Permaculture Design: Tools for Climate Resilience

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Andrew Millison

Andrew Millison has been studying, teaching and practicing Permaculture since he took his first design course in 1996. He started teaching Permaculture at the college level in 2001, and has been an instructor at OSU in the Horticulture Department since 2009. Andrew currently teaches the for-credit courses Permaculture Design Course (Hort 285) and the Advanced Permaculture Design Tools for Climate Resilience (Hort 485) at OSU, on campus and online.

Andrew teaches non-credit courses for the general public as well, including the:

- Free Introduction to Permaculture Massive Open Online Course
- Free Permaculture Water Design: Drought Proofing Farms open source module
- Permaculture Design Certificate Course
- Advanced Permaculture Design Tools for Climate Resilience

Andrew also has produced two open source textbooks for his courses that are freely available:

- Introduction to Permaculture
- Permaculture Design Tools for Climate Resilience

Andrew first learned Permaculture in the drylands, where he studied at Prescott College for his undergraduate and Master's degrees.

In Arizona, his focus was on rainwater harvesting, greywater systems, and desert agriculture. He started a Permaculture landscape design and build company, and also worked in an ecologically-based Landscape Architecture firm. In recent years, Andrew's focus has been more on broad scale farm planning, Permaculture housing developments, and obtaining water rights. In 2015 he founded Permaculture Design International, a collaborative design firm for working on large scale projects globally. Andrew brings his rich experience of designing and building his own and clients' projects for nearly 20 years to his teaching, and seeks to impart real world experience to his students.

Andrew is a permaculture diploma holder from the Permaculture Institute of North America.
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Andrew Millison

April, 2018

PART I

PART 1: CLIMATE ASSESSMENT

Korail in Dhaka. Photo by Development Planning Unit University College London.

One of the 12 Permaculture principles articulated by its' co-founder David Holmgren[1] encourages us to "Design from Patterns to Details". This means that we establish a general ecological and social context for a site before ever examining and designing intricate details of a place. We begin to establish our site context from the widest possible view. Climate is the largest scale geophysical pattern that we need to understand in order to place ourselves within the world.

Climate is also where we begin the design process in another tool referenced in the Permaculture design

1. Holmgren, David. Permaculture Principles and Pathways Beyond Sustainability. Alice Springs: Meliodora Publishing. 2002. Print

system. This is the Scale of Landscape Permanence, originated by P.A.Yeomans, the founder of Keyline™ Design.[2] Yeomans asserts that the order of design is:

1. Climate
2. Landshape
3. Water Supply
4. Roads/Access
5. Trees
6. Structures
7. Subdivision Fences
8. Soil

This book is predominantly about climate, and the macro influences of climate and climate change on design. As we get through the topics of climate analogues and climate change forecasting, we will end up moving down this list to see the climate's influence on specific design choices.

2. Yeomans, P.A. Water For Every Farm. Southport: Keyline Designs, 1968. Print.

1. Climate

Climate Definition

According to the Intergovernmental Panel on Climate Change:

> Climate in a narrow sense is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.[1]

In the permaculture design process every design is site specific and responds to it's unique conditions. We have a lot of examples to observe and study that can help guide our design decisions based on what has worked for other people in similar climates. Identifying and assessing our climate type is the first major step to understanding what the major forces are that we will be responding to in our designs.

Resilience Definition

1) The capability of a strained body to recover its size and shape after deformation caused especially by compressive stress

2) An ability to recover from or adjust easily to misfortune or change [2]

1. "Glossary". Working Group 1: The Scientific Basis. Intergovernmental Panel on Climate Change. Web. Dec. 2017. https://www.ipcc.ch/ipccreports/tar/wg1/518.htm
2. "Definition of Resilience". Merriam-Webster. Web. Mar.2018 https://www.merriam-webster.com/dictionary/resilience

Climate Resilience

Climate resilience is a term that begun to show up as a search term on Google and gained popularity starting around 2008. It is used by governments and scientists to encompass the dual process of both mitigating risk and adapting to changes. It can be seen as a shortening of the phrase "climate change resilience" and has various definitions. The following section will explore just a few of many out there:

"The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption."

- The National Oceanic and Atmospheric Administration's "U.S. Climate Resilience toolkit" [3]

"Climate-resilient pathways include strategies, choices, and actions that reduce climate change and its impacts. They also include actions to ensure that effective risk management and adaptation can be implemented and sustained."

- International Panel on Climate Change [4]

"Resilience is the capacity of a system, be it an individual, a forest, a city or an economy, to deal with change and continue to develop. It is about how humans and nature can use shocks and disturbances like a financial crisis or climate change to spur renewal and innovative thinking."

- Stockholm Resilience Centre of Stockholm University in Sweden[5]

"Climate resilience can be generally defined as the capacity for a socio-ecological system to: (1) absorb stresses and maintain function in the face of external stresses imposed upon it by climate change and (2) adapt, reorganize, and evolve into more desirable configurations that improve the sustainability of the system, leaving it better prepared for future climate change impacts."

3. "Glossary". U.S Climate Resilience Toolkit. Web. Mar.2018. https://toolkit.climate.gov/content/glossary
4. Denton, F., T.J.Wilbanks, A.C. Abeysinghe, I. Burton, Q. Gao, M.C. Lemos, T. Masui, K.L. O'Brien, and K.Warner. "Climate-resilient pathways: adaptation, mitigation, and sustainable development. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change" [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Print.
5. "What is resilience? An Introduction to a Popular Yet Often Misunderstood Topic". Stockholm Resilience Centre. Web. Stockholm University. Mar. 2018.http://www.stockholmresilience.org/research/research-news/2015-02-19-what-is-resilience.html

- Wikipedia's definition which is a conglomeration of several sources [6]

From the permaculture perspective, this text takes the approach that "the problem is the solution", and focuses on identifying some of the tools and techniques that can help social-ecological systems to both forecast and innovate around climate change disturbances in a creative way. This will allow for the continual development of productive and ecologically harmonious human societal systems as a response. The interpretation of resilience being used in this text does not see Earth's socio-ecological systems bouncing back to what they were prior to accelerated climate change, because the changes are already well under way and are set irreversibly in motion. Our definition sees resilience as evolution, where humanity adapts or transforms its relationships with socio-ecological systems in an inventive way in the face of massive disturbance. The results of this metamorphosis being a novel and healthy ecosystem.

Social Dimensions of Climate Change

The social dimensions of climate change is a topic that could fill many books unto itself, and there are many books and articles dedicated to the subject. It's impossible to get into any detailed discussion about climate change's impact without the human economic, social and political implications arising. How we respond now and in the future will determine the direction of humanity.

Some of the disruptions that are projected to affect people and nations are sea level rise, the intensification of oceanic-borne super storms, drought-induced crop failures, wildfire, stress and failure of water distribution systems, the migration of insect-borne diseases, and a myriad of other possible outcomes from climate destabilization. There will be changes in the geographic range that particular crops will thrive in. There will be extreme heat events in cities that will stress power grids and other critical infrastructure. There will be those working on mitigation and adaptation to these problems and those that deny and blame and point fingers.

The destabilizing effects of climate change are bound to have the greatest impacts on the poor who do not have the financial agency to relocate, survive a crop loss, rebuild a destroyed home, or turn on or up the air conditioner during an extreme heat wave. Countries like The Netherlands, who are mostly below sea level and have been designing around protection from sea levels since their inception have striking engineering feats like massive sea walls and floodgates to protect them from the sea. But these are costly pieces of infrastructure which will only ever go in to protect the most valuable real estate in the current capitalist world economy.

6. "Climate Resilience". Wikipedia. Web. Mar.2018. https://en.wikipedia.org/wiki/Climate_resilience#Definition_of_climate_resilience

Photo 1: Oosterscheldedam Sea Wall, The Netherlands. Creative Commons

For many people, fleeing a bad situation and becoming refugees or staying where they are in abject poverty and substandard living conditions will be the only options. For some societies war will be the response to the stresses that climate instability will cause. There are dark roads that humanity has taken in the past in response to crises of survival, and these are pathways that we need to dedicate ourselves to avoiding.

This book aims to provide vital tools of foresight into what we are expecting to face so the design response can be inventive and insightful. Having the ability to decipher the patterns of landscape and climate and foresee the potential shifts provides pertinent information for an appropriate permaculture design response.

Although this book is primarily focussed on the geophysical mechanics of climate change, deciphering the projections, finding analogue climates, and learning the major design responses to the hazards we face, at its core the goal is to better prepare humanity so we can enter this disruptive phase with grace, foresight and intelligence. The permaculture ethics of "Earth Care, People Care, and Reinvestment of Surplus" into those ethics are served by this work. Please use these tools for the betterment of earth and it's peoples.

Climate Analogue Introduction

Throughout the planet there is an exceptional diversity of climate zones and microclimates within those zones. Each ecoregion of the world is unique in so many ways. precipitation patterns, temperature, topography, vegetation, and global air and ocean circulation patterns, for example. That's not even mentioning the incredibly diverse human elements including culture, politics, history and land use.

No two places are exactly alike in all of these regards, so the design patterns for a particular region will not look exactly the same anywhere else. Permaculture is about comprehensively site specific design. Each place has its unique confluence of factors, both human and ecological, which the design is a response to.

There are, however, a great many similarities between ecoregions. Many places do have similar rain and snowfall patterns, prevailing winds, elevation profiles, plant types, and average high and low temperatures. When you locate another place on the planet with very similar conditions to your own, there is a treasure trove of information to be gleaned. What are the thriving plants species present there? What are the traditional and indigenous agricultural and horticultural practices? What is the vernacular architecture? What animals are present? Are there species and practices that could be relocated or borrowed that would assist in the development of a permaculture system in another location?

The answers to the above questions are the reasons to locate your climate analogue. This is not just a practice to help design within your region as a permaculturist. It also helps when assessing and designing a site anywhere in the world. Maybe you are not familiar at all with the plant types and practices in Hangzhou, China, but perhaps you are familiar with plants and methods in Jacksonville, Florida, USA which has a similar latitude, elevation, and location on a continental eastern coast with the same potential for powerful hurricanes and typhoons. The knowledge possessed about Jacksonville is now directly transferable to working in Hangzhou.

Climate Analogue and Climate Change Analogue

Terminology within the permaculture field is often different from conventional terminology. The jargon around permaculture is actually a common critique. In the permaculture field a climate analogue (as described above) is a climate that is currently analogous to another. However, in more mainstream scholarly articles a climate analogue primarily refers to the future climate after climate change.

In this book I will be discussing both current and future climate analogues. So for clarification, I will refer to a current climate analogue as a **Climate Analogue** and a future climate analogue to a **Climate Change Analogue**.

Climate's Ingredients

Robert G. Bailey put it simply in his seminal work Ecosystem Geography: "The spatial distribution of life forms today [is] a function of latitude, continental position, and elevation".[7] These are the three primary geographic positions that determine climate, and in this next section we will be looking at different aspects and ways to articulate these three basic elements.

The Earth is an incredibly diverse place with many unique combinations of factors that shape the climate conditions of a particular location. Every place has dominant forces that are the most important conditions to design for in order to create a resilient and productive Permaculture system. As we go through each of the climate ingredients, you should be filling out the "Climate Analogue Worksheet" for your location, located in the appendix of this book. The information that you gather will be used later on to find climates that are analogous to your own. You can glean important knowledge about things that are working in other similar climatic locations to you in other parts of the world. From a practical design sense this could include plant and animal species to responsibly introduce[8], water management practices, architecture and building techniques, village and city design, wildfire mitigation, gardening and horticultural techniques, cultural practices, and other things. The possibilities are endless for what can be learned from studying an analogue climate.

