al*., 2005). Specifically, available moisture is the most important factor determining the growth and productivity of hybrid poplars (Shock *et al*. 2002; Joss *et al*. 2007; Agri-Food Canada 2003). In contrast, cold temperatures relating to northing and elevation have not been found to substantially affect the growth of hybrid poplars (Pinno, 2008). Available moisture is a function of precipitation and potential evapotranspiration (related to high temperatures), which is measured as moisture index (MI). For this study the MI was determined using the method from Loey Knapp *et al*. (1996), which is calculated monthly by subtracting potential evapotranspiration (PET) from precipitation (P).

$$MI=P-PET$$

Where P is monthly precipitation and monthly PET is calculated using the Hamon model (Hamon, 1961) as:

$$PET=13.97*D^2*W$$

Where D is the monthly mean hours of daylight in units of twelve hours, and W is the saturated water vapor density calculated as:

$$W=4.95e\text{^}(0.062*TC)/100$$

Where TC is the monthly temperature in degrees Celsius.

Using the national climate data from the PRISM Group, which provides mean monthly temperature (C) and precipitation (mm) (averaged from 1971-2000), average MI was calculated for each month.

In a study from Joss *et al*. (2007) in South Central Canada, growing season precipitation below 240 mm was considered not suitable, levels approximating 307.5 mm (the mid-point between 240 and 375mm) were considered marginally suitable, and levels above 375 mm were rated highly suitable for hybrid poplar. Using conclusions from a recent study by GreenWood (appendix C), precipitation levels below 300mm per year would require irrigation, while moderate growing conditions range from 300-350mm a year, with at least 50% falling during the growing season (March-August).

Following this process, suitability classes were defined as the total MI for the months of March-August. MI totals of 240-375mm are marginally suitable and greater than 375mm are highly suitable. Anything below 240mm requires irrigated unless there is a ground water table (see the section 2.2.3 Available Ground Water).

2.2.2. Soil

While climate is important for defining growth conditions across large areas, it is soil conditions that are most important at local sites where management decisions are being made (Pinno, 2008). In a study by Pinno (2008) the most important predictor of hybrid poplar productivity was soil texture, represented by percent silt and clay. For trembling aspen (*Populus tremuloidies)*, Pare *et al.* (2001) in Quebec and Martin and Gower (2006) in Manitoba found that aspen trees were taller on finer textured clay soils as opposed to coarser textured soils, presumably because of the greater water holding capacity of the clay soils.

Using the GIS soil dataset STATSGO from the NRCS soil data mart it was decided that the soil classification “Available Soil Water” (ASW) would be the best for predicting site suitability at this regional scale. This is because ASW incorporates soil depth and soil texture (percent clay and sand), as texture is related to amount of water that can be stored.

Based on data from Perry *et al.* (2001) available soil moisture of 10-20cm/m were considered marginally suitable, and greater than 20cm/m good suitability. Less than 10cm/m ASW was considered unsuitable for hybrid poplar plantations.

2.2.3. Slope

Slopes are an important factor in the planting of hybrid poplar. Much of the literature suggests that slopes less than 10% are the best sites for hybrid poplar plantations. Slope is a factor in erosion and runoff that affect soil available water, and therefore will affect the growth and productivity of hybrid polar (Andrew Bourque, GreenWood 2009, pers. comm.)

Following the Greenwood Report, slope was grouped into four suitability classes: <5% good, 5-10% moderate, 10-15% low, and >15% unsuitable.

3.0 Results

3.1. Suitable land analysis

3.1.1. The West Coast Region

The regional characterization resulted in the final suitability map for the West Coast states identifying 18 different suitability classes ranging from “high suitability”=no irrigation needed, good soil, <5% slope to “low suitability”=irrigation needed, moderate soils and 10-15% slope (Figure 4). Areas classified as low suitability due to the need for irrigation could actually be highly suitable if optimal irrigation was supplied. Therefore, if moisture was not a limiting factor sites with good soil and low slope would equal “high suitability.”

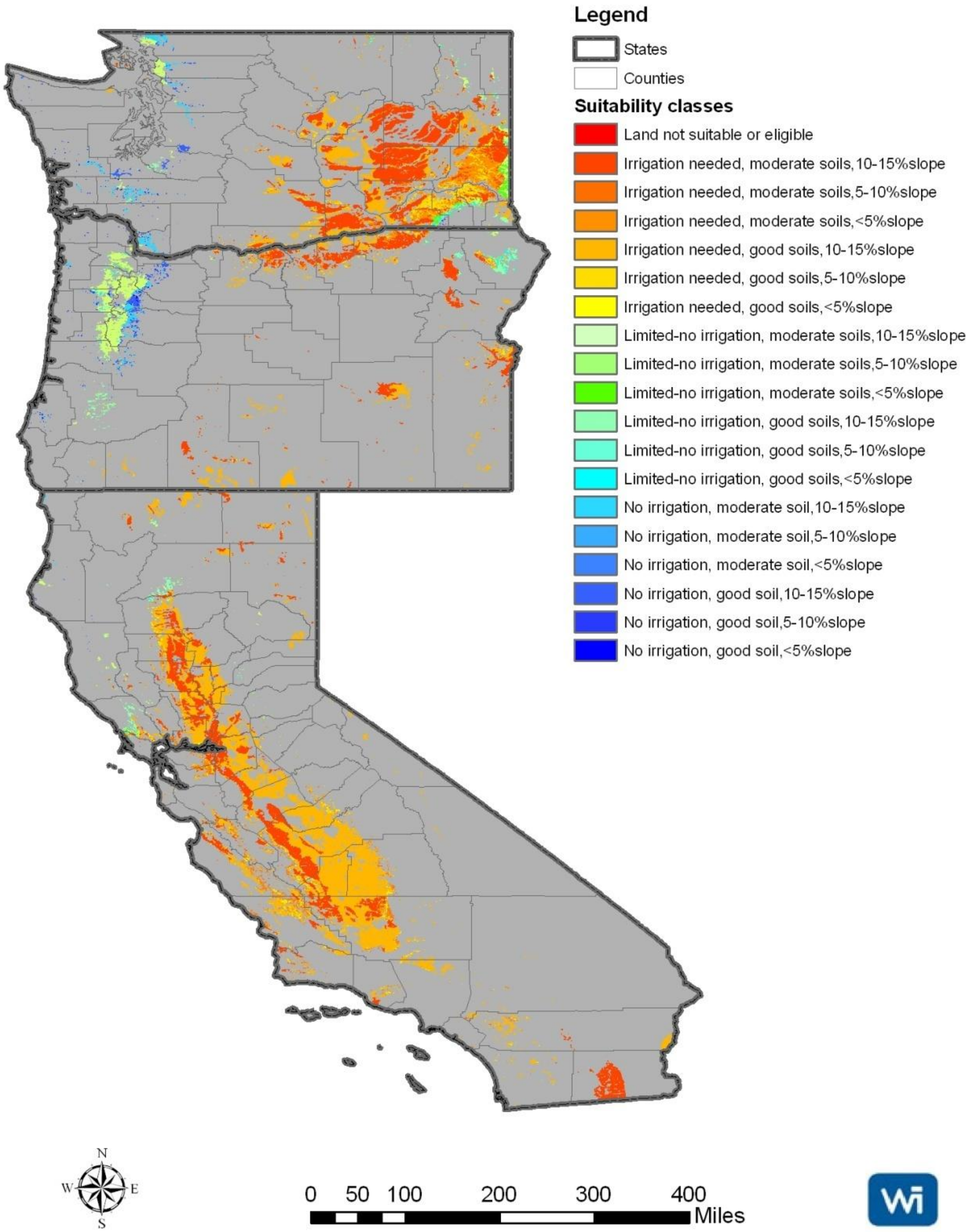

Figure 4. The final suitability map for the West Coast Region. Red to yellow indicates dryer climates where irrigation would be needed, while green to blue indicate wetter climates where limited to no irrigation would be needed. See Appendix A for a map with county names.

3.1.2. California

In the State of California there are approximately 14,205,000 acres of eligible land, with the majority in the Central Valley. Ninety-six percent of the land would need irrigation, with 3% needing limited irrigation and less 1% needing no irrigation (Figure 5).

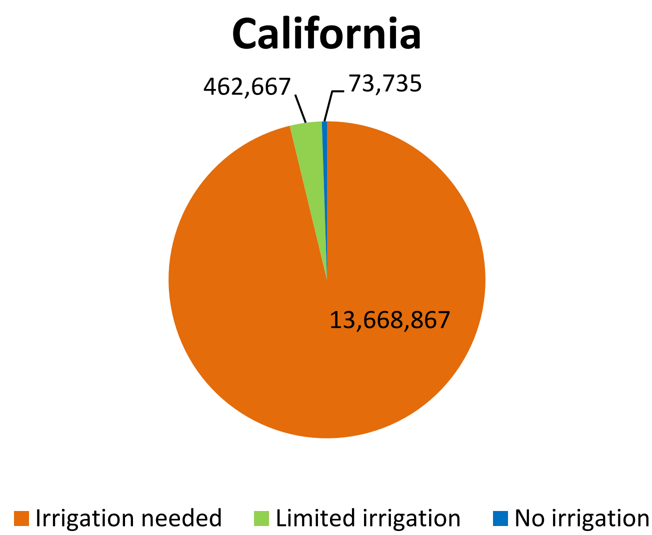

Figure 5. The amount of land (ac) in California that is eligible for hybrid poplar with irrigation, limited irrigation and without irrigation. For a county level analysis see Appendix B.

Out of the 57 counties in California, Kern County had the most total area eligible for hybrid poplar with 1.6 million acres, all of which would need irrigation (See Appendix B). Fresno, Tulare and Kings Counties had the next largest amount of land eligible for hybrid poplar, with 1,504,556, 959,867, 735,052 acres respectfully. All of these lands would need irrigation for the plantation of hybrid poplar (Appendix B).

Counties in California that have some land that may not need irrigation were Sonoma, Shasta, Mendocino, Humboldt and Trinity counties, with 106,415, 94,561, 78,526, 73,045, 12,555 acres of total eligible land, respectfully.

3.1.3. Oregon

Oregon has the least total area among the West Coast states for hybrid poplar plantations, with approximately 4,971,000 acres in total, 59% which would need irrigation, 28% needing limited irrigation and 13% needing no irrigation (Figure 6). Almost half of that area is located in the Willamette Valley where considerable rain and cool summers may provide good conditions for limited to no irrigation hybrid poplar planting.

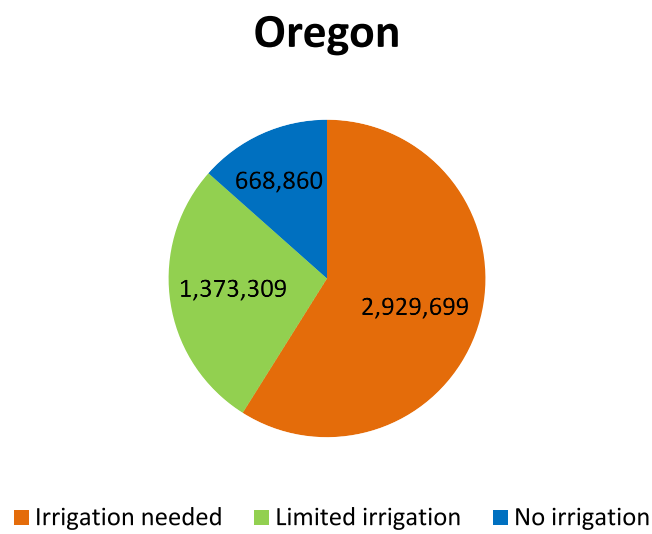

Figure 6. The amount of land (ac) in Oregon that is eligible for hybrid poplar with irrigation, limited irrigation and without irrigation. For a county level analysis see Appendix B.

In Oregon State, Umatilla County had the most total area eligible for hybrid poplar plantation, with 543,859 acres, however 96% would need irrigation (Appendix B). In contrast, along the eastern edge of the Willamette Valley Linn, Clackamas, Marion, and Lane counties all had near or above 100,000 acres of land that would not need any irrigation and would be highly suitable for hybrid poplar plantations (Appendix B).

3.1.4. Washington

Washington State has around 8,424,716 acres of suitable land for hybrid poplar, with 82% needing irrigation, 8% needing limited irrigation and 9% not needing any irrigation (Figure 7). Most of that land is in the dry valleys east of the Cascade Mountains, however in the Pacific Northwest and near the Canadian border almost 1.5 million acres could provide opportunities for limited to no irrigation hybrid poplar plantations.

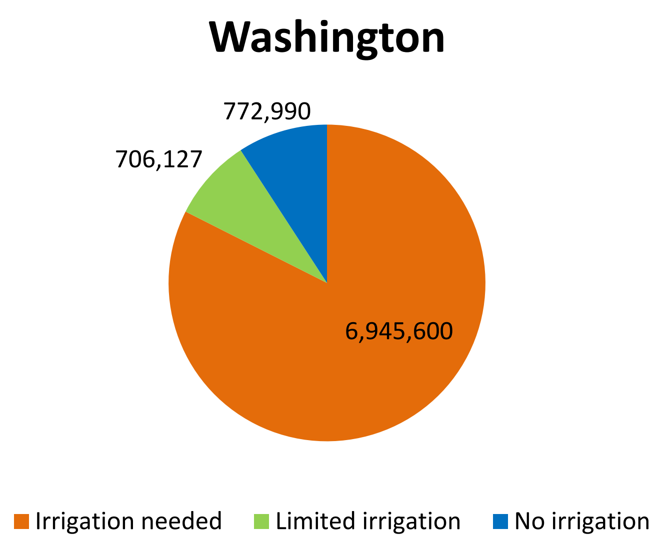

Figure 7. The amount of land (ac) in Washington that is eligible for hybrid poplar with irrigation, limited irrigation and without irrigation. For a county level analysis see Appendix B.

The three counties with the highest percent of suitable land in Washington State are Whitman, Adams, and Grant, with 888,561, 881,726, 778,518 acres respectfully (Appendix B). All are located in the dry southeast portion of the State. In the western part of the State all the counties are dominated by wet growing seasons that provide good land that would need limited to no irrigation. These western counties with the most eligible land for hybrid poplar plantations are Lewis, Whatcom, Skagit and Clark, with 154,861, 126,728, 109,349, 107,715 acres respectfully that would likely need limited to no irrigation (Appendix B).

3.2. Hybrid poplar growth and yield

The estimated growth and yield of most tree species is usually derived using regression equations from field measurements that predict individual tree biomass or stand biomass on a per area basis. Individual tree equations and stand biomass have been published for poplar by several authors including Tuskan and Rensema (1992), Clendenen (1996), Lodhiyal and Lodhiyal (1997), Scarascia-Mugnozza *et al.*(1997), Kort and Turnock (1999), Netzer and Tolsted (1999), and Zambek Prescott (2006) (from Zambeck and Prescott, 2006). These studies have shown that plantation grown hybrid poplar productivity is variable depending on site suitability (primarily available moisture and soil), density of planting, management regimes and genotype (Zabek and Prescott, 2006). The purpose of this section of the report, and section 3.3, is to relate potential productivity and carbon sequestration of hybrid poplar plantations to the suitability map. Due the lack of information on hybrid poplar's growth and yield under different site conditions over an extended growth period (≈20 years) assumptions had to be made to relate growth and yield to the suitability map.

3.2.1. Growth and yield

The current literature on the growth and yield of hybrid poplar (primarily *P. trichocarpa* × *P. deltoids*) as summarized by Zabek *et al.* (2006) reports that in the US above ground green woody biomass of commercial hybrid poplar ranges from 5-16 t /ac.yr planted in densities ranging from 295-4040 stems/ac. However, many of the high growth results were achieved by small plot sizes associated with experimental studies. More realistic estimates for commercial plantations ranged between 4-11 green tons/ac.yr. At the high end, plantations in the Pacific Northwest achieved an average of 11 green tons/ac.yr at densities of 465-630 stems/ac (Stanturf *et al.* 2001). At the lower end, hybrid poplar in the Central US achieved between 5-6 green tons/ac.yr with stem densities of 683-747 acre (Hansen, 1992). In Sweden plantations achieved between 6-8 green tons/ac.yr with 404 stems/ac (Karacic *et al.* 2003), and in Lake County Oregon estimated growth ranged between 4-9 green tons/ac.yr at planting densities of 440-1,450 stems/acre (Boswell *et al.* 2008).

Based on the literature it is assumed that the growth and yield of hybrid poplar across the West Coast Region ranges between a mean annual increment (MAI) of 4 to 11 green tons/ac.yr, depending on environmental conditions. These differences in growth have been shown to be correlated with moisture availability/climate (Hogg 2005; i.e. moisture deficit; Shock et al. 2002; Joss et al. 2007; Agri-Food Canada 2003) and soil (Pare *et al.* 2001; Perry *et al.* 2001; Pinno 2008). Slope is also an important variable, however there was no literature we found that related growth and yield to slope. For moisture availability, Pinno (2008) showed a linear trend of growth and yield for hybrid poplar, ranging from 1-4cm diameter growth difference, at increasing levels of summer moisture during the first two years planted. These same levels of moisture were considered when defining the suitability map. For soil, Pinno (2008) showed that the growth and yield of hybrid poplar during the first few years of growth increased linearly from 1-2.5cm diameter growth deference, based on the percent silt and clay in the soil. The percent of silt and clay is directly related to the ASW that we used to define the soil maps in the suitability analysis.

Using this information it was estimated that highly suitable sites with plenty of available moisture, good soils and level slopes could achieve 11 green tons/ac.yr, while sites with poor suitability, where water is limited, the soil is poor and slope is steep, productivity would be closer to 4 green tons/ac.yr. Using this assumption, a growth curve from Boswell *et al.*(2008) that shows hybrid poplar grown on poor sites (MAI of 4 green tons/ac.yr) to good sites (MAI of 9 tons/ac.yr) was adapted to include very good sites at 11 green tons/ac.yr. These growth curves projected the growth and yield of hybrid poplar (P. trichocarpa × P. deltoids) over 20 years (Figure 8). These growth curves were then related to the suitability map assuming a linear increase in productivity with increasing site conditions to identify the potential growth and yield of hybrid poplar across the West Coast Region.

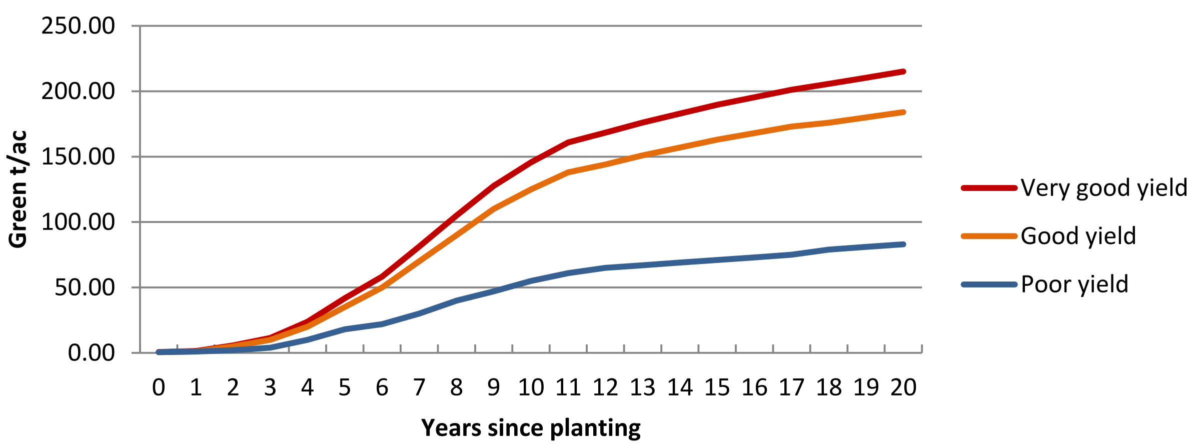

Figure 8. Growth curves for hybrid poplar (P. trichocarpa × P. deltoids) over 20 years.

3.3. Hybrid poplar carbon sequestration

3.3.1. Carbon sequestration

The growth and yield curves for hybrid poplar (above ground green tons/ac) can be converted to carbon by calculating the total dry biomass. For this study the total carbon for a hybrid poplar tree farm per acre was calculating by first adding above ground and below ground biomass together to get total biomass. The below ground biomass for hybrid poplar is assumed to be 40% of above ground (Boswell *et al.* 2008). Green tons were then converted to bone dry tons assuming hybrid poplar biomass is 45% dry matter (Boswell *et al.* 2008). Bone dry tons were then converted to carbon which is approximately 50% of the dry biomass.

The resulting carbon sequestration curves show that over a 20 year rotation hybrid poplar would range from 81 t C/ac on highly suitable sites, to 69 t C/ac on good sites, and 31 t C/ac on poor sites (Figure 9). These results were then related to the suitability map.

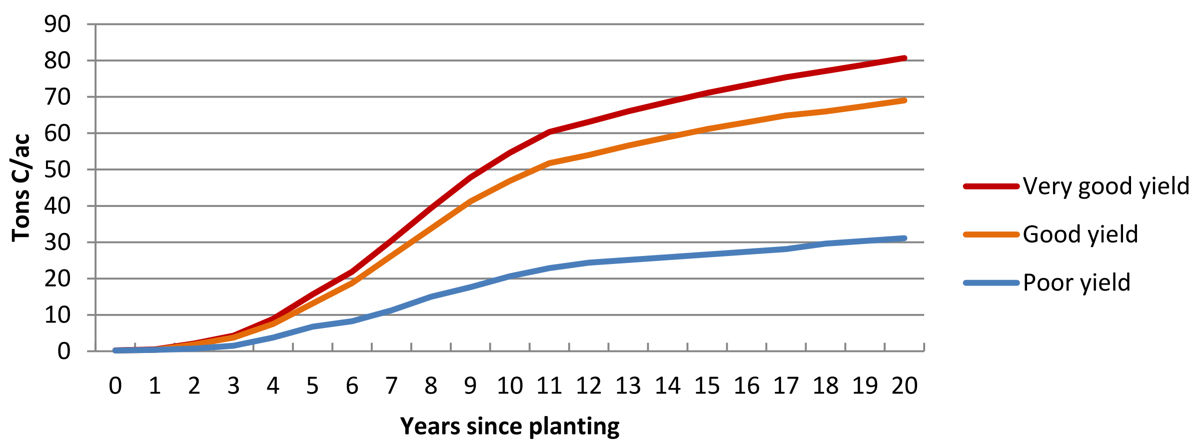

Figure 9. Cumulative quantities of sequestered carbon (tons per acre) for a hybrid poplar plantation over 20 years for three different site conditions.

To project potential carbon sequestration based on the suitability map two scenarios were developed: 1) irrigation is available and used on all eligible land, and 2) irrigation is not used on any eligible land.

From the growth and yield numbers the amount of carbon sequestered each year ranged from 1.5-4.1 t C/ac.yr with increasing site conditions. Again, growth was assumed to increase linearly from poor site conditions to very good site conditions.

Using the scenario where irrigation is provided, it is assumed that hybrid poplar can be grown on all suitable sites. Under these conditions climate and moisture is not considered a factor, therefore, the amount of carbon per acre per year ranges from 1.5-4.1 t C/ac.yr depending on the suitability of the soil and slope (Table 3).

When no irrigation is provided all sites with less that 240mm of available moisture during the summer months are considered not suitable for hybrid poplar. On sites with 240-375 mm of available moisture during the growing season, carbon sequestration ranges between 1.5-3.1 t C/ac.yr depending on soil and slope. In areas where available moisture is >375 mm during the growing season, carbon sequestration is between 2.5-4.1 t C/ac.yr depending on soil and slope (Table 3).

Table 3. The carbon sequestration potential (t C/ac.yr) with and without irrigation that was related to the suitability map.

Suitability classes	Without Irrigation	With Irrigation
Irrigation needed, Moderate soil, 10-15% slope	na	1.5
Irrigation needed, Moderate soil, 5-10% slope	na	2.0
Irrigation needed, Moderate soil, 0-5% slope	na	2.5
Irrigation needed, Good soil, 10-15% slope	na	3.1
Irrigation needed, Good soil, 5-10% slope	na	3.6
Irrigation needed, Good soil, 0-5% slope	na	4.1
Limited irrigation, Moderate soil, 10-15% slope	1.5	1.5
Limited irrigation, Moderate soil, 5-10% slope	2.0	2.0
Limited irrigation, Moderate soil, 0-5% slope	2.5	2.5
Limited irrigation, Good soil, 10-15% slope	2.0	3.1
Limited irrigation, Good soil, 5-10% slope	2.5	3.6
Limited irrigation, Good soil, 0-5% slope	3.1	4.1
No irrigation, Moderate soil, 10-15% slope	2.5	1.5
No irrigation, Moderate soil, 5-10% slope	3.1	2.0
No irrigation, Moderate soil, 0-5% slope	3.6	2.5
No irrigation, Good soil, 10-15% slope	3.1	3.1
No irrigation, Good soil, 5-10% slope	3.6	3.6
No irrigation, Good soil, 0-5% slope	4.1	4.1

3.3.2. California

In the state of California, assuming that all 14 million acres of eligible lands are irrigated and are planted with hybrid poplar, the total carbon sequestration amounts to just over 40.6 million t C/yr, with 39 million t C/yr on land that needs irrigation, 1.2 million t C/yr needing limited irrigation, and 180,000 t C/yr that *d*oes not need irrigation (**Error! Reference source not found.**). The counties with the most otential for carbon sequestration from hybrid poplar plantations with irrigation are Kern, Fresno, Tulare and Kings, with about 4.7, 4.5, 2.4 and 2 million t C/yr respectfully (Appendix B). All of these counties would need almost 100% of their area irrigated**.**

If irrigation is not provided the amount of total area eligible for hybrid poplar plantations drops to 536,000 acres, with the potential for 1.3 million t C/yr (Figure 11). This is distributed between 1.1 million t C/yr that could be achieved with limited irrigation, and 235,000 t C/ac.yr in areas where no irrigation would be needed.

If irrigation is not provided, the counties with the most potential for carbon sequestration are Sonoma, Shasta, Humboldt and Mendocino, with 234,000, 231,000, 215,000 and 194,000 t C/yr respectfully (Appendix B). This relates to 106,000 acres in Sonoma, 95,000 acres in Shasta, 73,000 acres in Humboldt and 79,000 acres in Mendocino (Appendix B). Twenty six counties in California have no suitable land for hybrid poplar without irrigation and another 20 counties have less than 10,000 t C/yr potential (Appendix B).