Latitude

Finding an analogous latitude is one of the important and first things to look at when identifying a climate analogue for your current location. There are the general climate types based on latitude which are the frigid, temperate, subtropical and tropical zones in both the Northern and Southern hemispheres (see diagram below). Each of those zones covers a wide expanse, and there are significant differences between the extreme ranges within each zone. For example Anchorage, Alaska and San Francisco, California are both located at sea level on the coast within the temperate climate zone but are 24 degrees latitude apart and have extremely different day-length variations and average daily mean temperatures over 20°F (10°C) apart.

Solar radiation, also known as insolation, is highest at the equator and decreases as one travels towards the poles. This variation is due to the amount of atmosphere which sunlight needs to pass through, and the angle with which it strikes the Earth's surface. This angle becomes more acute during winter as one gets closer to the poles, and the sun passes through a lot of atmosphere when it is hitting the land at an acute

7. Bailey, Robert G. Ecosystem Geography. New York: Springer, 1996. Print.
8. Observe codes of conduct to reduce the threat of invasive species introduction. Chart from this page: https://www.bgci.org/resources/article/0698

angle. The closer a location is to the poles, the more day-length varies with the seasons and the colder average temperatures are when all other things are equal, like elevation and proximity to a water body. At the Arctic and Antarctic circles it is dark all day and night on the Winter Solstice, and is light all day and night on the Summer Solstice. At the equator day length does not vary throughout the year.

There is no solid rule for determining the temperature change as one changes latitude. If the Earth were a homogenous sphere with no topography or different materials or currents, there would be a consistent temperature gradient that would follow latitude and the decrease in solar radiation as one moves away from the equator. But topography is irregular. Mountain ranges are found at every latitude, running in every direction. There are oceans, ice caps, land masses, and currents that have different capacities to absorb, store, reflect, and transfer heat. Because of this and other factors that influence temperature in a particular region, it is very seldom that latitude is an isolated influence and temperature changes can be mapped solely on latitude changes.

On the coasts there are warm and cold ocean currents that affect temperature. Islands and peninsulas have temperatures moderated by surrounding ocean. The tip of the Southern Hemisphere is surrounded by ocean with substantial temperature moderation. The Gulf Stream current brings warm water that moderates the temperature in Western Europe. The interiors of continents have mountain ranges and elevation changes that alter temperature and the flow of warm and cold air masses. The Earth is just too irregular to have a solid rule about latitude's effect on temperature. But there are general trends.

The tropics are located between the equator and tropics of Cancer and Capricorn at 23.5 degrees North and South. In the tropics latitude's effect on temperature change is lowest because the angle of the sun does not change dramatically with the seasons. The angle stays mostly overhead and latitude is not a dominant factor in determining climate.

The subtropics compose a relatively narrow band roughly between 23.5 degrees and 34 degrees. The change in temperature due to latitude begins to increase here. But it is still not a major factor due to the narrow range of the subtropics.

The rate of change in the temperate zone becomes much more dramatic, which exists from around 34-66 degrees latitude. This dramatic rate only increases beyond the arctic circle where each degree change in latitude provides an exceptional difference in insolation and temperature.

In the Southern Hemisphere there is a lot more ocean, and this really moderates the rate of temperature change between latitudes. So there will be less change as one goes further South. Additionally, South America and Africa are shaped like points to the South, so the increasing amount of ocean surrounding them as one goes further South helps to moderate the temperature just as the latitude affects increase.

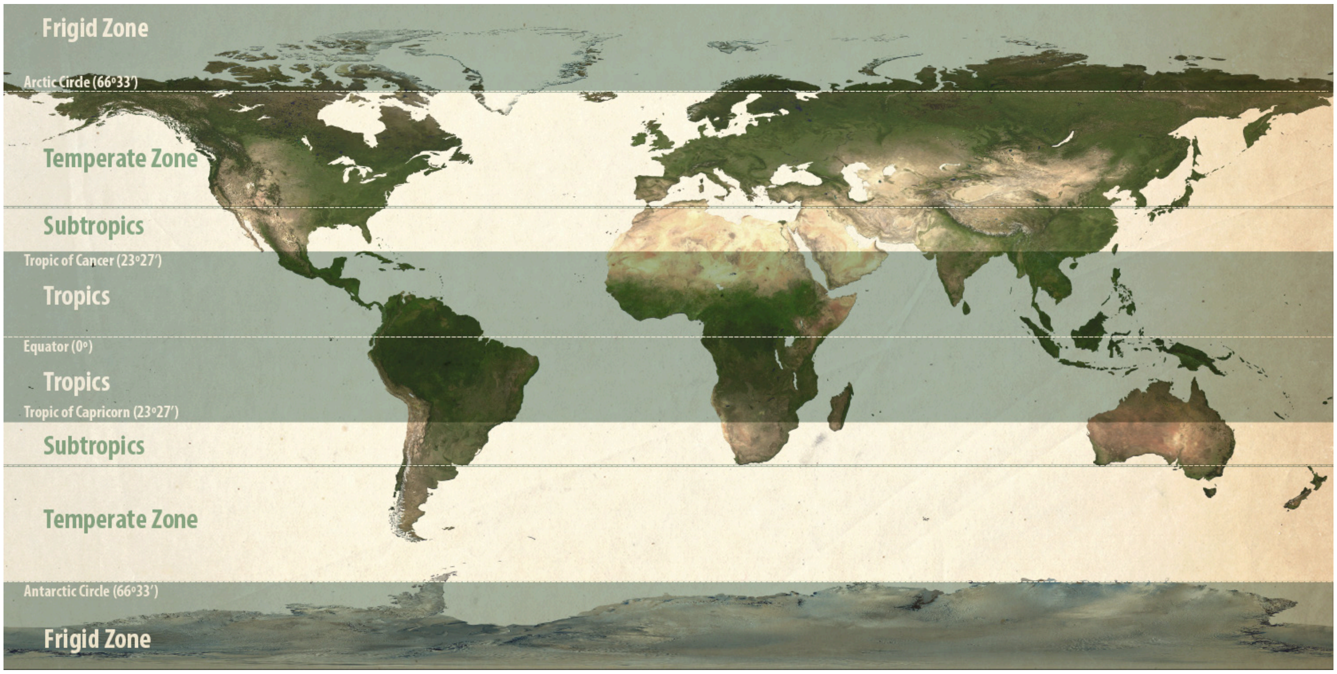

Figure 1: Climate Zones

Elevation / Altitude

> **"We can describe the actual arrangement of ecosystems by the interplay of the principal of climatic regularity and surface irregularity." – Robert G. Bailey[9]**

Elevation serves a huge role in determining the climate of an area. If it were not for elevation changes, the world would have much more regular and consistent temperature gradients based on latitude. Changes in elevation are irregular and were formed by plate tectonics. Elevation seems to have no correspondence to latitude. There are interesting interactions between latitude and elevation that influence climate on a macro scale. For instance, on the west coasts of North and South America, the major mountain ranges are running in a north-south direction, placing them perpendicular to the atmospheric flows of the subtropical and polar jetstreams. This makes it easier to find an analogous climate because there is somewhat of a mirror image between these two continents on the West coasts.

The change in temperature is measurable with rise and fall in elevation because air expands and cools as it rises in altitude. The average rate of atmospheric cooling is 6.5 degrees C per kilometer. So as an easy "rule of thumb" way to calculate the temperature effects of altitude change this translates to roughly 2 degrees C per 300 meters or about 3.5 degrees F per 1000 ft.[10]

9. Bailey, Robert G. Ecosystem Geography. New York: Springer, 1996. Print.
10. Dasch, E. Julius. "Macmillan Encyclopedia of Earth Sciences"Simon and Schuster Macmillan, 1996

This means that where I lived in the high desert town of Prescott in the Arizona Mountains at an elevation of 5300' (1600m) and a latitude of 35°N, the mean annual temperature is just about the same as that of The Dalles, Oregon located at 700' (215m) and at a latitude of 45°N. Higher altitudes at lower latitudes equal lower altitudes at higher latitudes. There are many resources to determine elevation. Below is a world map of elevations. Determining a location's elevation is a key component to finding a climate analogue.

It's important to remember that there are also other topographic influences that can play a big role in temperature. For example, cold air drainage in a canyon or bottomland where a valley bottom can be cooler than the temperature at a higher elevation. It's important not to always assume that higher elevation means it is cooler. All other factors need to be examined as well.

It's also important not to assume that just because two areas have the same elevations and the same average temperatures, that they are analogous climates. If these areas are at different latitudes, then they may have very different solar declination, day length, seasonal variation, and rain and snowfall patterns.

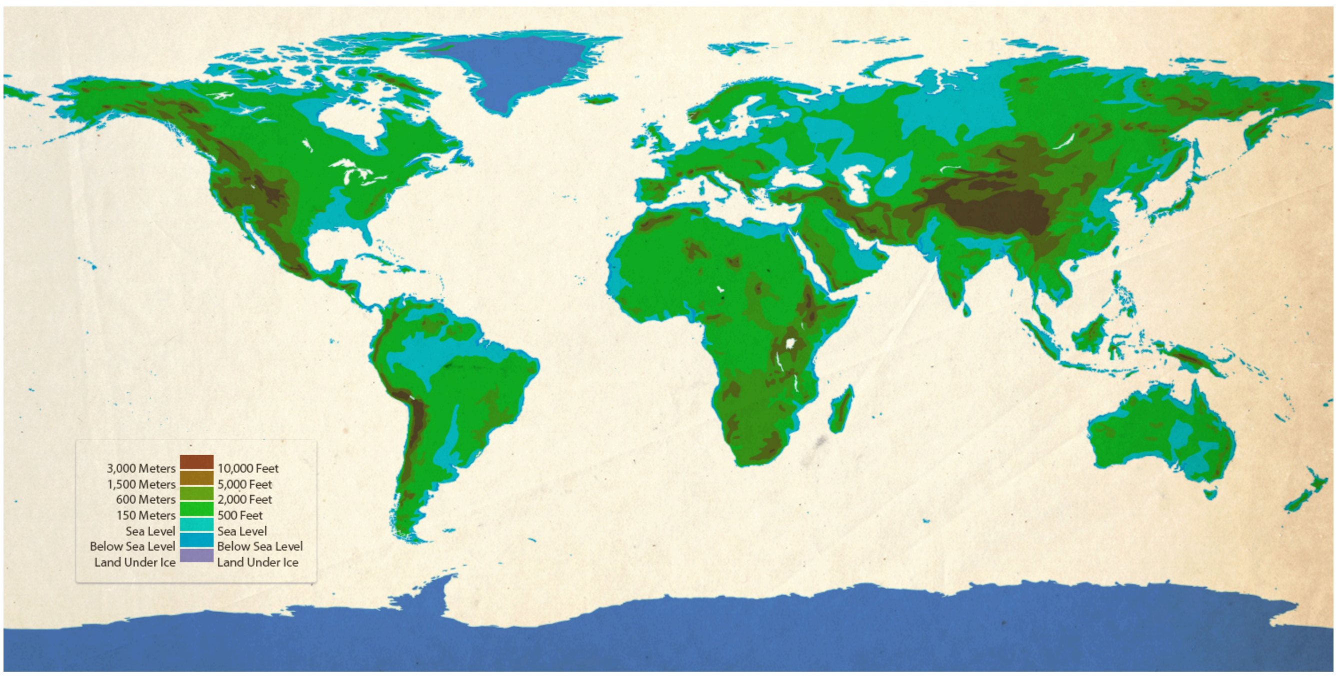

Figure 2: Elevation Map

Proximity to Large Water Body

Proximity to large water bodies is another major distinction between climate types, and divides them into Oceanic and Continental climates. As has been discussed already, large bodies of water have a temperature moderating effect; they keep coastal areas cooler in summer with ocean breezes and thermal storage of a large body of water, and warmer in winter without the same freezing temperatures that can be found in the continental interior at the same latitude.

Temperature has the ability to fluctuate much more over land masses that can heat and cool much more quickly than large volumes of water. Continents with a large interior land area also have the capacity to convey polar air masses deep down towards the equator. A polar air mass cannot come down over the ocean like it can over land. So the farther away that an area is from the ocean, the more capacity there is for a cold air intrusion from the poles during winter.

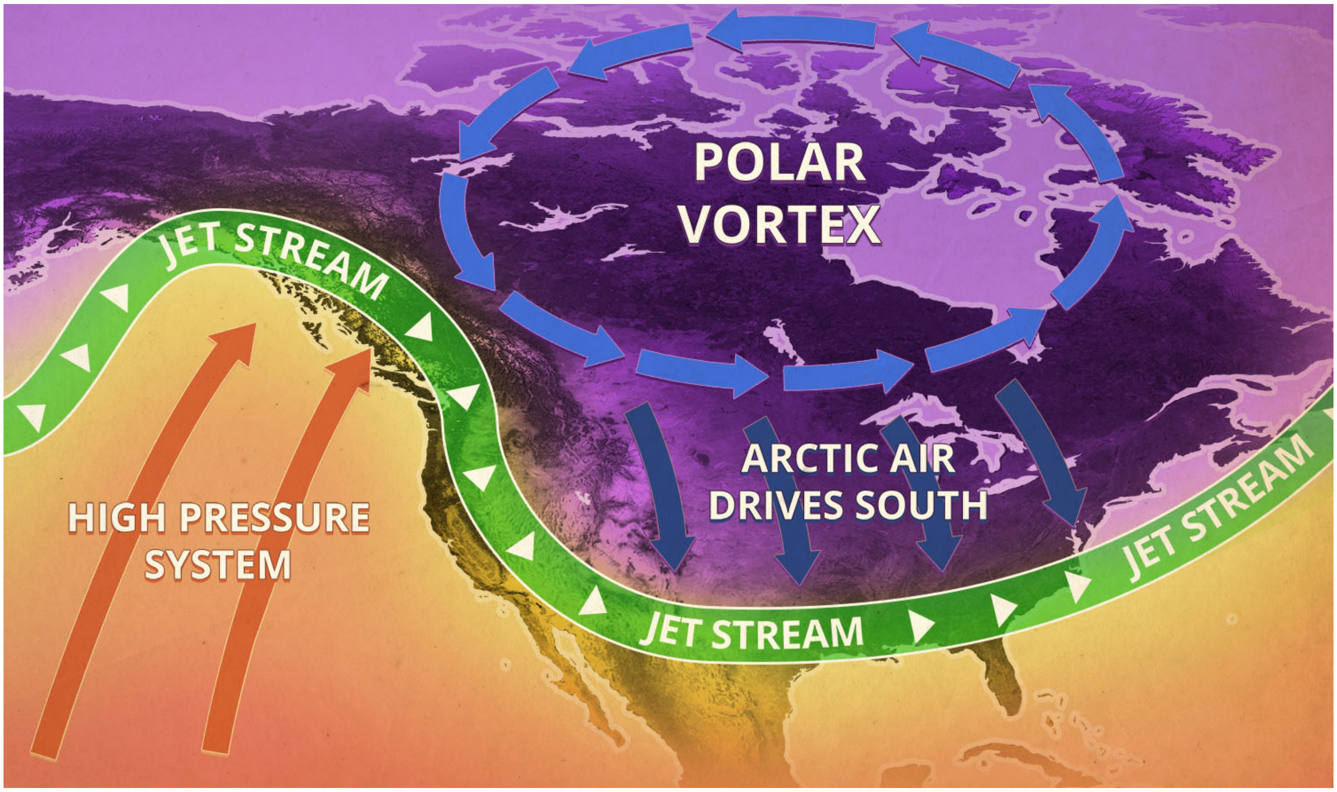

Figure 3: Polar Vortex

Not only does cold air find its way toward the equator over large landmasses, but heat can build up in interior deserts without the cooling effect of the ocean. A high pressure system can build a heat dome that can be sustained for a long time in the continental interior. It is only when that heat dome gets so big that it can push out to the coasts that there is a coastal heat wave in the oceanic climate zones.

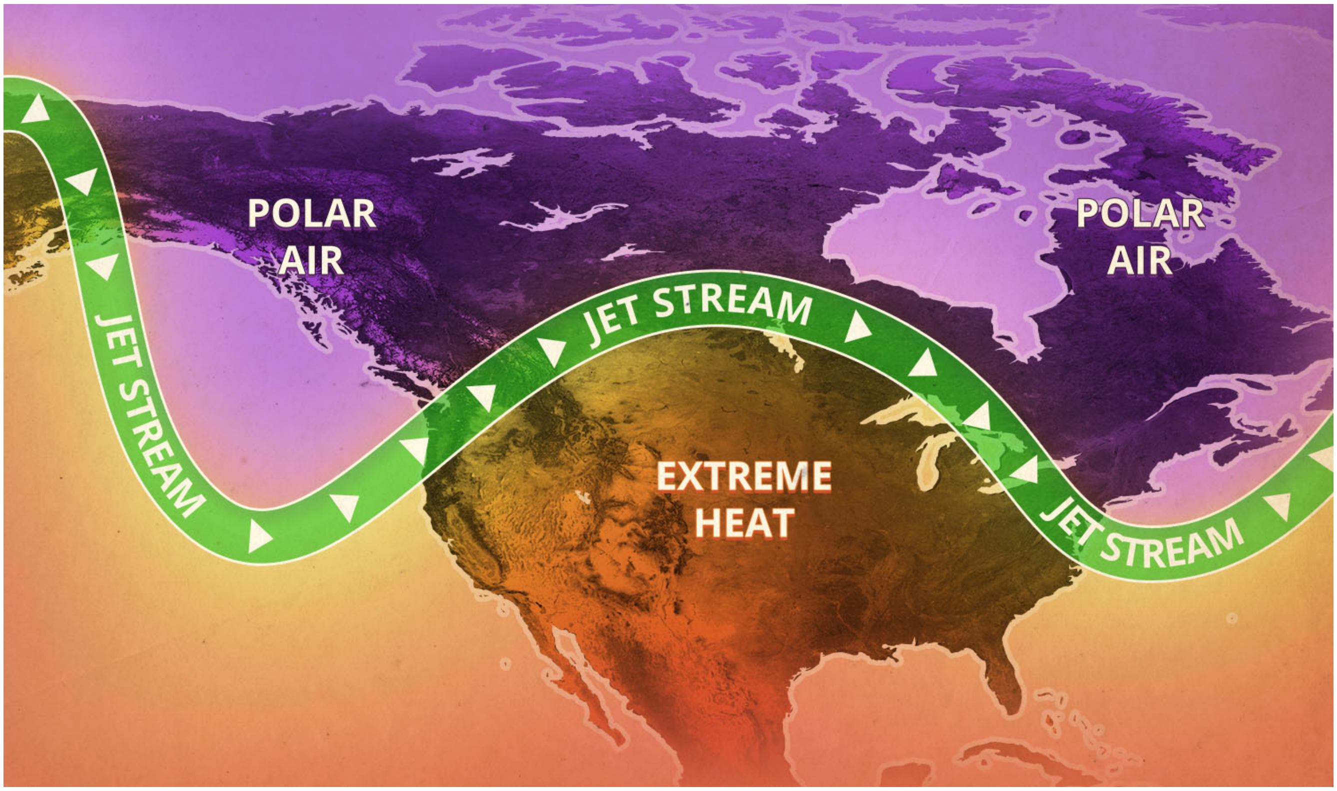

Figure 4: Heat Wave

The effects of the climate and weather patterns on a site can be dramatically influenced by it's proximity to the moderating temperature and humidity effects of a large water body. When assessing a site's climate conditions and finding it's analogue, it is important to note it's proximity to a large water body or distance into the interior of a continental land mass and check that any analogue has a similar position relative to these factors.

Precipitation Amount

The volume of precipitation is one thing that distinguishes one climate zone from another and has very obvious effects in vegetation type and size, streamflow, hydrology, humidity, and animal species. Precipitation includes both rain and snowfall.

Precipitation is not a factor that can be looked at in isolation because temperature plays such a big role in how the precipitation moves through the landscape system, whether as rain or snow, during a growing season or during dormancy. So directly along with the precipitation volume is the precipitation seasonality for determining the major aspects that define a climate and its analogue.

Precipitation Seasonality

The timing of precipitation is one of the main defining elements of climate, and represents one of the major components of many climate classification systems. Whether or not a climate zone receives consistent rainfall determines whether or not there is a dry season. The presence or lack of a dry season has a great influence on vegetation types, the surface flow of water, and subsurface hydrology.

If there are wet and dry times of the year, then the timing in relation to temperature is a defining feature. In the wet-dry tropics, the variation in seasons is defined by the seasonality of precipitation. In temperate climates with a wet and dry season, whether the rain comes during the warm or hot growing season or the cool or cold winter season dictates what plant and animal species are present.

Allan Savory in his Holistic Management system created a scale where the "brittleness" of a landscape is based on the seasonal humidity and its effect on the cycles of decay and decomposition. So the rates and processes of decay are another really important ecological function that is affected greatly by the seasonality of precipitation, and can be a factor that is considered and designed around in land management and stewardship. [11]

Global Air Circulation and Storm Systems

The global circulation patterns are the agents of weather and provides the climatic engine which determines the seasonality of precipitation, the strength and direction of winds, and the exchange of air masses between the poles and equator through cold air intrusions. The mechanism of this circulation involves the rising and falling of air masses called Hadley cells, which cause the Subtropical and Polar Jet Streams to wiggle their way around the planet, with cold air masses towards the poles and warm air masses towards the equator. Within these meandering jet streams are bands of precipitation moving around the planet.

Tropical storm systems come up from the Equator and bring monsoons, typhoons and hurricanes to bear upon land masses. These storms are derived within the warm regions of the Equator and move warm moist air masses to become entrained into the jet streams, pulling warm air out of the Equator towards the poles, keeping the temperature of the planet in balance.

Understanding the normal and extreme patterns of these circulatory systems is a big part of understanding the factors that shape regional climate. Literacy in the global air circulation system is a great asset to understanding the roots of climate zones.