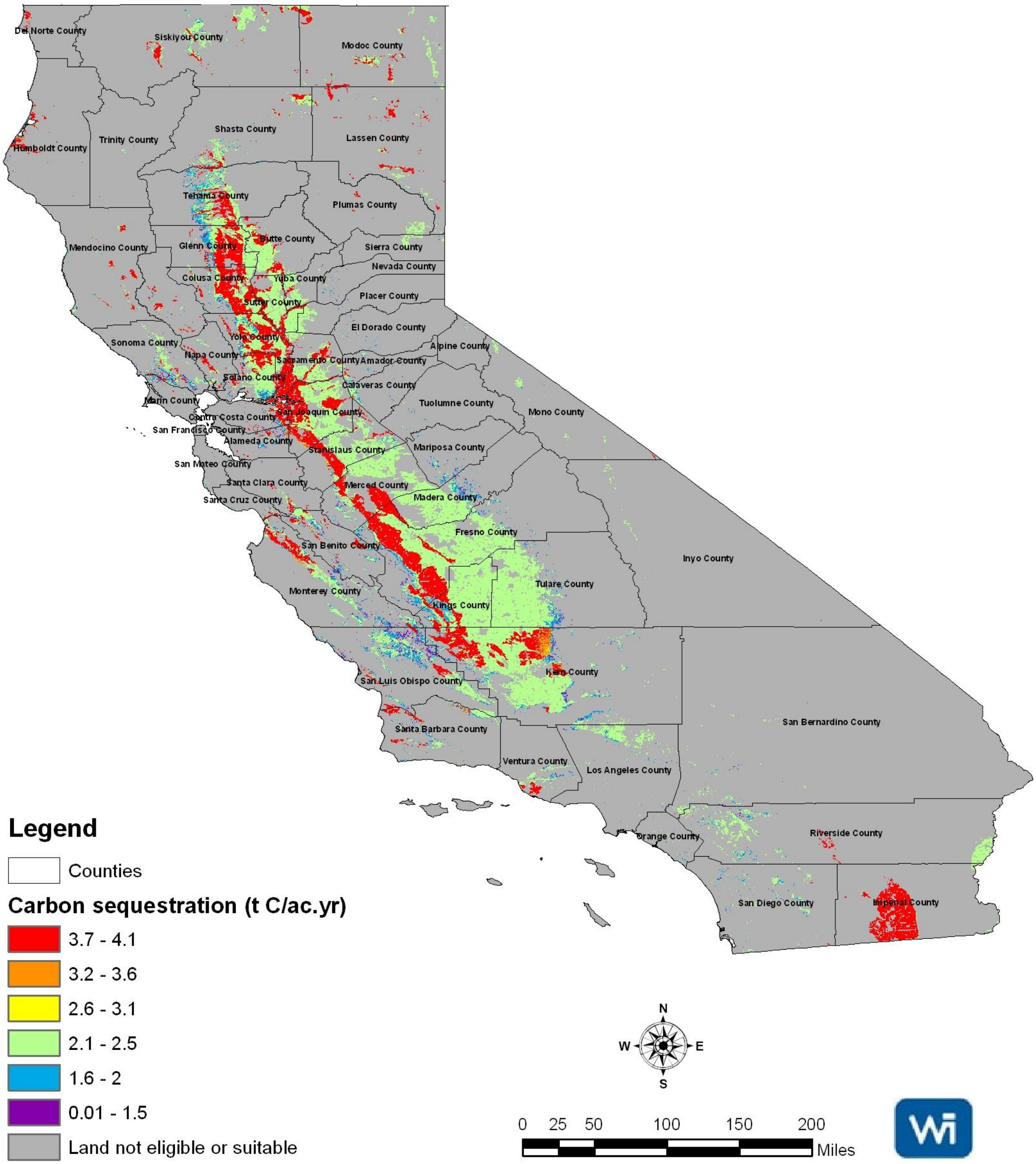

Figure 10. Potential annual rate of carbon sequestration (tons of carbon per acre per year) for hybrid poplar plantations in California with irrigation based on the suitability map

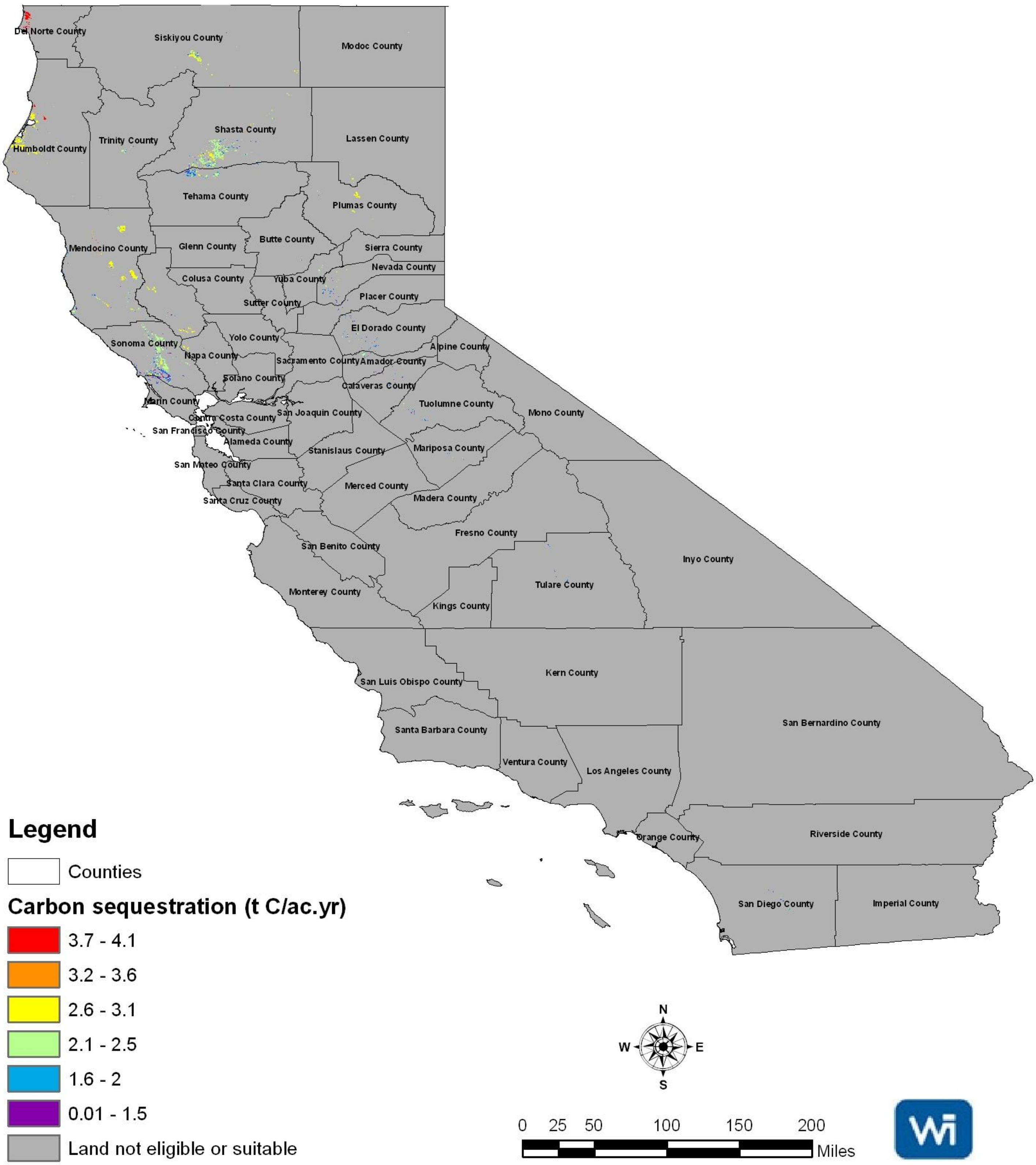

Figure 11. Potential tons of carbon per acre per year for hybrid poplar plantations in California without irrigation based on the suitability map.

3.3.3. Oregon

Oregon State has around 5 million acres of land eligible for hybrid poplar plantations if irrigation is provided. If all eligible lands were planted with hybrid poplar plantations it would amount to 16 million t C/yr, with 9.4 million t C/yr on lands that would need irrigation, 4.7 million t C/yr where limited irrigation would be needed, and almost 2 million t C/yr on lands that would likely not need any irrigation (Figure 12 A). The counties with the most potential for carbon sequestration from hybrid poplar plantation if irrigation is provided are Umatilla, Malheur, Linn and Morrow, with 1.9, 1.3, 1.3 and 1.1 million t C/yr (Appendix B, Oregon). While Malheur and Morrow would need almost 100% irrigation, Linn County could achieve about 1.3 million t C/yr on 147,000 acres of land that would need limited to no irrigation, and to a lesser extent Umatilla could achieve 73,000 t C/yr on 21,000 acres of land that needs limited to no irrigation (Appendix B, Oregon)

If irrigation is not provided the amount of total area available for hybrid poplar plantations goes down to 2 million acres, equating to roughly 6 million t C/yr, with 3.7 million t C/yr on land that would need limited irrigation, and 2.3 million t C/yr on land that would not need any irrigation (Appendix B, Oregon).

Without irrigation the counties with the most potential for carbon sequestration are Linn, Marion, Lane and Clackamas, with 1.1 million, 845,000, 567,000 and 531,000 t C/yr respectfully. This equates to 350,000 acres in Linn, 269,000 acres in Marion, 180,000 acres in Lane and 165,000 acres in Clackamas that would need limited or no irrigation for hybrid poplar plantations (Appendix B, Oregon).

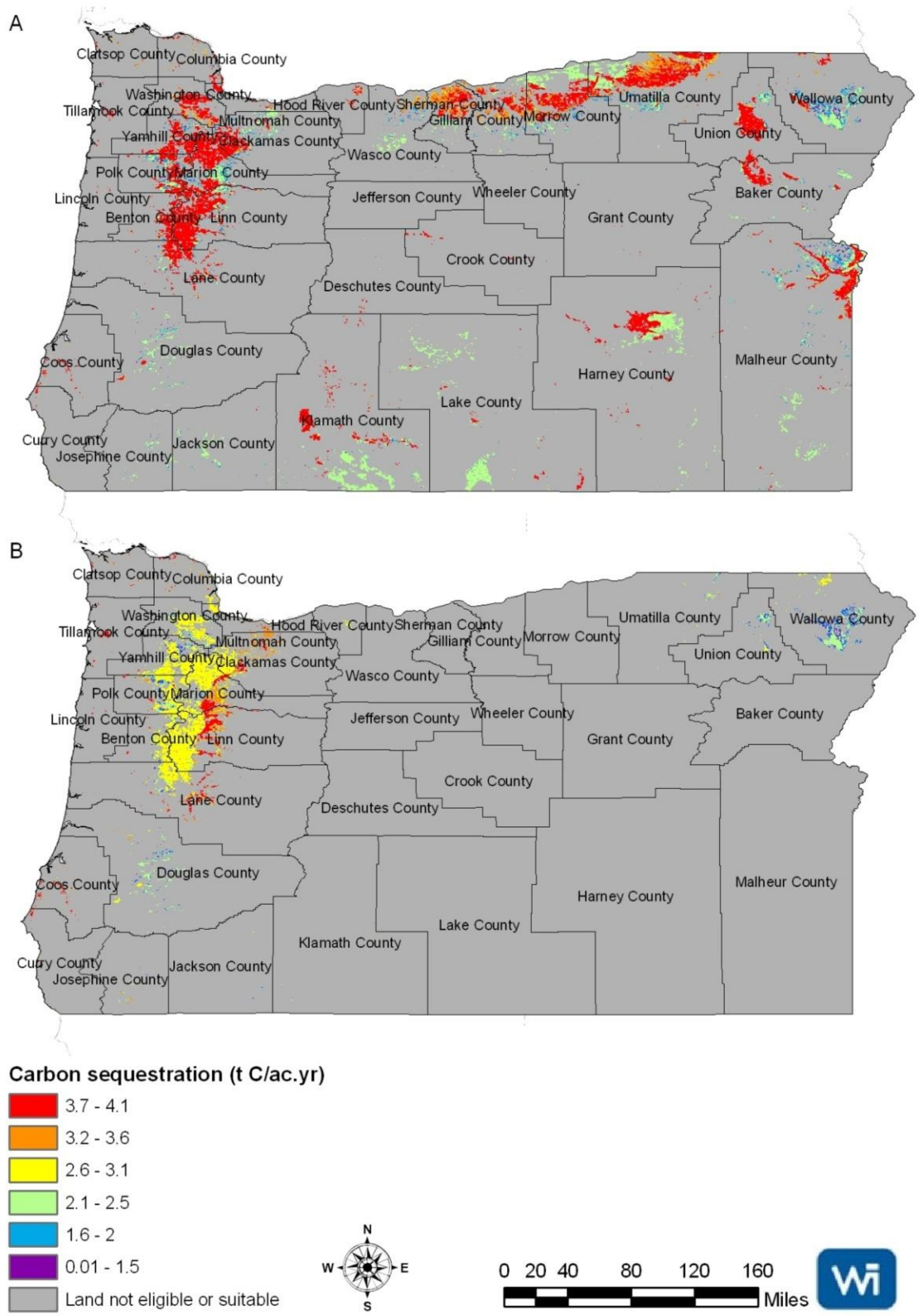

Figure 12. Potential tons of carbon per acre per year for hybrid poplar plantations in Oregon with irrigation (A), and without irrigation (B), based on the suitability map.

3.3.4. Washington

Washington State has about 8.4 million acres of land that is eligible for hybrid poplar if irrigation is provided. Assuming all that land is planted in hybrid poplar the total amount of carbon sequestration would be 28.5 million t C/yr, with 23 million t C/yr on the east side of the Cascades where irrigation would be necessary, and 5 million t C/yr west of the Cascades where wet cool summers provide potential for limited or no irrigation (Figure 13 A).

With irrigation the counties in Washington that have the highest potential for carbon sequestration are Whitman, Adams, Lincoln and Grant, with 3.7, 3.2, 2.9 and 2.6 million t C/yr respectfully (Appendix B, Washington)All of these counties are in the dryer area east of the Cascade Mountains.

If irrigation is not provided the total area of land eligible for hybrid poplar decreases to around 2 million acres with 1.8 million t C/yr on limited irrigation land and 2.8 million t C/yr on land that would not need any irrigation (Figure 13 B). Without irrigation the counties with the most potential for hybrid poplar plantation are Lewis, Whatcom, Whitman and Clark, achieving about 561,000, 466,000, 433,000 and 402,000 t C/yr respectfully. This equates to 155,000 acres in Lewis, 127,000 acres in Whatcom, 165,000 acres in Whitman and 108,000 acres in Clark (Appendix B, Washington)

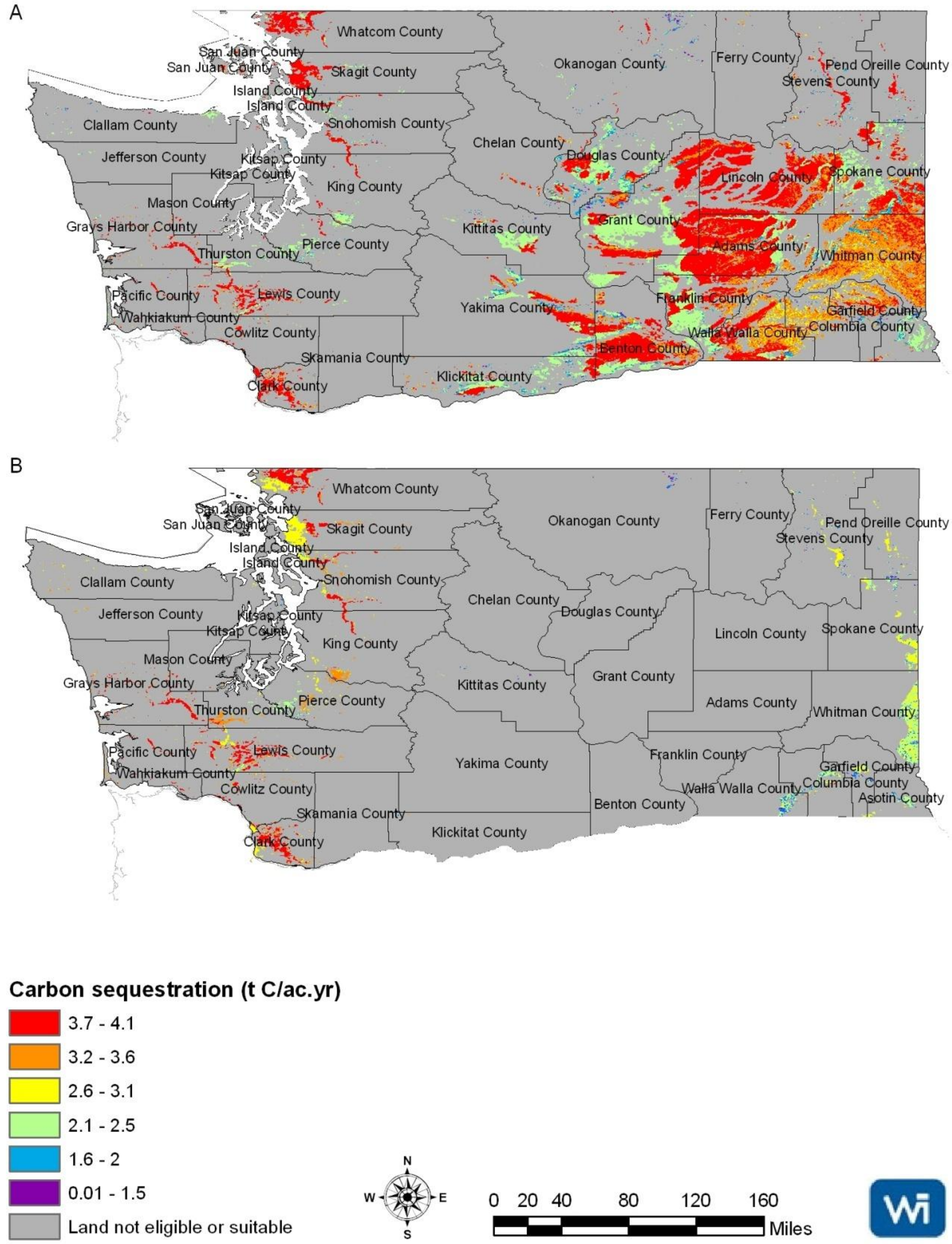

Figure 13. Potential tons of carbon per acre per year for hybrid poplar plantations in Washington with irrigation (A), and without irrigation (B), based on the suitability map.

3.3.5. West Coast Region analysis by county

To identify which counties in the West Coast Region have the highest potential for carbon sequestration from hybrid poplar plantation, the carbon per unit area (total carbon/total county area—t C/ac) was calculated. The carbon per unit areas for each county was then analyzed with and without irrigation (Figure 14 and Figure 15).

This analysis shows that with irrigation, counties in the Central Valley of California, the Central Willamette Valley of Oregon and the Eastern Cascades of Washington have the highest potential for hybrid poplar plantation (Figure 14). In particular Adams, Walla Walla, Whitman and Garfield in Eastern Oregon, and Kings County in Central California. These counties ranged from 6.6-5.4 T C/ per unit of land.

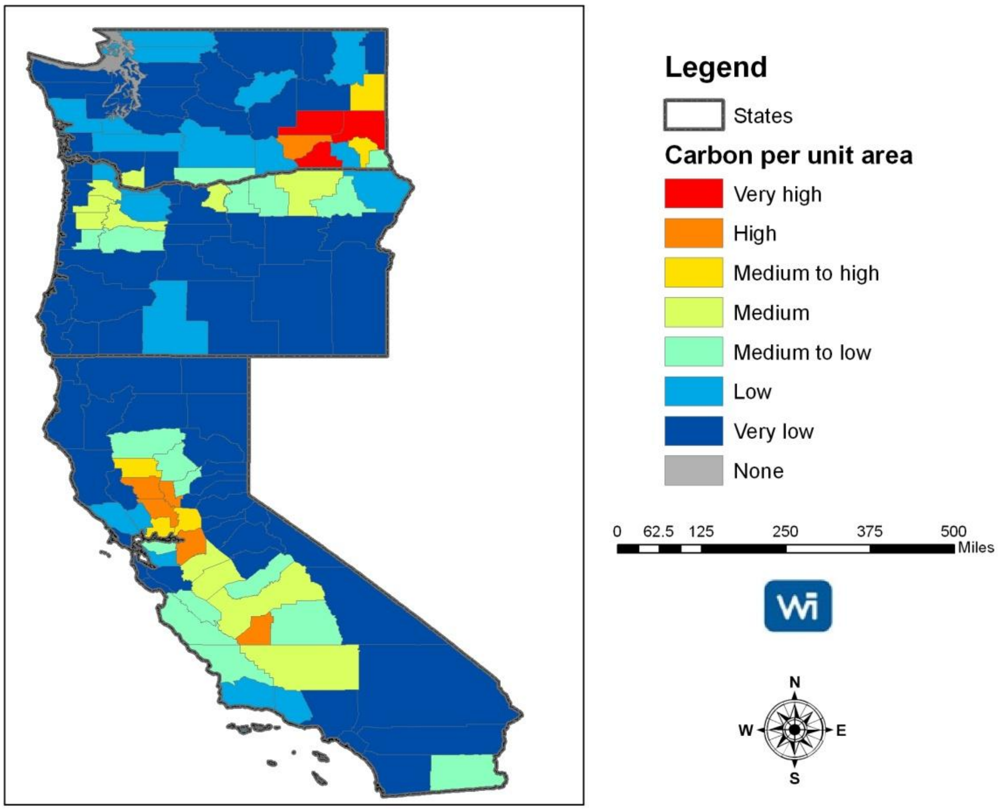

Figure 14. Potential carbon sequestered each year (t C/ac) for each county in the West Coast Region with irrigation. Tons of carbon sequestered each year assumes all eligible lands are planted with hybrid poplar. For a map of county names see Appendix A.

When irrigation is excluded, the majority of the counties that have high potential carbon sequestration per unit of land shift to the Willamette Valley in Oregon and the Pacific Northwest of Washington (Figure 15). The counties with the highest carbon per unit of land are Clark County in Washington, with 2.3 t C/ per unit of land, and Marion, Polk and Yamhill in Oregon with 2.4, 2.2 and 2.1 t C/per unit of land respectfully.

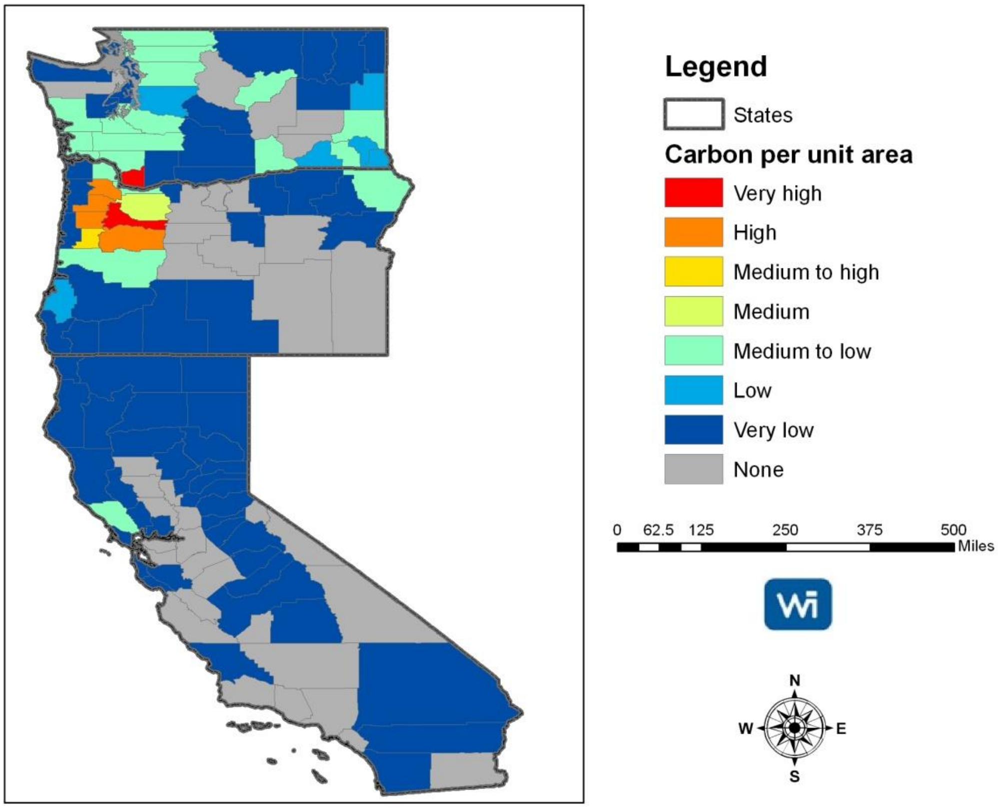

Figure 15. Potential carbon sequestered each year (t C/ac) for each county in the West Coast Region without irrigation. Tons of carbon sequestered each year assumes all eligible lands are planted with hybrid poplar. For a map of county names see Appendix A.

3.4. Financial analysis

The focus of this financial analysis is on large scale hybrid poplar plantations as afforestation and reforestation projects with carbon credits as a primary component. Two management scenarios were reviewed: 1) long rotation (≈20years) multiple market wood products (which includes lumber, veneer, and other wood products), and 2) as a short rotation (≈6years) bioenergy crops used as feed stock for local power plants

The development of large-scale hybrid poplar plantations requires initial research into areas where there is enough suitable land available within reasonable distance from markets. These markets would be, for example, the presence of a bioenergy plant for biomass crops, or a local mill for the processing of wood products. A purely carbon based projects would not have the limitation of local market demand.

Once a location and market has been found, a cost benefit analysis should be conducted analyzing the cost of production for hybrid poplar, and the estimated revenue. Below is a brief break down of the costs and processes associated with the production of hybrid poplar and an estimation of the potential revenue. Information was gathered from literature and from Greenwood's report for Lake County Oregon by Boswell *et al.* (2008) (see Appendix C of this report).

3.4.1. *Cost of production*

The cost of production varies depending on the management scenario. For a dedicated biomass plantation trees are harvested every 6-7 years using a system of coppicing, where stumps are allowed to resprout after being cut. This technique is generally acceptable for about 5 harvests before new plant material is needed. Biomass crops are usually planted at densities of 1000-2000 stems/acre, and require little maintenance. In contrast, multiple market wood products crops are generally harvested on 15-20 year rotations, are planted at densities of 100-500 stems/ac, and require pruning and other types of tree maintenance necessary for producing good sawlogs. The harvesting of sawlogs for wood products also requires properly felling trees and preparing logs for the mill. Table 4 shows a comparison between a dedicated biomass and multiple wood products management scenario adapted from Boswell *et al.* (2008).

Table 4. Comparison of dedicated biomass and multiple market management systems.

	Biomass	**Wood products**
Density (trees per acre)	1450	440
Regeneration	Coppice	Replanting
Rotation	6	20
Harvesting	Whole tree chipping	Log merchandizing
Stand improvement	None needed	Pruning
Site suitability	poor to good	marginal to good
Integrated pest management	similar	similar
Plant material	similar	similar

The costs of these two management scenarios can be broken down into two groups: 1) establishment, and 2) running cost.

Establishment costs would be relatively similar for both market scenarios. General site establishment should start in June, but late August can suffice. Typically sites will be mowed and after some regrowth, herbicide applied (Downing 1996). Within 1-2 weeks, disking (plowing) should occur to bring grass rhizomes to the surface where they can be killed by drying. The field should be smoothed and groomed, and if erosion is a concern a cover crop should be planted. In the spring weeds need to be removed again and stems planted at designated densities (Boswell *et al.* 2008, Downing 1996). Based on the report by Greenwood, the capitol costs for site preparation are around $539/acre for bioenergy crops, and $632/acre for multiple market wood products (Table 5). The difference in costs between biomass crops and wood product crops is associated with the more intensive site preparation necessary to establish trees that are good for sawlogs.

Table 5. Costs for the establishment of a hybrid poplar plantation.

Activities	Biomass	Wood products
Establishment and preparation	$159.92	$277.87
Site preparation	$39.42	$52.01
Planting and replanting	$326.59	$228.00
Infrastructure development	$13.51	$74.30
Cost per acre	$539.44	$632.18

Running costs include management fees, harvesting, transportation and land rental and irrigation (Table 6 and Table 6). Management costs are crop care, such as pruning and pest management, salaries for managers and any other costs concerning the maintenance of the trees. Transportation includes maintenance activities and the delivery of products to the mill or biomass plant. Fell and skid are the harvesting costs, and Processing is the costs associated with preparation of logs for the mill or power plant.

Table 6. Harvesting, processing and transportation costs.

Activities	Biomass	Wood products
Management fees	$81.08	$2,307.31
Transportation	$324.33	$1,337.35
Fell and skid	$432.45	$2,139.76
Process logs	$432.00	$2,134.34
Total cost per acre	$1,269.86	$7,918.76

While these costs are estimates, and can vary depending on location, it is assumed for this study that they will be relatively consistent across the West Coast Region. In contrast, the costs for land rental and irrigation can vary greatly across the West Coast region.