11. Ward, Bruce. "The Implications of Brittleness." Bruce Ward Legacy Trust. Web. Mar. 2018. http://www.holisticresults.com.au/green-participant-area/biodiversity-supports-everything/1-3-1-the-implications-of-brittleness

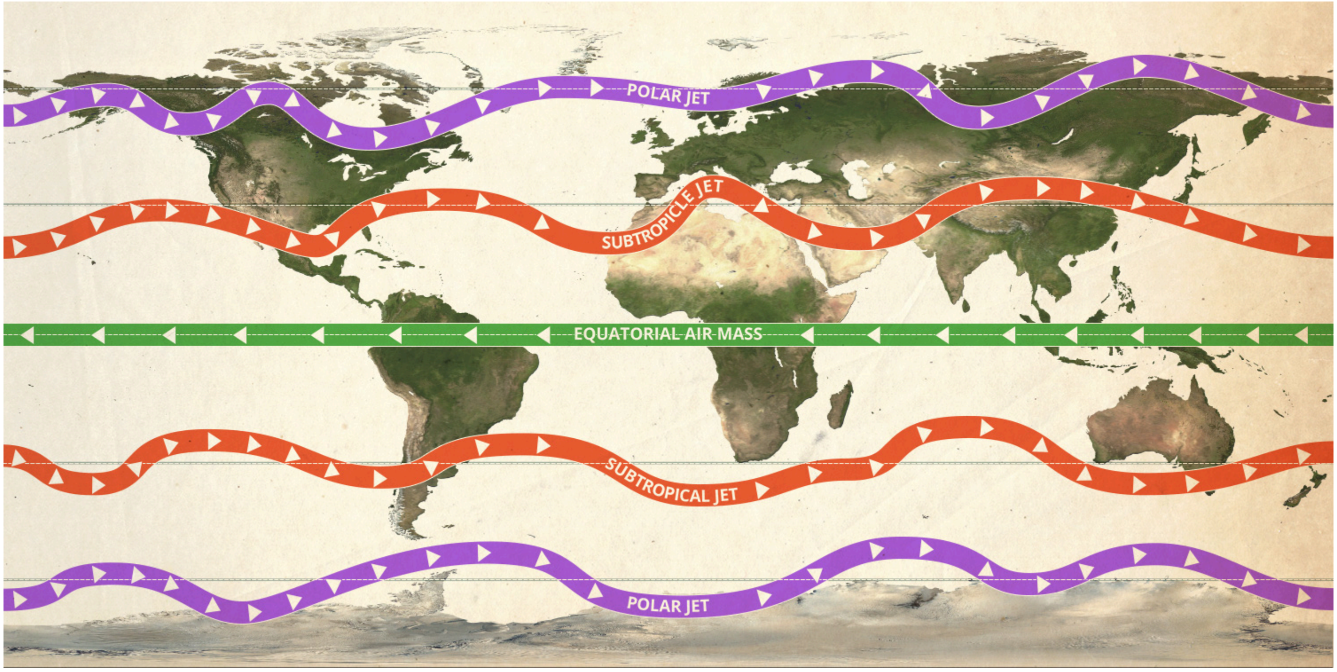

Figure 5: Jet Streams

Ocean Currents

The oceans have consistent currents that alter the climate on coastal areas and land masses. One well-known ocean current is the North Atlantic Current that brings warm water from the tropical Gulf of Mexico up along the Eastern Seaboard of the United States and across the Atlantic over to the UK and Western Europe. This causes the temperature in the UK and Western Europe to be milder in winter compared to coastlines of the same latitude that have cold ocean currents, like the West Coast of North America. Ocean currents play a large role in determining the climate of some areas, so it's an important thing to be aware of.

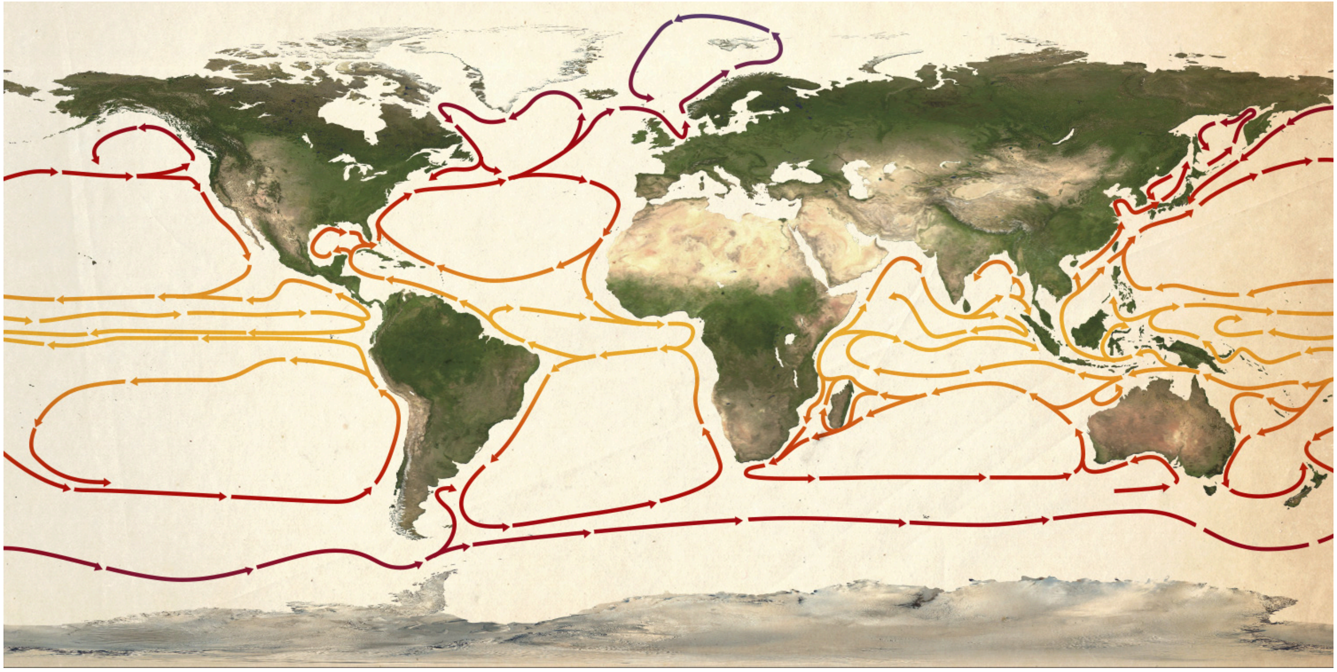

Figure 6: Ocean Currents

Geographic Features

Where a region sits within the topography of the landscape has a major climatic influence for a number of reasons. On every topographic feature like a mountain range or hills there is a windward and leeward side. The windward side is facing the direction of the prevailing winds which carry storm systems from the oceans over continental land masses. As air rises up against mountain ranges, it cools and water vapor condenses into precipitation. The windward side therefore is the wetter side and usually has a very different plant composition. This change in atmospheric conditions based on the change in elevation is called the orographic effect.

Figure 7: Orographic Effect

As an air mass moves onto a continent from the ocean and hits a mountain range, warm air rises, cools, and condenses, and dropping out precipitation. This creates a rainshadow on the other side, as air descends, warms, and loses it's capacity to hold water vapor. This same orographic effect continues into the interior of the continent for each mountain range that runs perpendicular to the direction of prevailing storms. [format] Arthur, Michael, and Demian Saffer. "The Orographic Effect." Integrate: Interdisciplinary Teaching About Earth for a Sustainable Future. Web. Pennsylvania State University. Mar. 2018 [/format]

Another geographic feature to note are major rivers that create their own climate zones within their proximity due to the deposited soils, moisture content, and moderated temperatures of a large mass of water. The delta of a river in particular has very distinct ecological conditions, with the edge between salt and freshwater, containing high levels of nutrients as well as specific types of plant, animal and aquatic species.

Landscape Positioning & Microclimate

The more detailed we examine a particular region, and then a specific site within that region, it becomes a tapestry of different microclimates that have their own climatic conditions. For example, whether a slope is facing North, South, East or West determines how the sun hits that slope throughout the year, which has a big effect on temperature and moisture. The compass direction that a slope faces is called 'aspect'.

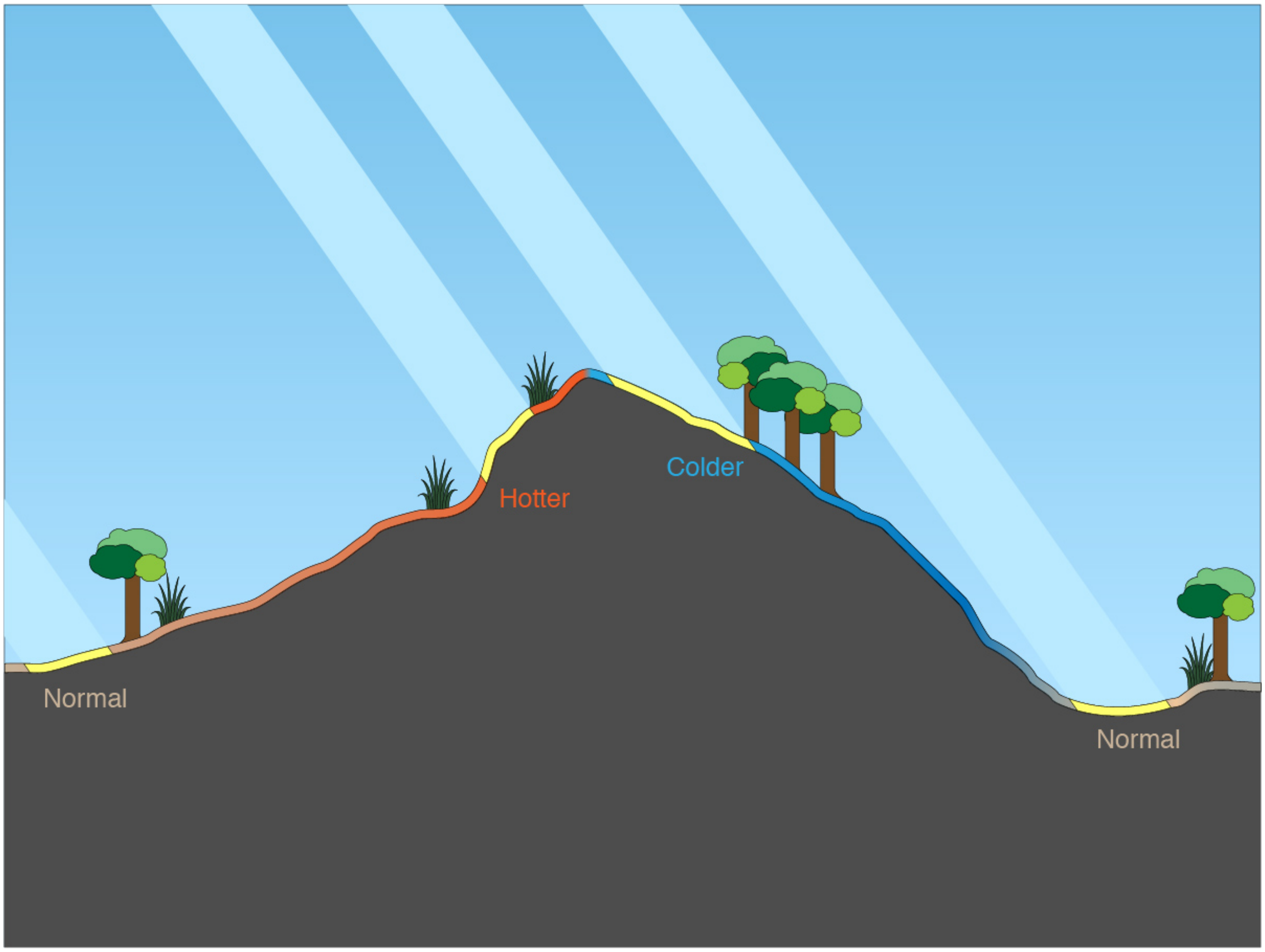

Figure 8: Landscape Position (Adapted from Ecosystem Geography, Bailey, Robert G. New York: Springer, 1996. Print)

Whether a slope is steep or gentle impacts the angle that the sun hits it in different seasons and affects the amount of solar radiation it absorbs. Vegetation can be completely different on the north facing or south facing slopes of a valley because of the solar radiation and the subsequent moisture retention of that slope and evapotranspiration of the plants.

If a location is in a canyon or valley surrounded by elevational features like mountains or plateaus, then cold air can drain down and create a frost pocket in the lowlands. A valley bottom position has multiple elements flowing down into it: frost, water, and soil deposition. Diurnal winds also provide an updraft through mountain valleys during hot days.

The mid-slope of a region is often a “banana belt”, where cold air drains down and an area remains warmer above the frost pocket. A banana belt is any segment of a region that has warmer weather than the surrounding region, and the positioning within the greater geographic landscape is often the cause.

Evapotransporation rates

Evapotransporation rates have a large influence on climate, and when the evaporation of moisture from the air and transpiration of water from plants (evapotranspiration) exceeds rainfall in an area, that is the definition of a desert. The evapotransporation rate is not an element that will be calibrated as a stand-alone number in a climate classification survey, but is a component in systems that look at the moisture index, which assesses evaporation rates, temperature, and day length.

The rate at which a plant and soil lose water to the atmosphere is a critical factor in the overall moisture level of an area which affects the types of plant and animal species living there..