The cost of irrigation varies depending on different combinations of sources, suppliers, distribution systems and other factors such as proximity to water, topography, aquifer conditions, and energy source (Gillehon & Quinby, 2004). Costs for irrigation in California in 2003 ranged from $36/ac to $79/ac, while costs in parts of Washington State range from $10/ac to $41/ac (Gillehon & Quinby, 2004). The cost of agricultural land rental also varies substantially across the West Coast Region, from two thousand dollars per acre along California's coast to as low as $25/ac in the Northeast of Washington and Oregon.

For this study, to estimate the cost of land rental and irrigation per county, data from the USDA/NASSA National Agriculture Statistics Service was used (USDA, 2009). This data shows the land rental rates with irrigation for select counties in each state, and for the remaining counties an average for the region is applied. These data were mapped across the West Coast Region (Figure 16).

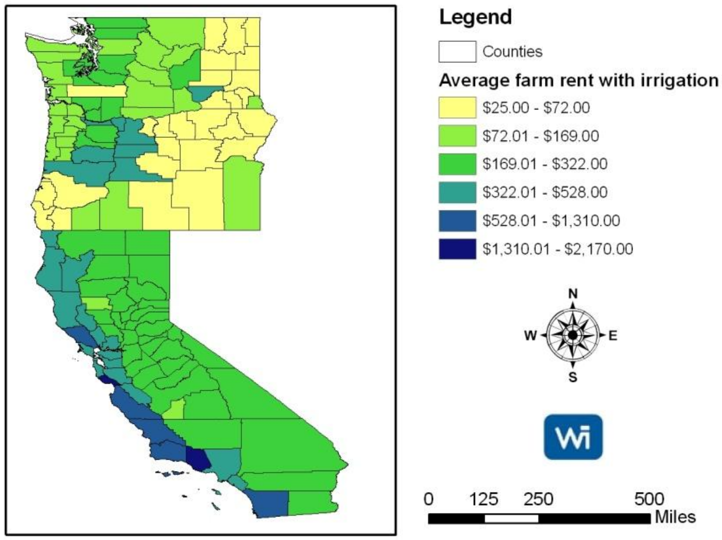

Figure 16. Average farm rental costs per acre across the West Coast Region. For a map of county names see Appendix A.

The results show that rental costs including irrigation can vary widely from $25/ac in areas like Eastern Washington to over $2,000 in the Central and Southern Coast of California. Therefore, the rental and irrigation costs would likely play an important role in deciding the feasibility for the establishment of a hybrid poplar plantation. However, in reality the establishment of hybrid poplar is most suited to marginal farm and pasture land that is of limited value. Based on expert opinions and the average cost of sub prime farm land rental values calculated from the USDA/NASSA data set, it was determined that land rental with irrigation of around $56/ac was the best estimate for the rental and irrigation costs associated with land that would be suitable for hybrid poplar plantations. Any land much more expensive than this would probably be financially unfeasible. While Figure 16 shows that most counties would be excluded from considering hybrid poplar plantations based on land rental costs, it must be understood that even within counties land rental and irrigation is highly variable. Therefore counties that show a higher than $56/ac average rental cost should not necessarily be excluded. Based on the assumption that yearly rental and irrigation costs are $56/ac rental and irrigation costs were calculated. This resulted in total land rental costs of $336 over 6 years for bioenergy crop, and $1,120 over 20 years for multiple wood products crops.

3.4.2. Revenue

Revenue depends on the market the wood is designated for and the potential carbon credits that can be generated over the period of the crop rotation. For bioenergy the revenue is from wood chip and small logs. For multiple market wood products the revenue is from sawlogs and residuals wood products from the excess cuttings. For either management scenario initial capital would be needed because no trees are harvested during the development period. Therefore, there would be several years of negative cash flow followed by a relatively large positive net cash flow to perpetuity (Boswell *et al.* 2008).

3.4.2.1. *Multiple market wood products crop*

Planting hybrid poplar for carbon sequestration and multiple market wood products is estimated to be feasible at a 20 year harvest rotation. This was based on growth trajectories and the tree size necessary for merchantable sawlogs (Boswell *et al.* 2008). These growth trajectories and harvest rotation will vary depending different location across the West Coast Region, with higher potential in the Pacific Northwest, and possibly lower potential due to limited available moisture in drier Southern and Eastern regains. Development of a 20 year rotation carbon and multiple market tree farm is suggested to have approximately 440-680 stems per acre planted in stages so that a fully developed farm would have an even age class distribution and a sustained harvest volume. Carbon pools would grow steadily through the first twenty years as more acres were planted, peaking during the twentieth year (Boswell *et al.* 2008).

Based on the report by Green Wood Resources (Appendix C) for Lake County, to make a multiple market tree farm feasible it is estimated that approximately 17,900 acres would need to be planted. This would most likely be achieved by aggregating many different land owners in a particular area. The justification for a development of this scope is based on attracting the infrastructure that would be needed for cost effective delivery of goods and services, including nursery, production, farming and harvesting. A production volume of this magnitude would be necessary to attract the value added processing necessary to drive sawlog prices into the range of $400-$500 per thousand board feet (Boswell *et al.* 2008).

The revenue for a multiple market wood product crop over a 20 year rotation with a yield of 9 green tons/ac.yr is expected to be around $17,947/ac excluding carbon. This revenue is based on projected prices from the Greenwood report of $90/green tons for sawlogs, and $33/green tons for residual wood and small logs. The revenue from carbon credits after 20 years at $4/ton of $C0_2$ would be $425/ac, at $7/ton of $C0_2$ it would be $743/ac, and at $15/ton of $C0_2$ it would gross $1,592/ac.

For the multiple market wood product crop the net revenue with carbon is estimated to be $9,821/ac at a carbon price of $4/ton of $C0_2$, $10,139/ac at a carbon price of $7/ton of $C0_2$, and $10,989/ac at a carbon price of $15/ton of $C0_2$ (Table 7).

Table 7. Estimated revenue from a multiple market hybrid poplar crop over a 20 year rotation.

Products	Wood products
Sawlogs	$14,443.41
Small logs	$2,189.91
Residual	$1,313.95
Carbon credits *	$425 - $1,592
Gross revenue	$18,372 - $19,539
Net revenue (Gross – Cost)	$9,396 - $10,989

The carbon credits generated from a multiple market wood crop are based on a MAI 9 green tons/ac.yrac.y(Boswell *et al.* 2008) (Figure 17). This assumes marginal to good site suitability with 440 stems per acre, and irrigation supplied where needed.

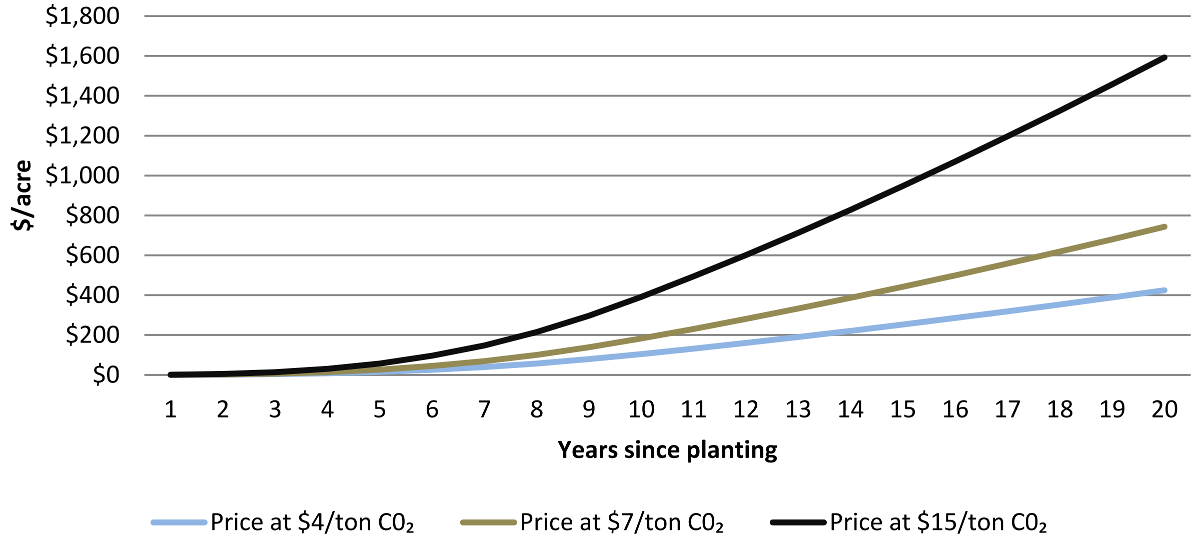

Figure 17. The revenue from hybrid poplar carbon credits per acre over twenty years of growth under a multiple market management scenario.

3.4.2.2. *Dedicated biomass energy crop*

A dedicated biomass energy tree farm where the only product is feedstock for a regional biomass plant is a very different management scenario than the multiple market wood product plantation. A dedicated hybrid poplar bioenergy plantation would require a short rotation of around 6 years, regenerated by coppicing. To achieve the financial requirements to meet market demands biomass crops generally requires relatively fewer acres with higher planting densities (stems/ acre) than multiple market plantations.

Using the numbers from the Greenwood report (Appendix C), the revenue from a dedicated bioenergy crop is estimated to be $650/ac, based on a 6 year rotation at a price paid per ton of $58/green ton. When carbon credits are included the net revenue at $4/ton of $C0_2$ is $737/ac, at $7/ton of $C0_2$ it is $802/ac, and at $15/ton of $C0_2$ it would be $976/ac (Table 8).

Table 8. Estimated revenue from a dedicated biomass hybrid poplar crop over a 6 year rotation.

Products	Biomass
Sawlogs	na
Small logs	$2,799.00
Residual	na
carbon credits	$86 -$325
Gross revenue	$2,885 - $3,124
Net revenue	$737 - $976

The carbon credits generated from a dedicated biomass crop are based on a MAI 8 green tons/ac.yr (Boswell *et al.* 2008) (Figure 18). This assumes marginal to good site suitability with 1,450 stems/acre, and irrigation is supplied where needed.

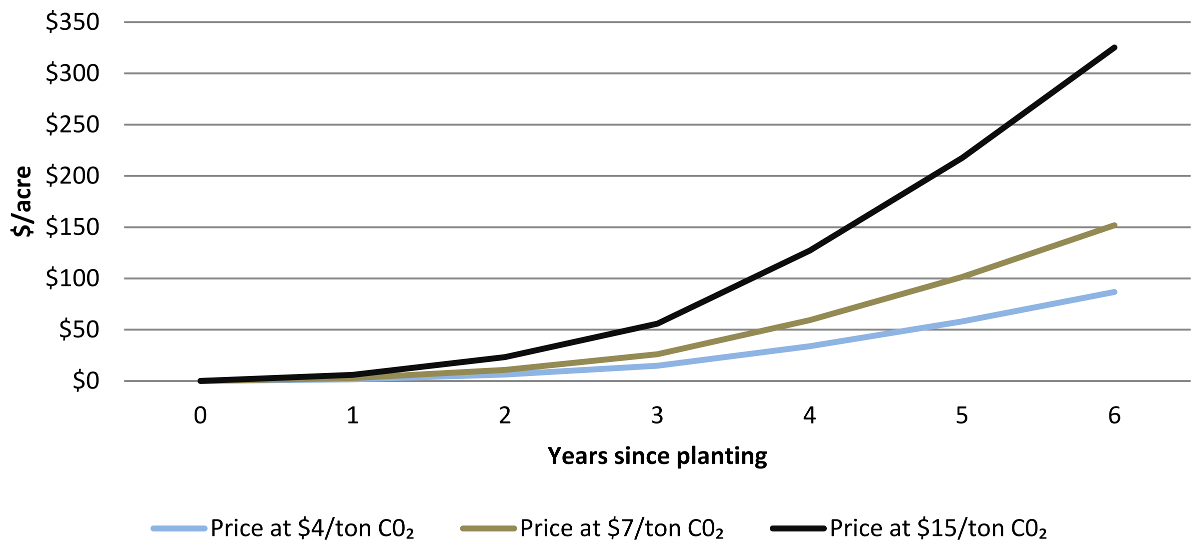

Figure 18. The revenue from hybrid poplar carbon credits per acre over six years of growth under a dedicated biomass management scenario.

4.0 Conclusions and Recommendations

4.1. Conclusions

This report describes the spatial distribution of potential afforestation sites where fast growing high-yielding forestry crops, most notably hybrid poplar, could be established. Results show that most of the prime lands ideal for hybrid poplar, and where no irrigation or limited irrigation would be needed, is located primarily in the counties west of the Cascade Mountains in Oregon and Washington State. If irrigation is supplied in areas where moisture availability is limited, the amount of highly suitable land throughout the West Coast Region more than doubles, and the counties identified with high potential for hybrid poplar plantations shift to the Central Valley of California, and the farm lands east of the Cascade Mountains in Washington State. The areas reported in this study as "eligible" for hybrid poplar may or may not be "available," and should only be interpreted as eligible for consideration. In reality many of the areas identified as eligible are prime farmlands which would not likely be considered for conversion to hybrid poplar because of the economic benefits of the current crops being grown on them. Similarly, areas such as native grassland would not be eligible for hybrid poplar due to the potential loss of important native biodiversity and ecosystem services. The reality is that areas within the eligible lands for hybrid poplar plantations would mostly be on marginal agricultural lands, degraded areas or as riparian buffers where both the economic and ecological benefits of planting poplars can be better realized.

The development of hybrid poplar growth and yield based on the suitability classes from the regional characterization map involved assumptions on the potential productivity of poplar under different site conditions. To improve the ability to project productivity and carbon sequestration more research needs to be conducted on growth and yield over longer periods of time and under different site conditions.   It also needs to be mentioned that due to the extent of this analysis productivity of hybrid poplars is based on generalized site conditions, and a more detailed analysis (for example, on a county level) should be conducted for locations identified as valuable for hybrid poplar plantations.