Temperature

Temperature is the most basic measure of a climate along with rainfall and seasonality of precipitation. Many of the previous climate ingredients like proximity to the ocean, landscape positioning, ocean currents, elevation and latitude can all be summed up with the simple average yearly temperature of a place.

Temperature determines evaporation rates and plant and animal species. Temperature does not necessarily give one a clue about latitude, elevation, or the seasonal fluctuations of a place. On the top of Mount Kilimanjaro in Kenya which sits on the equator there are arctic conditions because of the great height.

Plant Hardiness

An important climate classification system that is commonly used by gardeners and agriculturists the world over are plant hardiness zones. Plant hardiness zones look strictly at the average annual extreme minimum temperature.

Interestingly, the USDA Plant Hardiness Zone Map was updated in 2012 and the new map is generally one 5-degree Fahrenheit half-zone warmer than the previous map throughout much of the United States. This is attributed to more sophisticated temperature measurement technology and also the fact that the temperature has risen in recent years.[12]

12. Kaplan, Kim. USDA Unveils New Plant Hardiness Zone Map. Agricultural Research Service 25 Jan. 2012. United States Department of Agriculture. Web. Jan. 2018

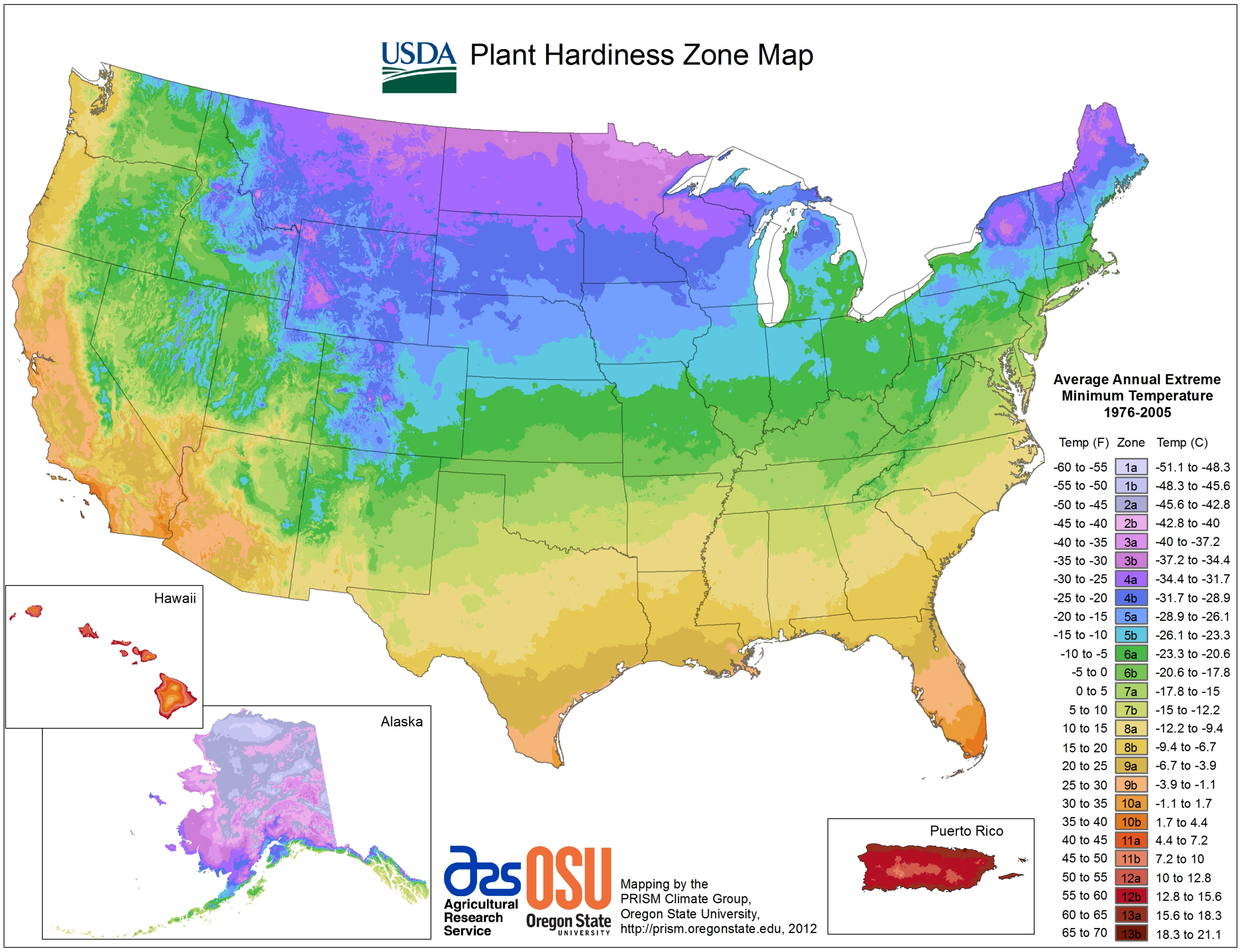

Figure 9: US Plant Hardiness Zone Map

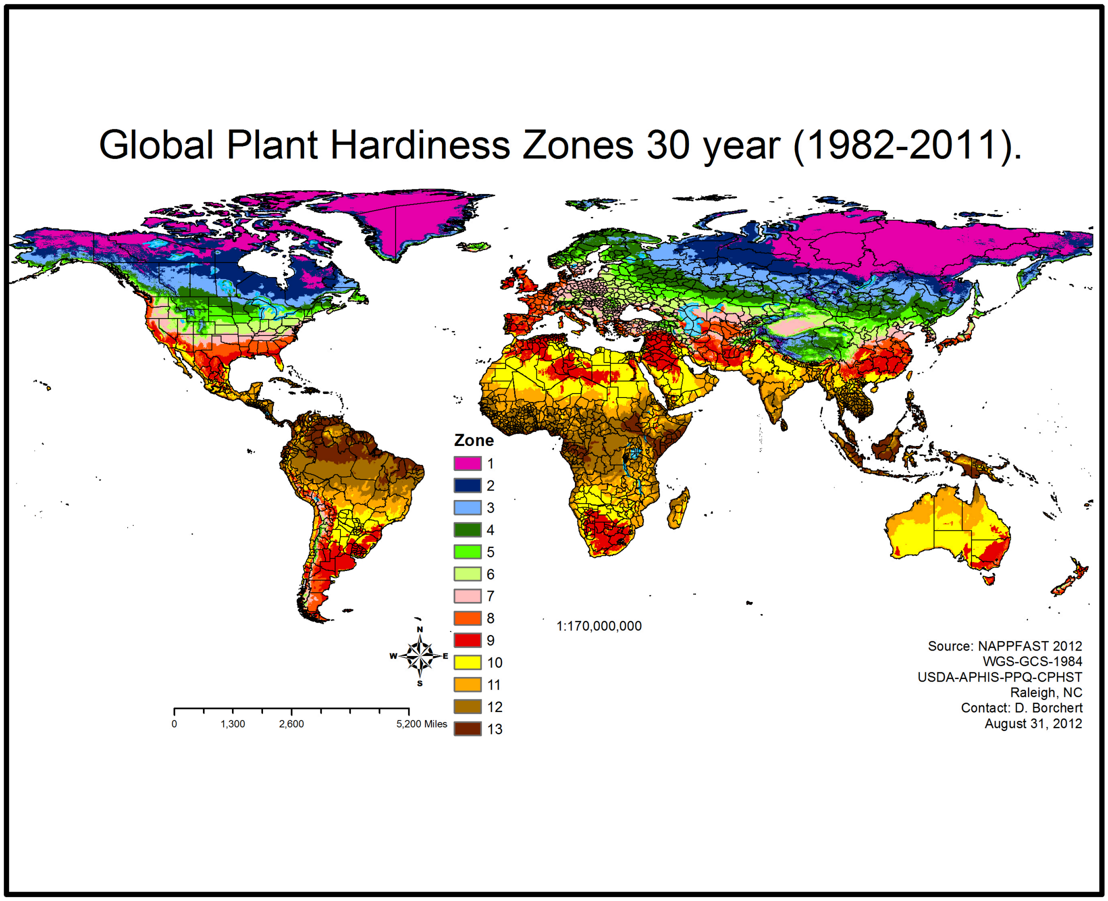

Figure 10: Global Plant Hardiness Zones 30 Year (1982–2011)

2. Climate Classification Systems

Koppen-Geiger

The Koppen-Geiger climate classification system was originally developed in 1884 by Wladimir Koppen, and then repeatedly revised, finally by Rudolph Geiger in 1961. It is the most widely used tool in the world for categorizing climate zones, and this is primarily because it is based on temperature and precipitation which are the least demanding data sets to come by for any location on Earth {Bailey, Robert G. "Ecosystem Geography: From Ecoregions to Sites" Springer, New York 2009, p.65}

It divides the Earth's climate types into 5 major climate types, and all of these types are primarily defined by temperature except for B which is defined by precipitation:

A: Tropical

B: Dry (Arid and Semi-Arid)

C: Temperate

D: Continental

E: Polar and Alpine

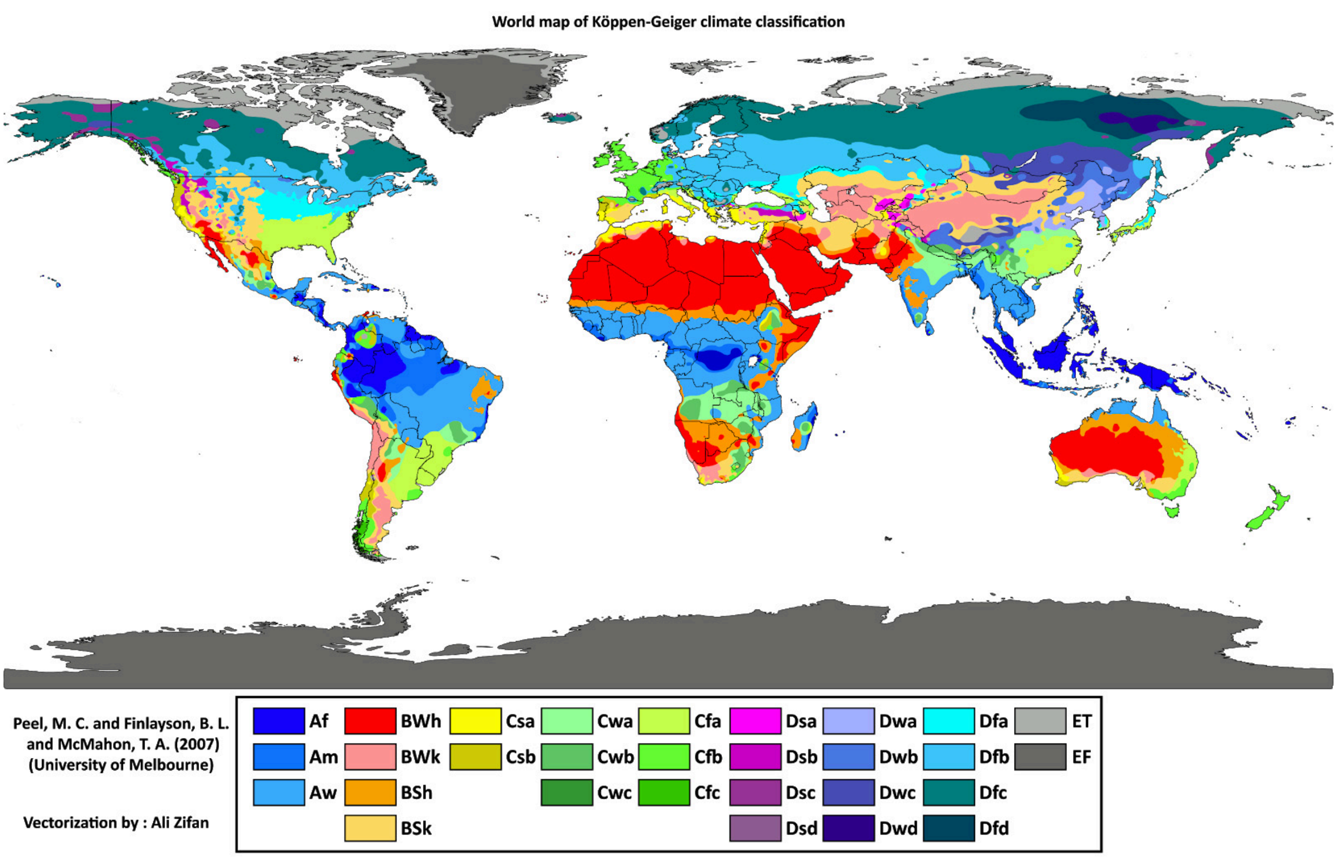

Figure 11: World map of Koppen-Geiger Climate Classification.