The results from the financial analysis showed decent revenues from hybrid poplar as a bioenergy crop and as a multiple wood product crop. When carbon is included in the revenue, bioenergy crops receive a much higher return than multiple wood products, with carbon from bioenergy crops making up 10-50% of the revenue, while for wood products carbon only makes up 2-10% of the potential revenue. However, any large scale hybrid poplar afforestation project needs to be assessed on a site by site basis, and depending on local markets, the price of goods, and the price of carbon credits financial feasibility will vary considerably.

The planting of hybrid poplars on pasture, farmland, or degraded lands has multiple environmental benefits in addition to its potential for reducing global greenhouse gasses through carbon sequestration. In particular hybrid poplars have been cited as valuable along riparian areas to reduce erosion, and as ground water filters taking up excess nutrient and chemicals coming from farmlands and other developed areas (Johnson, 1999; O'Neill and Gordon 1994; Schultz *et al.* 1994). Hybrid poplars have also been planted in degraded areas specifically to absorb organic chemicals such as trichloroethylene, carbon tetrachloride and atrizine dumped or spilled on the soil (Johnson, 1999; Gordon *et al.* 1997).

While these environmental benefits are all important considerations when evaluating the potential for establishing a hybrid poplar plantation, it is also important to consider the water demands that hybrid poplar needs for good production and the effects that those demands will have on the local and regional environment. Within the West Coast Region almost 75% of the eligible land is considered arid and prone to drought. Because of this the risks and environmental consequences of planting water demanding crops, such as hybrid polar need to be considered. In addition, climate change models predict that average temperatures in the Western US will increase, and the frequency and severity of some extreme weather events such as drought will also increase making some ecosystems, particularly vulnerable (IPCC, 2008).

Many poplar species are native to areas where there is high soil moisture; however, hybrid poplars are being used in many areas where soil moisture may be limiting and evaporative demands high (Nash 2009). Throughout these moisture-limited areas, which accounts for the majority of eligible hybrid poplar land in the West Coast Region, the availability of water for irrigation is going to be a major factor in poplar establishment, growth and survival.

Water requirements for hybrid poplar in the arid region of Eastern Oregon was found to be around 21 ac-in/ac of irrigation during the first year, 35 ac-in/ac during the second year, and 44 ac-in/ac for all the remaining years(1 acre-inch ≈ 27,100 gallons). By the end of the third year, trees receiving optimum irrigation averaged 26 ft tall and produced 256 ft^3 of wood/ac (Shock et al 2002). These irrigation requirements after the third year of growth are about 10-20ac-in./ac more than traditional crops such as sweet corn, which needs 20-35 ac-in/ac, and wheat, which uses about 25 ac-in/ac. In the more arid and water restricted areas of the West Coast Region these water requirements are considerable, and therefore may not be feasible.

While concerns about the amount of water available for hybrid poplar production is important, the amount of water that escapes as runoff is equally important to consider when looking at whole catchments. This is because forests are known to have a significant effect on water yield; as amounts of land change from open arable land to closed forest, water downstream may become limited (Perry *et al.* 2001). Studies that looked at other short rotation woody crops in the Southern US showed no difference in runoff when compared to corn or cotton during the first two growing seasons, but once the canopy closed, runoff volumes were lower (Thornton *et al*., 1998). In the Netherlands changes in soil water balance during a conversion from arable land to hybrid poplar showed a 23% reduction in percolation (Rijtema and de Vries, 1994). Measurements in Wisconsin show that the timing of water yield also changes as forests replace cultivated fields and other non-forested types of land use (Potter, 1991). Therefore, large areas planted in hybrid poplar may generate cumulative watershed effects on the cycles of flooding and on total water yield (Perry et al. 2001). These potential changes in the hydrology of watersheds due to increased plantations of woody crops like hybrid poplar could have varying effects on downstream water availability.

In summary hybrid poplar crops may provide considerable ecological and financial benefits if planted responsibly in locations that can support the needed production. These requirements include the ability to provide ample water now and into the future, good soil, investment into the proper infrastructure to properly establishment and maintain a healthy hybrid poplar crop, and a robust market demand that is predicted to remain strong over time.

4.1 Recommendations

Based on the conclusions from this Regional Characterization study, future research should be undertaken by conducting more detailed characterization studies on a county or local level, in areas identified to have high potential for hybrid poplar plantations. A more detailed local characterization study would follow a similar methodology, but would use a higher resolution soils analysis and, if available, a land ownership, current and past land use dataset. This next step would be essential for any project developer that wanted to begin identifying individual properties and sites for the establishment of hybrid poplar or other fast growing forestry crops. Development of local regional characterization studies could be accomplished in 2-4 month of time, and would likely cost from $25,000 to $35,000.

In addition, areas where large scale conversion of arable land to fast growing woody crops is planned, research should be conducted on water resources on a catchment level. The study would need to address the predicted change in the frequency of flooding events, and water availability downstream. A catchment level study like this would likely take 7-9 months and cost from $35,000 to $50,000.

More research into the growth and yield of hybrid poplar on different site conditions would greatly improve the estimated carbon sequestration numbers developed using the results from the suitability analysis. With better growth and yield numbers that are representative of different site conditions across the West Coast Region a more robust analysis could be conducted for the potential for hybrid poplar as a carbon sequestration crop.

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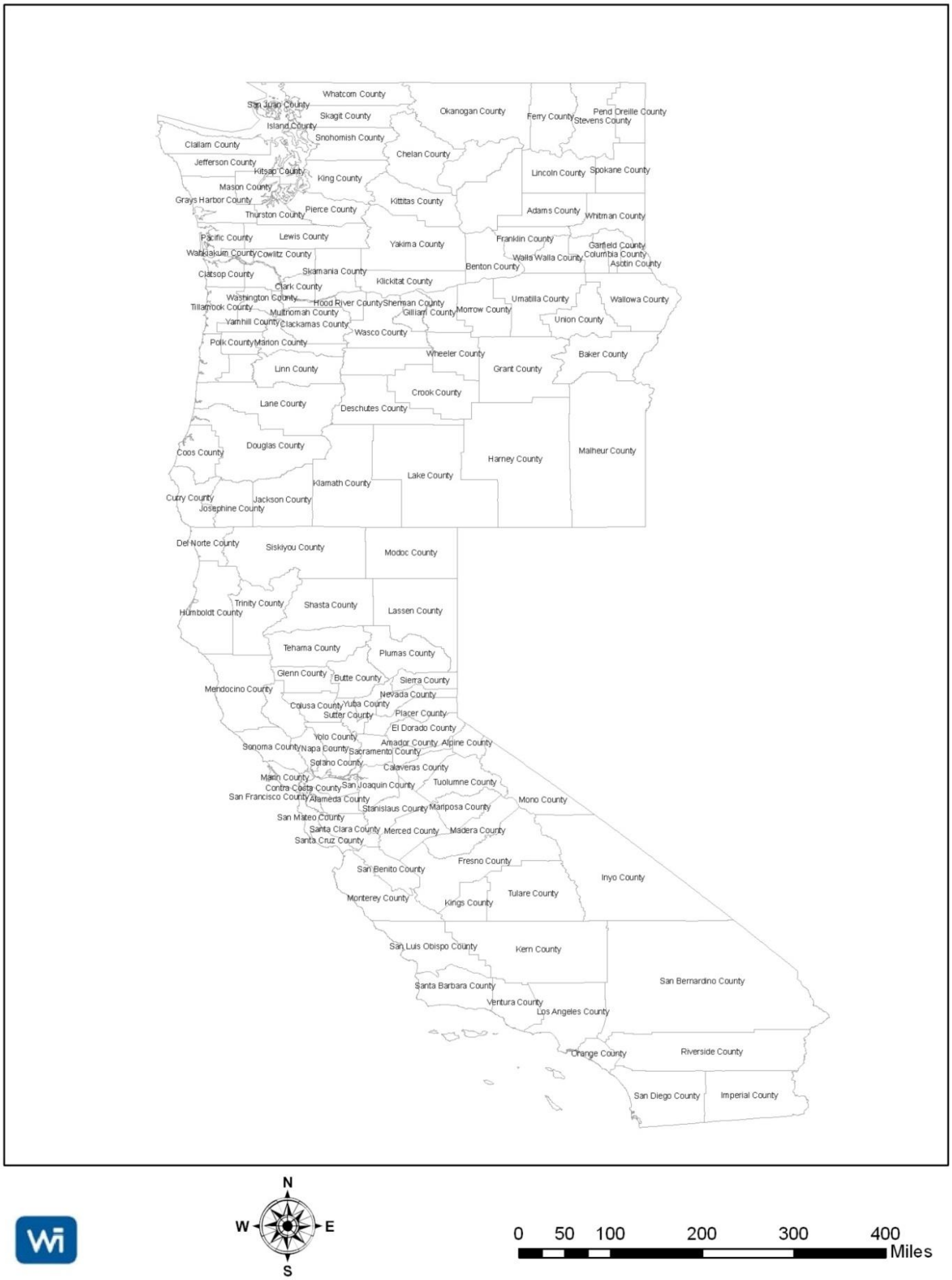
6.0 Appendices

Appendix A: County maps for the West Coast Region



Appendix B: Suitability tables

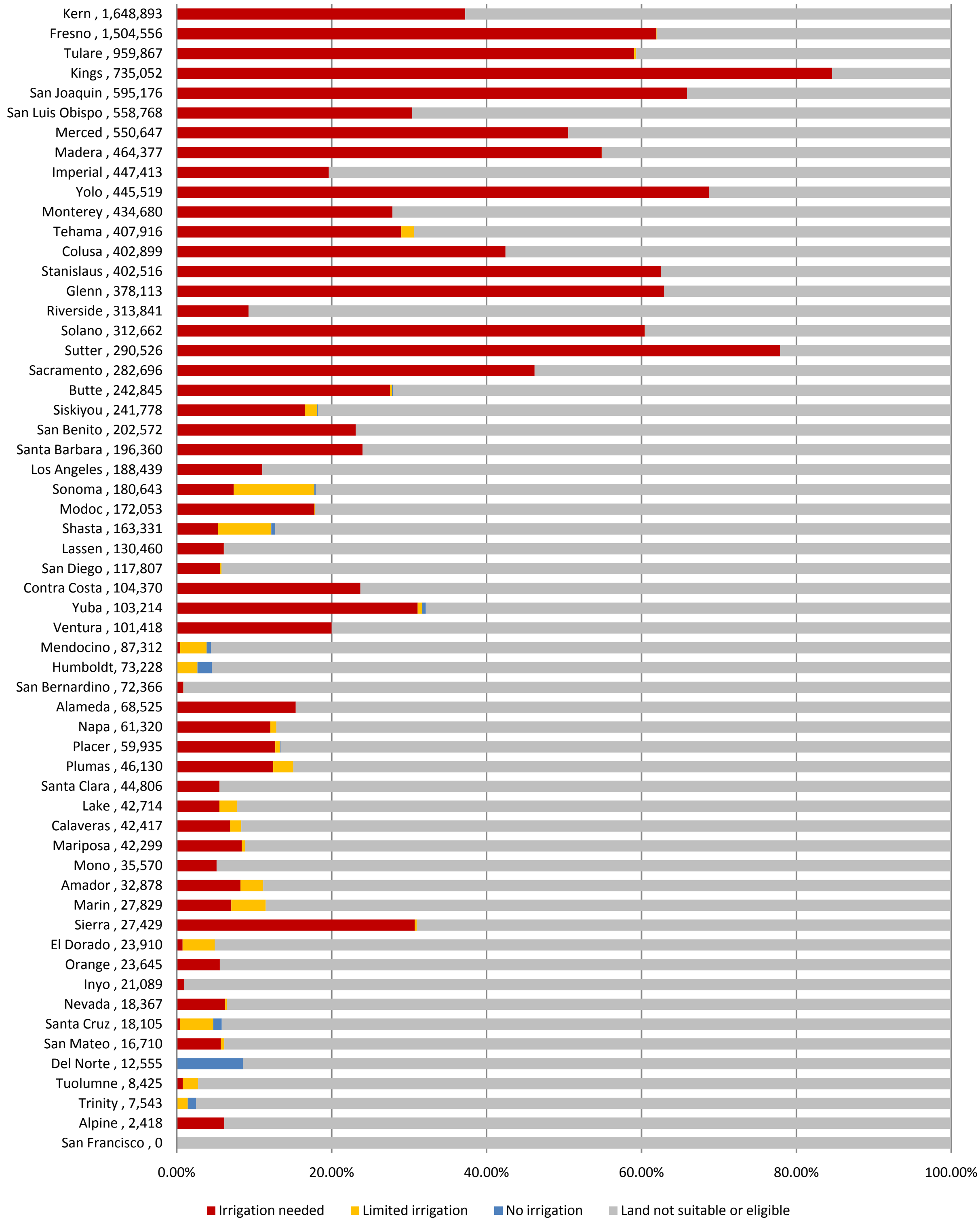
California

For each county in California: the total county area in acres and total area in acres for different suitability classes defined by irrigation need and soil quality. Counties are listed from the top starting with the county that has the most total suitable area and ending with the least.