The A,B,C,D,& E in the code represent those major climate types. The second letter in the code represents the seasonality of precipitation This tells us when during the seasons precipitation comes to that climate. Does it come as a deluge in a monsoon rain pattern? Are there dry winters, dry summers, or is it wet all year round? The second letter in the code answers those questions..

Koppen climate classification scheme symbols description table

1st	2nd	3rd
A (Tropical)	f (Rainforest)	
	m (Monsoon)	
	w (Savanna, Wet)	
	s (Savanna, Dry)	
B (Arid)	W (Desert)	
	S (Steppe)	
		h (Hot)
		k (Cold)
		n (With frequent fog)
C (Temperate)	s (Dry summer)	
	w (Dry winter)	
	f (Without dry season)	
		a (Hot summer)
		b (Warm summer)
		c (Cold summer)
D (Cold (continental))	s (Dry summer)	
	w (Dry winter)	
	f (Without dry season)	
		a (Hot summer)
		b (Warm summer)
		c (Cold summer)
		d (Very cold winter)
E (Polar)	T (Tundra)	
	F (Eternal winter (ice cap))	

Koppen Climate Classification Scheme Symbols Description Table

The third letter represents the level of heat, giving the range between hot, warm, cold, and very cold, depending on climate type. Whether a climate class is designated as hot, warm or cold depends upon the average temperature during the coldest and warmest months of the year, and the average temperature of several other months accounted as well. There are more detailed resources available that give lengthy specifications of the temperature classification criteria available in Appendix. C[1] Below is an example at the usefulness and dysfunctionality of this classification tool. Oregon State University is located is in Corvallis, Oregon in the Temperate Mediterranean climate type (Csb). This means that it is temperate, with a dry and warm summer.

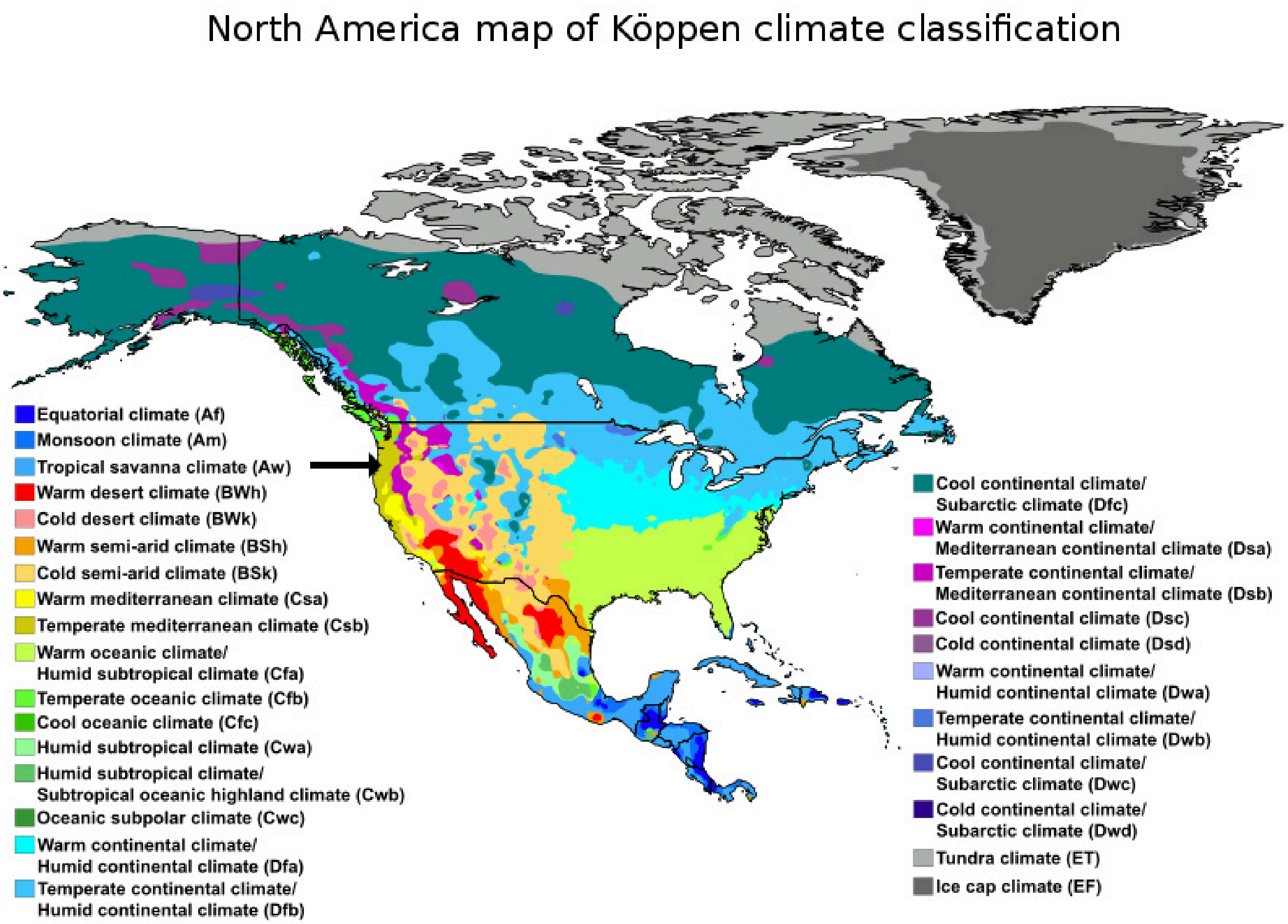

Figure 12: North American Map of Koppen Climate Classification. Modified from image by Ali Zifan. Derived from World Koppen Classification.svg., CC BY-SA 4.0

For anyone familiar with the climate of the West Coast of the United States, when we continue South from the Csb climate, the next climate type that we hit is the Warm Mediterranean (Csa), which is a temperate climate with a dry and hot summer in California's Central Valley, where olives and almonds grow in abundance. As we go North from Corvallis, the next climate type we find is the Temperate Oceanic

1. https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification

Climate (Cfb), which is a temperate climate with wet and warm summers as we find on the Olympic Peninsula in Washington State.

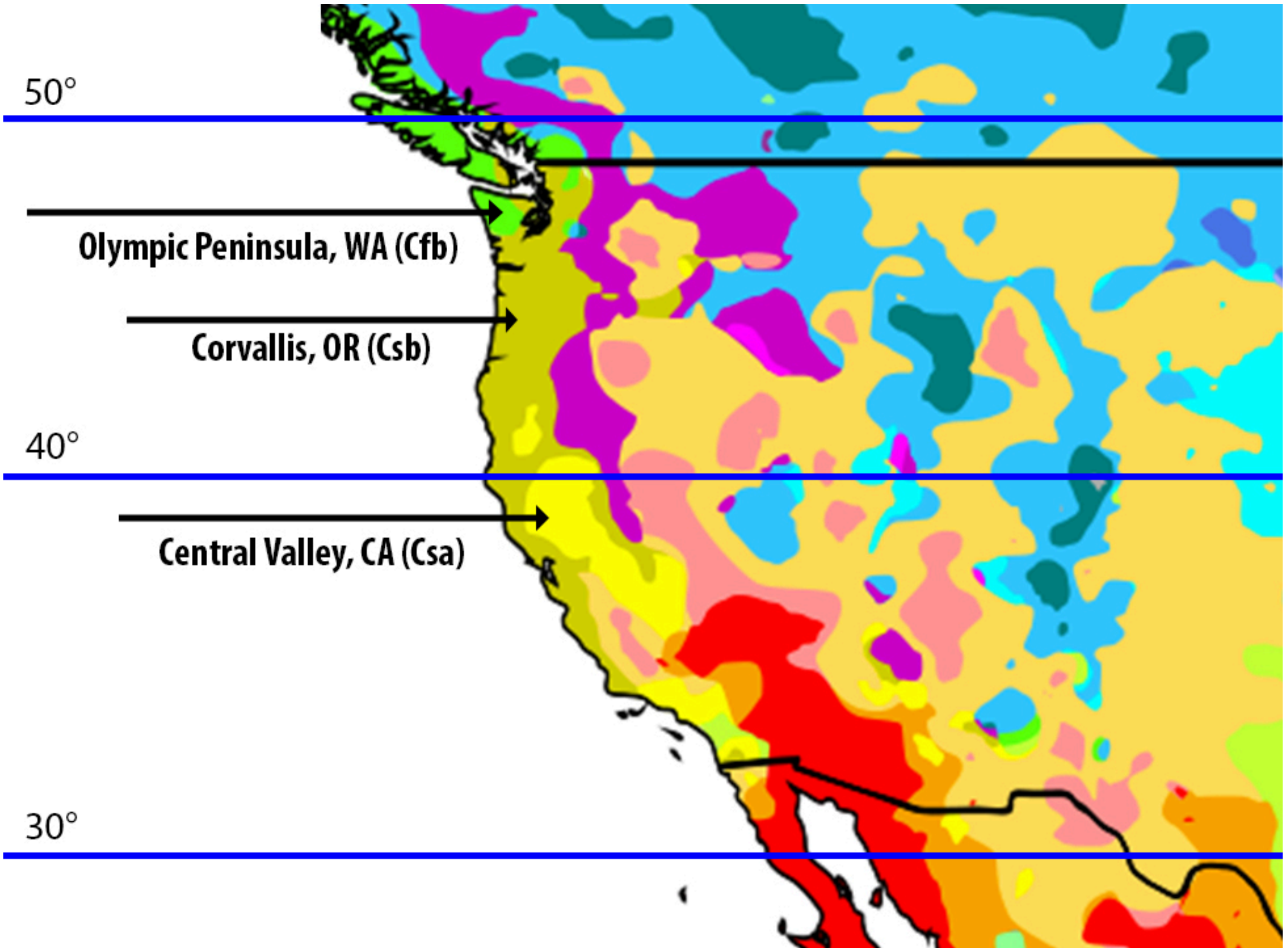

Figure 13: West Coast Climate Types

For anyone who really knows the area, there are a lot of things about this map that don't make sense. For instance, the Temperate Mediterranean Climate zone (Csb) encompasses both Bellingham, Washington, at 48 degrees N latitude, as well as Santa Barbara, California, at 34 degrees N latitude. These locations are 14 degrees latitude different, and are extremely dissimilar to each other in rainfall, temperature, vegetation types, day length and seasonal variation. They do both fall into the Csb climate classification type, but this shows that the Koppen Geiger classification system can be a pretty blunt instrument in some cases.