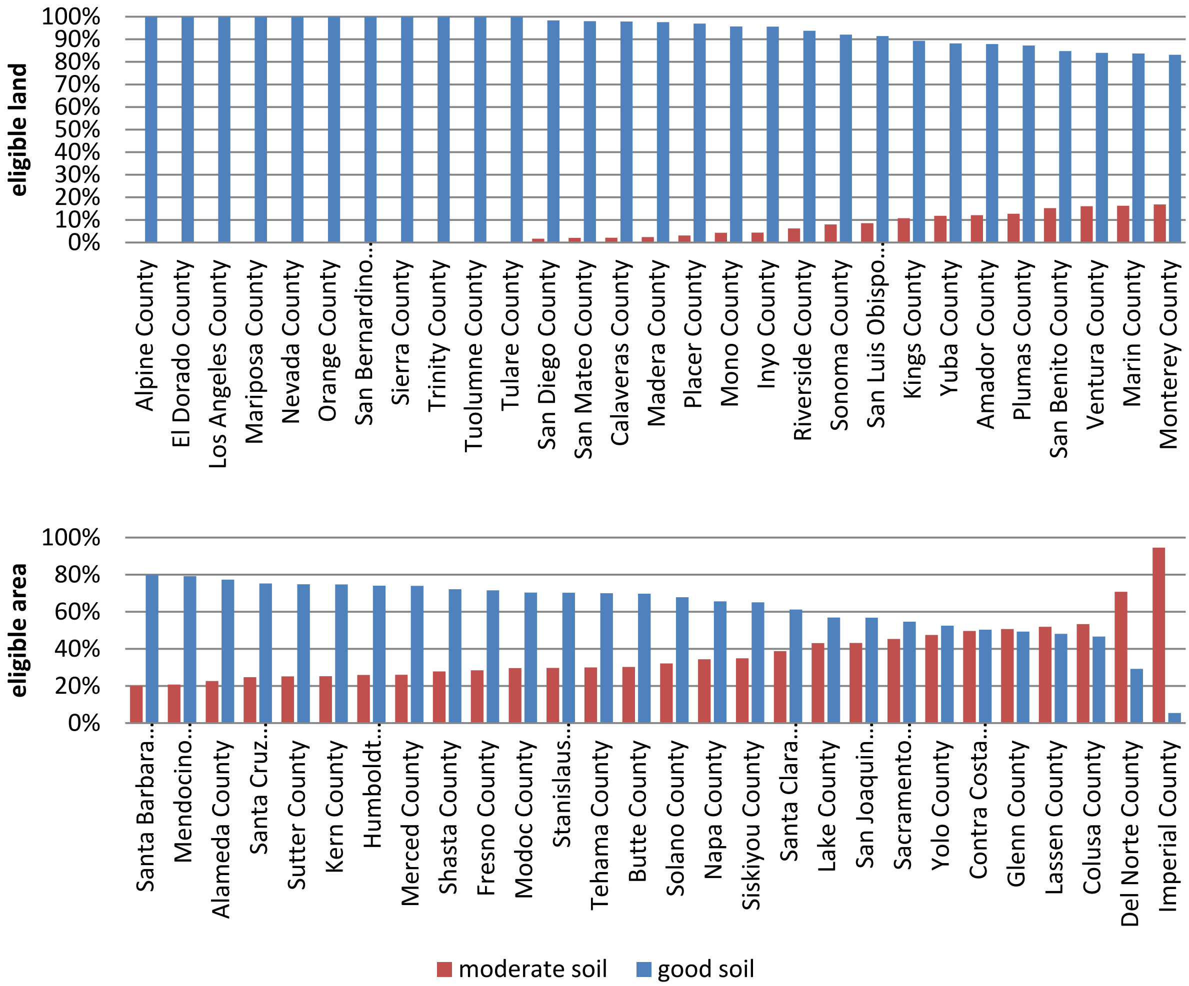
County	Total county area (ac)	Irrigation needed		limited irrigation		No irrigation	
		mod. soil	good soil	mod. soil	good soil	mod. soil	good soil
Kern	5,230,029	462,990	1,188,221				
Fresno	3,860,068	471,686	1,032,853		944		
Tulare	3,113,430	447	954,692		4,352		
Kings	886,075	82,604	652,746				
San Joaquin	909,370	259,866	335,751				
San Luis Obispo	2,110,712	56,680	501,500		37		
Merced	1,259,982	155,857	394,630				
Madera	1,376,835	12,637	451,025		294		
Imperial	2,906,856	432,838	14,483				
Yolo	649,929	219,693	226,251				
Monterey	2,119,460	102,625	332,108				
Tehama	1,893,861	123,068	262,848	1,559	20,382		37
Colusa	751,071	228,896	174,032				
Stanislaus	965,787	118,079	284,567				
Glenn	838,444	193,880	184,389				
Riverside	4,712,358	20,826	293,058		15		
Solano	530,486	105,148	207,988		7		
Sutter	388,378	72,589	217,902				
Sacramento	629,839	126,555	155,768				
Butte	1,070,372	71,926	167,298	163	2,024		904
Siskiyou	4,057,082	48,387	171,610	12,944	7,796	1,473	12
San Benito	893,088	47,959	155,054				
Santa Barbara	1,737,796	58,125	139,316				
Los Angeles	2,601,458		189,106				
Sonoma	1,017,997	11,970	62,116	6,459	98,016		1,678
Modoc	2,675,270	66,095	105,301		598		
Shasta	2,459,335	30,404	37,993	13,554	74,518	217	6,259
Lassen	3,034,187	77,340	52,276	815	467		
San Diego	2,737,798	3,035	110,816		4,035		
Contra Costa	461,288	65,175	38,786				
Yuba	412,063	12,459	87,240		1,740		1,601
Ventura	1,188,873	24,595	76,841				
Mendocino	2,252,637	4,789	4,001	28,811	38,277	1,965	9,462
Humboldt	2,280,571	121	62	40,954	2,155	5,147	24,765
San Bernardino	12,998,243		71,944		79		
Alameda	477,160	19,284	49,654				
Napa	502,674	24,758	32,811	2,664	1,035		
Placer	957,087	2,222	54,821		2,614		376
Plumas	1,670,256	54	37,865	6,057	1,858		
Santa Clara	825,451	19,675	24,711		84		
Lake	852,554	13,954	16,208	9,163	3,217		198
Calaveras	663,135	1,147	33,738		7,361		111
Mariposa	937,874		40,215		2,053		
Mono	2,000,916	2,026	33,513				

Amador	387,693	5,298	18,963		8,520		121
Marin	327,542	4,801	12,383	1,643	9,422		
Sierra	609,235		27,516		225		
El Dorado	1,143,277		3,660		20,181		25
Orange	507,643		23,683				
Inyo	6,562,967	959	20,186				
Nevada	627,701		1,231		13,396		3,464
Santa Cruz	284,960	5,726	11,627		625		
San Mateo	284,903	413	14,970		1,263		
Del Norte	647,515					11,683	877
Tuolumne	1,457,027		2,350		6,034		
Trinity	2,048,500		5		4,253		3,272
Alpine	472,833		2,424				
San Francisco	28,185						

The percent of land in each county in California State suitable for hybrid poplar plantations with irrigation, with limited irrigation, without irrigation and land not suitable or eligible for hybrid poplar. Counties are listed with their total acres of suitable land, and are listed from the top by county with the most suitable land to the least.



California counties and percent of eligible hybrid poplar plantation land that has 10-20cm/m of available soil moisture and >20cm/m.

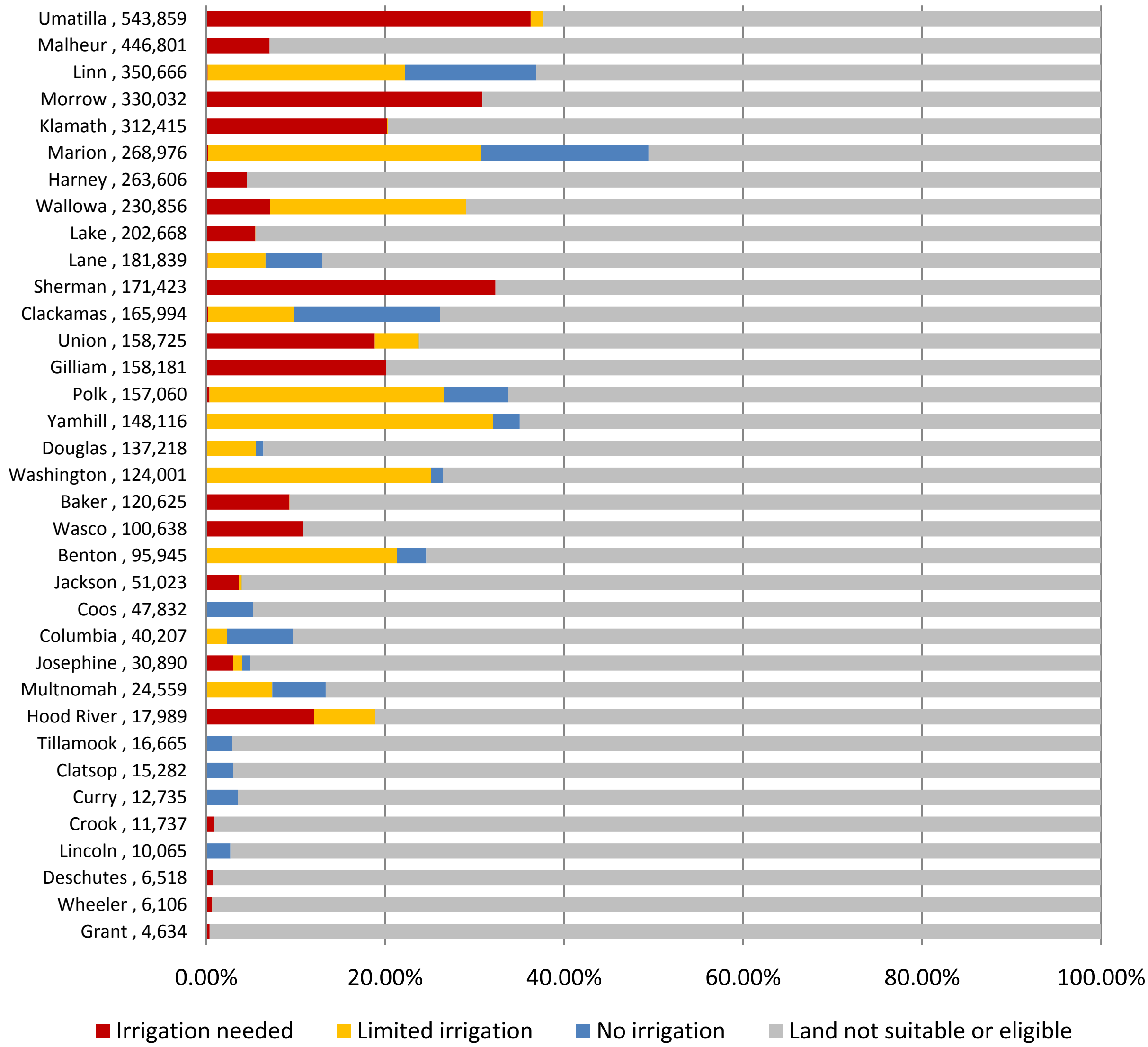


Oregon

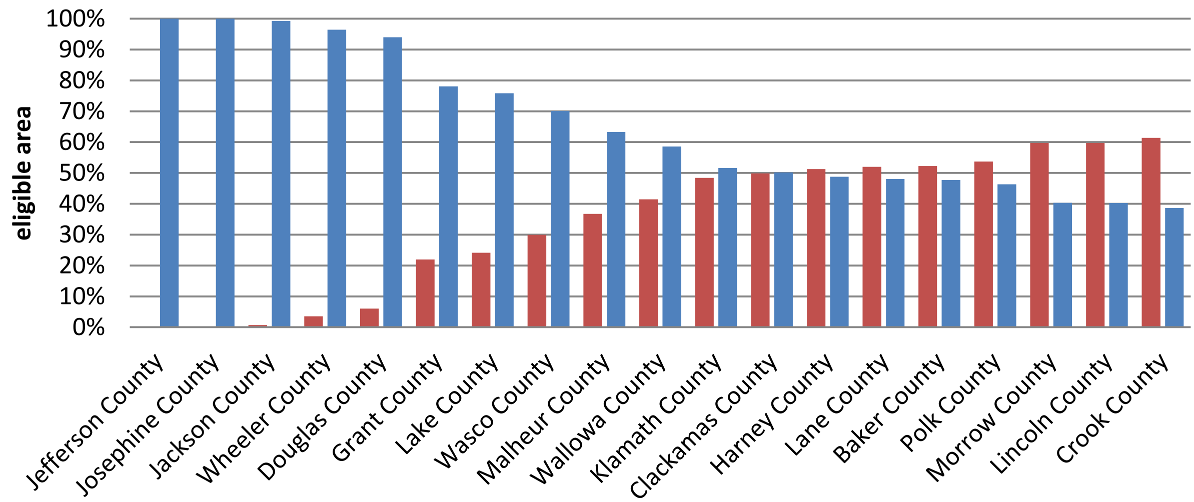
For each county in Oregon: the total county area in acres and total area in acres for different suitability classes defined by irrigation need and soil quality. Counties are listed from the top starting with the county that has the most total suitable area and ending with the least.