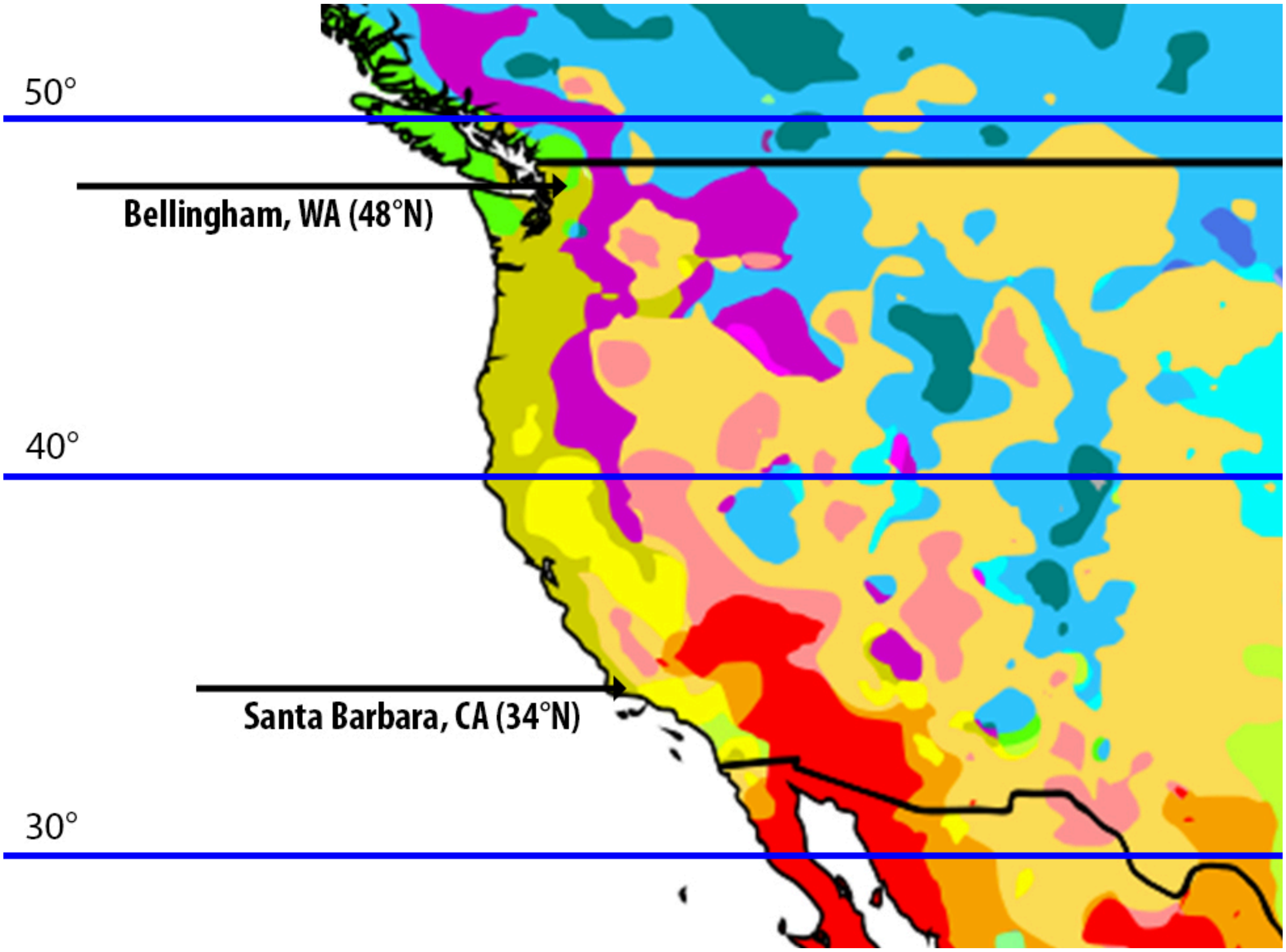

Figure 14

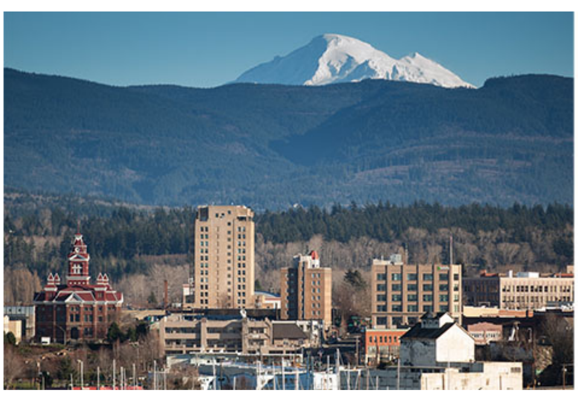

Photo 2: (left) Bellingham, WA. Creative Commons. *Photo 3: (right) Santa Barbara, CA. Creative Commons.*

Koppen-Trewartha

This was recognized by another geographer after Koppen named Glenn Thomas Trewartha, who revised the Koppen Geiger maps and produced the Koppen Trewartha maps in 1966 and then again in 1980. When we look at the Trewartha maps, we see that the area around Santa Barbara is characterized as steppe, and the area around Bellingham is considered Oceanic.

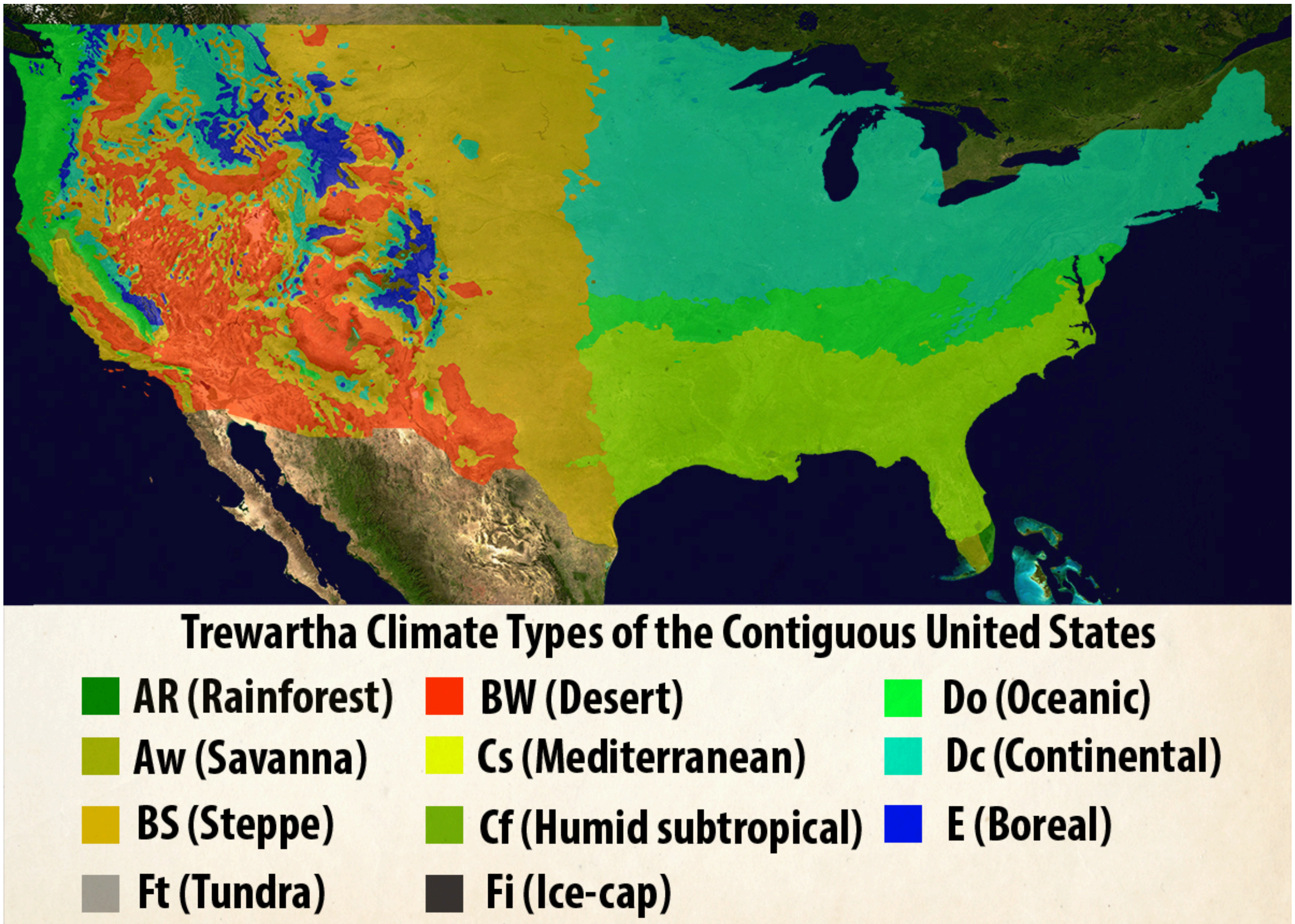

Figure 15: Trewartha Climate Types of the Contiguous United States. Modified from image by Adam Peterson. CC BY-SA 4.0.

Trewartha's maps did a lot more to define the climate zones in the mid-latitudes, especially in North America and Asia, to reflect vegetative zones and present a more useful map. When possible, it is preferable to use Trewartha's improved maps. Although Trewartha's maps are more reflective of ecosystem variations, it is much more common to find Koppen-Geiger's maps available for more locations. Koppen-Geiger is more widespread in its usage, and detailed maps have been created for more locations based on Koppen-Geiger climate classes.

Trewartha split the climate types into 6 categories with their defining temperature or precipitation amounts:[2]

A – Tropical: Frost is limited in continental locations; in marine areas the average monthly temperature is above 18°C (64.4°F)

B – Dry: Potential evaporation equals or exceeds precipitation

C – Subtropical: At least 8 months have average temperatures above 10°C (50°F)

D – Temperate: At least 4 months have average temperatures above 10°C (50°F)

E – Boreal: The warmest month has an average temperatures above 10°C (50°F)

F – Polar: All months have an average temperatures below 10°C (50°F)

When we break this down further, we get specifics for all of the Koppen-Trewartha's 13 climate types of the world: Note – the maps used here as examples show 11 climate types. Some maps you will find show 11, and some all 13.[3]

Ar Tropical wet: all months average above 18°C (64.4°F) and no dry season

Aw Tropical wet-dry: same as AR but at least 2 months dry in winter

BSh Tropical/subtropical semiarid: evaporation exceeds precipitation, and all months average above 0°C (32°F)

BWh Tropical/subtropical arid: one-half or below the precipitation of BSh, and all months average above 0°C (32°F)

BSk Temperate semiarid: same as BSh but with at least one month average below 0°C (32°F)

BWk Temperate arid: same as BWh but with at least one month average below 0°C (32°F)

Cs Subtropical dry summer (Mediterranean): 8 months average above 10°C (50°F), coldest month average below 18°C (64.4°F), and a dry summer

Cf Subtropical humid: same as Cs but no dry season

Do Temperate oceanic: 4-7 months average above 10°C (50°F), coldest month average above 0°C (32°F)

Dc Temperate continental: same as Do but with the coldest month average below 0°C (32°F)

E Boreal or subarctic: Up to 3 months average above 10°C (50°F)

Ft Tundra: all months average below 10°C (50°F)

Fi Polar ice cap: all months average below 0°C (32°F)

2. Adapted from: Bailey, Robert G. "Ecosystem Geography: From Ecoregions to Sites" Springer, New York 2009, p.121
3. Adapted from: Bailey, Robert G. "Ecosystem Geography: From Ecoregions to Sites" Springer, New York 2009, p.67