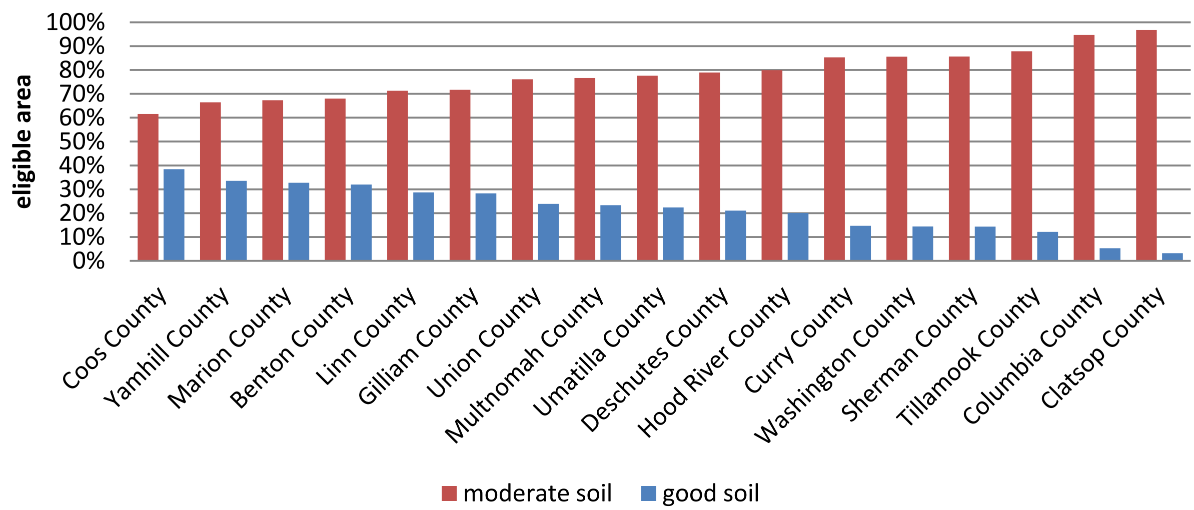
County	Total county area (ac)	Irrigation needed		limited irrigation		No irrigation	
		mod. soil	good soil	mod. soil	good soil	mod. soil	good soil
Umatilla	2,065,694	401,396	122,423	17,621	1,871	1,493	20
Malheur	6,359,939	181,517	265,386				
Linn	1,474,555	1,223	282	203,532	6,595	71,684	68,274
Morrow	1,306,137	206,960	123,118	403	5		
Klamath	3,917,677	120,236	190,376	497	1,011		
Marion	766,982	1,077		157,286	8,945	31,472	70,006
Harney	6,560,583	127,645	136,054				
Wallowa	2,023,678	18,877	38,052	32,055	142,108	27	
Lake	5,319,826	28,979	173,276	353			
Lane	2,952,154	1,307	880	72,680	18,815	44,072	44,626
Sherman	532,181	146,301	25,210				
Clackamas	1,205,138	1,129	86	56,971	3,709	30,345	73,745
Union	1,311,638	118,425	6,672	8,923	23,987	554	
Gilliam	789,084	114,229	43,988				
Polk	470,796	650	1,068	81,981	40,042	8,095	25,583
Yamhill	461,807	156	175	104,275	30,521	3,111	9,284
Douglas	3,233,476		1,300	8,530	109,739	1,611	16,109
Washington	469,981	69	74	108,832	8,627	2,261	3,988
Baker	1,983,789	74,521	46,222	17	126		
Wasco	1,529,122	28,761	71,973				
Benton	440,108	128	250	68,551	14,105	6,057	6,865
Jackson	1,788,473		46,862	647	3,195		341
Coos	1,019,176					37,662	10,094
Columbia	419,907	15		9,479	217	28,141	2,264
Josephine	1,044,672		19,047		6,331		5,535
Multnomah	270,509	17	32	13,134	447	6,133	4,653
Hood River	344,017	10,784	724	6,116	373		
Tillamook	694,396					16,159	516
Clatsop	512,313					14,965	321
Curry	1,037,627					12,467	284
Crook	1,913,239	11,174	568				
Lincoln	622,959					8,239	1,804
Deschutes	1,969,029	4,646	1,831				
Wheeler	1,094,675	158	5,874	72			
Grant	2,902,349	2,629	2,007				
Jefferson	1,143,034		2,385				

The percent of land in each county in Oregon State suitable for hybrid poplar plantations with irrigation, with limited irrigation, without irrigation and land not suitable or eligible for hybrid poplar. Counties are listed with their total acres of suitable land, and are listed from the top by county with the most suitable land to the least.



Oregon counties and percent of eligible hybrid poplar plantation land that has 10-20cm/m of available soil moisture and >20cm/m.



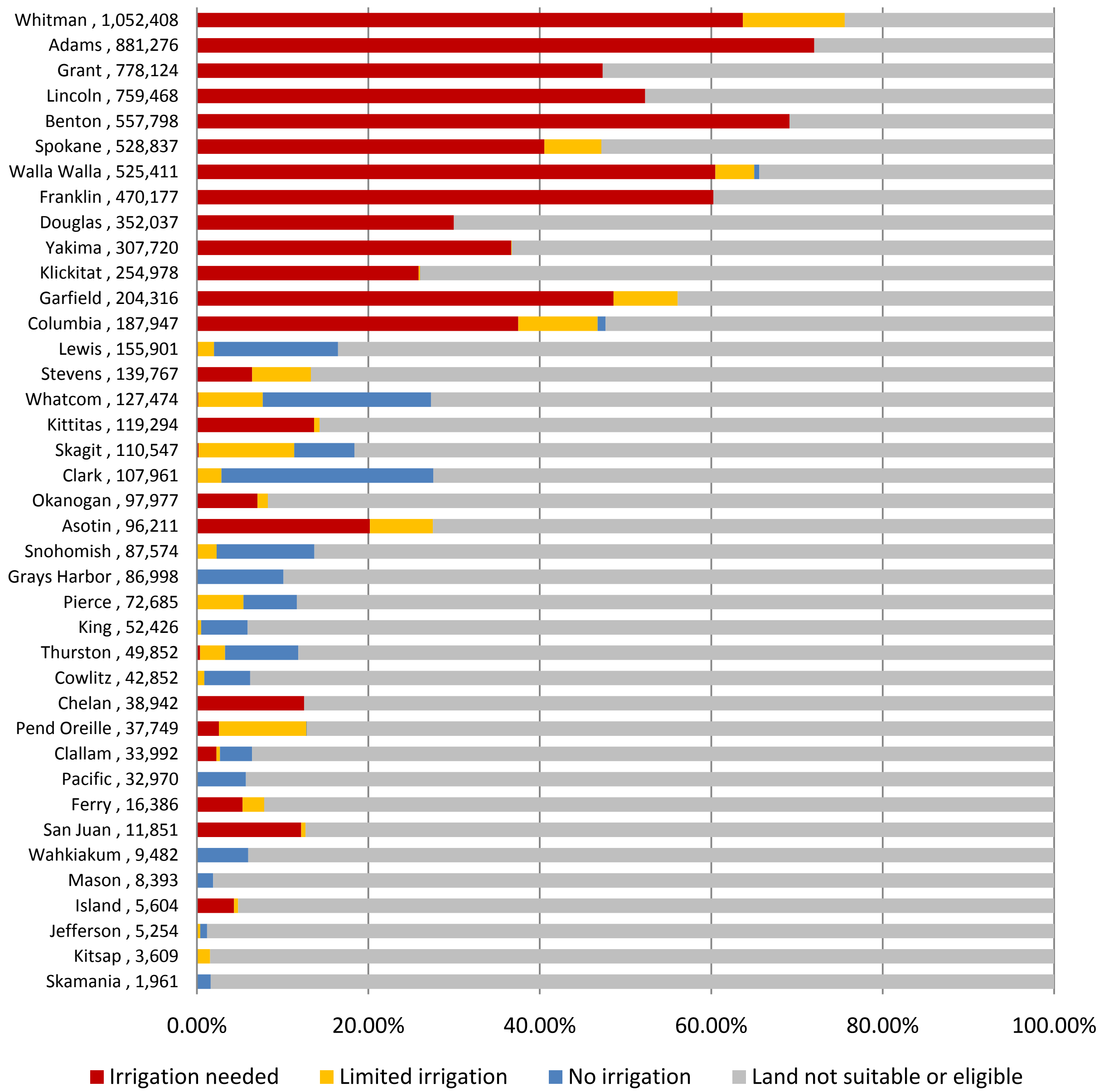


Washington

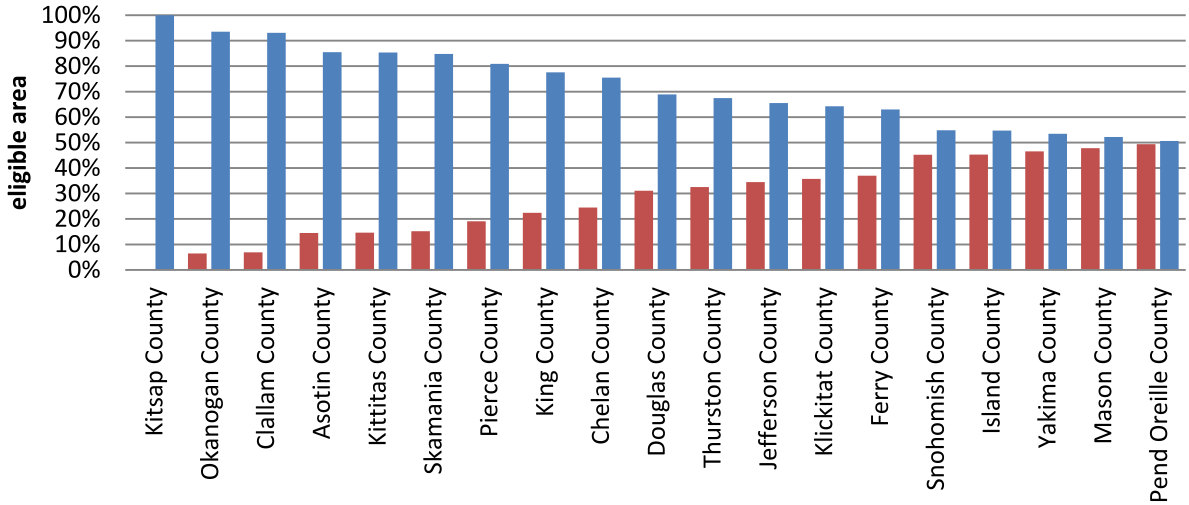
For each county in Washington: the total county area in acres and total area in acres for different suitability classes defined by irrigation need and soil quality. Counties are listed from the top starting with the county that has the most total suitable area and ending with the least.

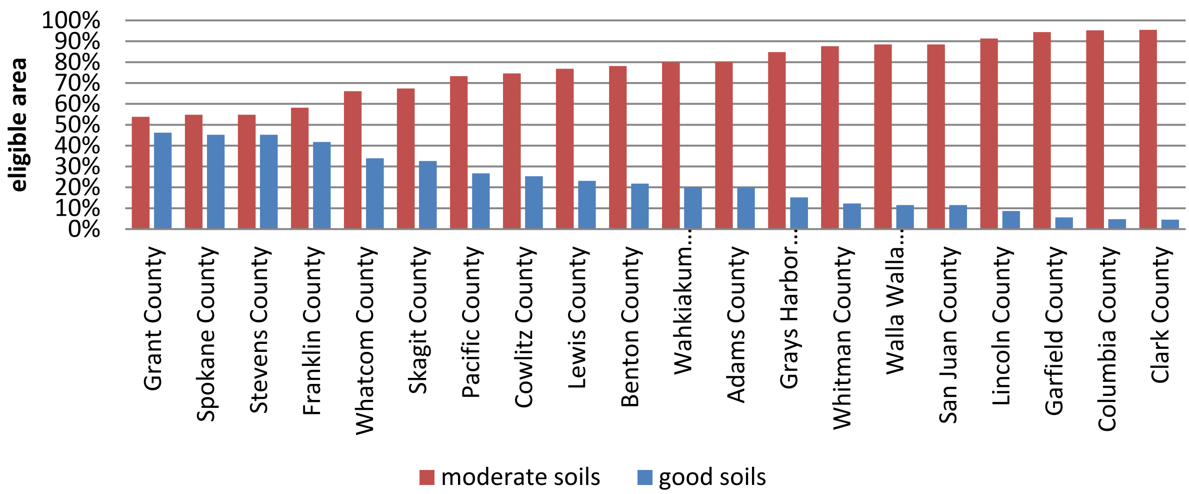
County	Total county area (ac)	Irrigation needed		limited irrigation		No irrigation	
		mod. soil	good soil	mod. soil	good soil	mod. soil	good soil
Whitman	1,394,249	805,702	82,858	163,787	1,675		
Adams	1,240,927	710,019	171,707				
Grant	1,787,544	417,863	360,655				
Lincoln	1,491,771	707,674	50,729				
Benton	1,118,059	427,992	130,037				
Spokane	1,147,277	242,217	211,170	52,872	21,953		5
Walla Walla	824,831	424,251	59,482	29,989	6,442	4,806	
Franklin	815,241	275,033	196,850				
Douglas	1,177,818	113,614	238,313				
Yakima	2,770,153	171,027	135,906	40	445	5	5
Klickitat	1,197,490	78,492	174,929	682	1,100	262	121
Garfield	460,833	174,213	2,765	19,517	7,675		
Columbia	554,868	140,482	7,347	36,370	17	3,605	15
Lewis	1,559,867	934	190	12,516	5,288	120,899	16,159
Stevens	1,625,069	48,117	19,611	37,158	34,865		5
Whatcom	1,372,249	731	25	34,259	853	81,959	9,657
Kittitas	1,491,040	23,898	89,980		5,382		126
Skagit	1,128,240	1,137		66,156	1,035	23,295	18,862
Clark	406,676	361		10,220	618	93,590	3,287
Okanogan	3,384,970	16,509	67,113		14,283		37
Asotin	410,151	2,908	67,750	6,845	18,756		
Snohomish	1,342,363	343	156	11,360	2,891	33,632	39,347
Grays Harbor	1,222,223					78,789	8,187
Pierce	1,077,276		410	6,716	26,673	5,323	33,602
King	1,408,057	15	44	4,186	77	13,003	35,075
Thurston	471,088	756	741	1,493	10,922	8,389	27,568
Cowlitz	732,014	269		5,187	447	30,496	6,338
Chelan	1,912,921	27,254	11,614				
Pend Oreille	904,984	5,810	1,727	14,918	14,982		131
Clallam	1,132,794	82	12,064	1,275	880	1,171	18,640
Pacific	592,068					24,736	8,318
Ferry	1,450,098	8,342	2,768	3,902	1,384		
San Juan	111,844	11,029	368	269	203		
Wahkiakum	161,625					8,417	1,107
Mason	621,205					6,346	1,955
Island	137,257	2,177	2,886	524			
Jefferson	1,165,425	15		1,638	20	74	3,511
Kitsap	254,420				3,628		
Skamania	1,067,436		10		82	1,463	393

The percent of land in each county in Washington State suitable for hybrid poplar plantations with irrigation, with limited irrigation, without irrigation and land not suitable or eligible for hybrid poplar. Counties are listed with their total acres of suitable land, and are listed from the top by county with the most suitable land to the least.



Washington counties and percent of eligible hybrid poplar plantation land that has moderate (10-20cm/m ASW) and good (>20cm/m ASW) soil conditions





Appendix C – Greenwood Report

See attached: “Lake County Hybrid Poplar Feasibility Study and Carbon Sequestration Opportunities.”