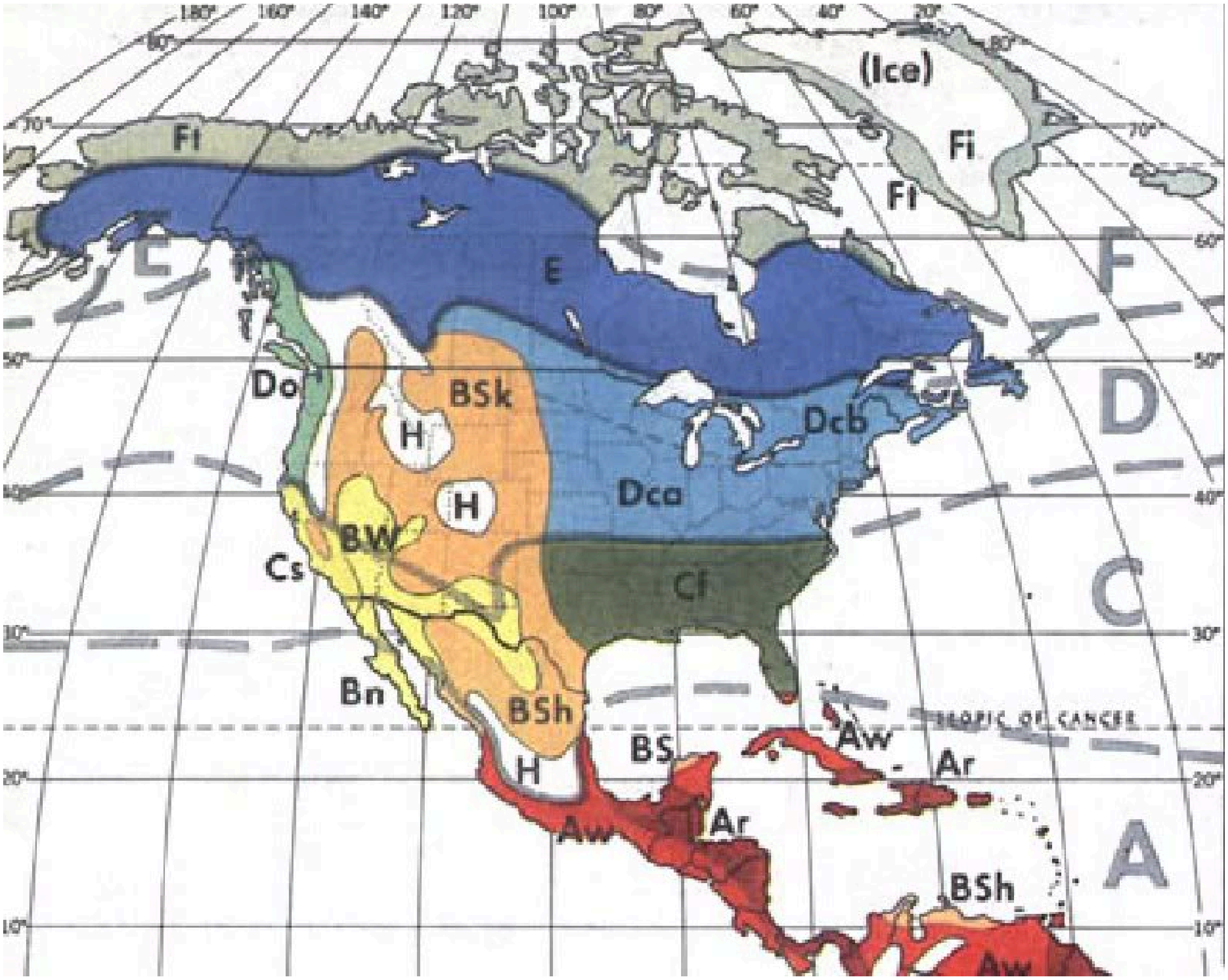

Figure 16: Trewartha Simplified Map of Climate Classification. Image by Jamesbond55 CC 3.0

This is Trewartha's simplified world map of climate classification, but there are many more detailed regional maps that can be found.

Thornthwaite

Another less commonly used climate classification system that you may find helpful is the Thornthwaite Climate Classification System. Charles Warren Thornthwaite was a US climatologist who devised his system in the 1930's and 1940's. His system was originally based purely on a mathematic equation factoring in precipitation and evaporation to identify climate types. This did not take into account the seasonality of precipitation or extreme high and low temperatures but purely the amount of water entering the system from the atmosphere and the amount leaving through evaporation. Later on he added other aspects to his equation based on the water demands by plants and their potential evapotranspiration, calculated from data on air temperature and day length.

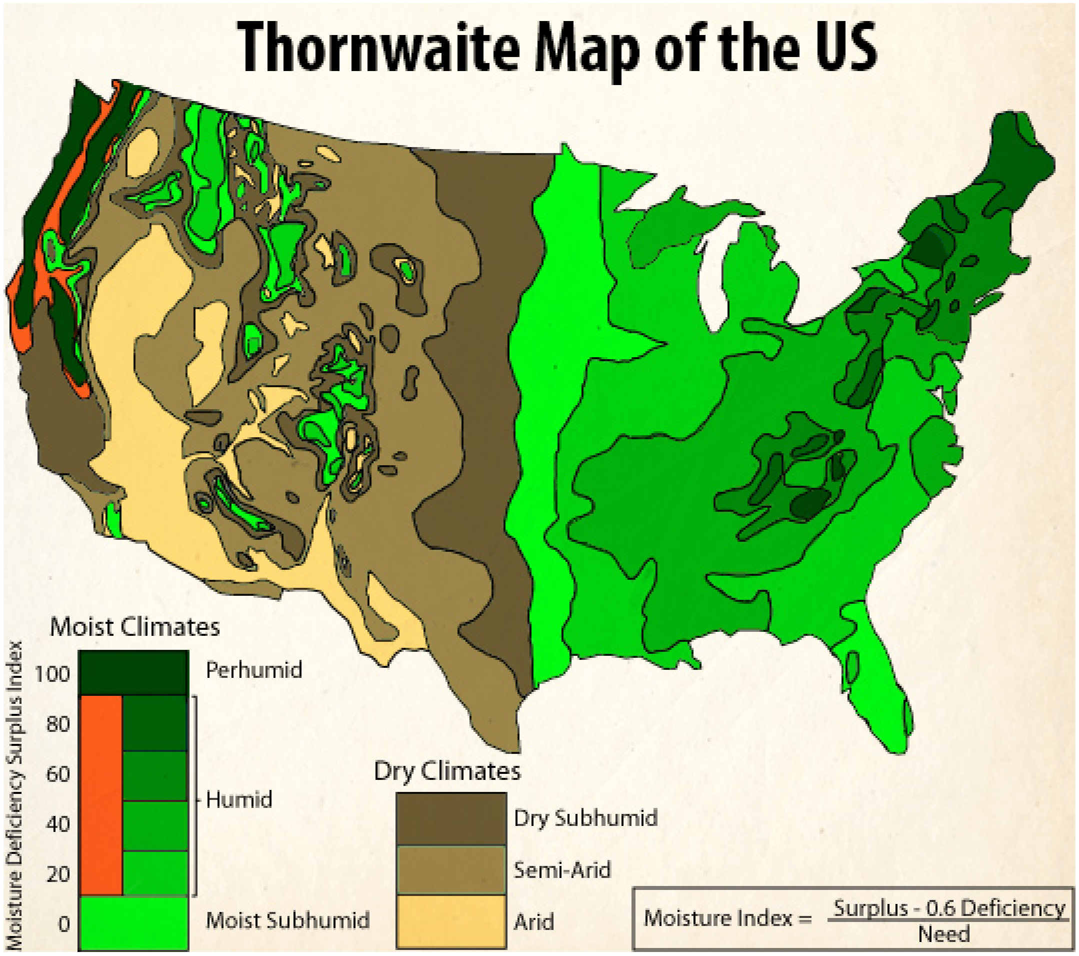

Figure 17: Thornwaite Map of the US. Adapted from Iowa State University figure.

When we view Thornthwaite's map of the US, the Western half looks very similar to Koppen and Trewartha's maps, but the Eastern half of the country looks quite different, more closely following elevation changes, with the Appalachian Mountain chain obvious in the zones of Perhumid and moist humid areas (black, dark blue, and green) in the Mid-Atlantic region of the country.

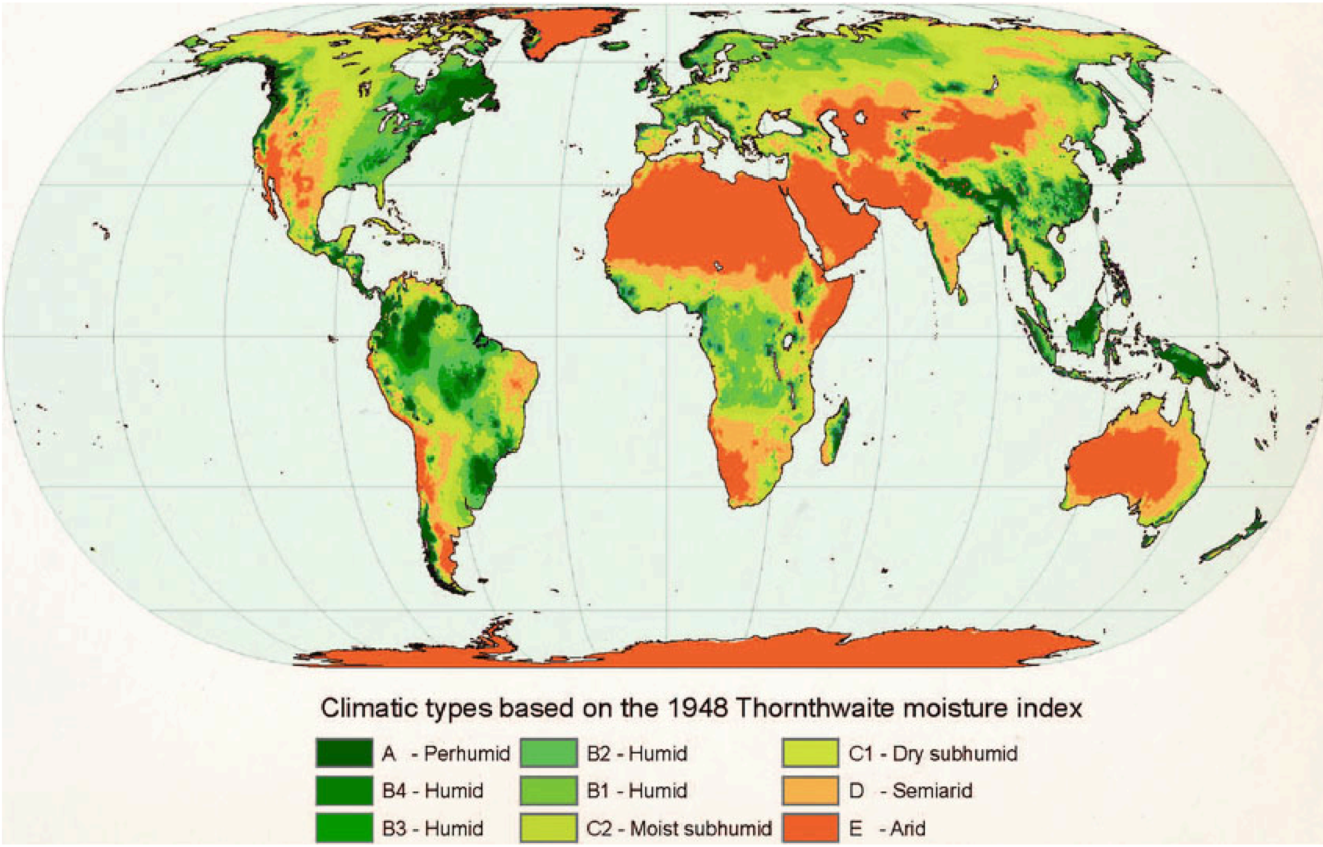

Figure 18: Climatic Types based on the 1984 Thorthwaite moisture index. Image adapted from the image by Johannes J. Feddema.

The Thornthwaite map will be most useful as another reference to check to make sure there are no major differences between areas that are being overlooked when assessing locations for their climate analogue and climate change analogue potentials.

It's important to recognize that any one of the climate classification maps shown are incredibly general, so looking at the particular factors of your site will be important for you to get to the next level of understanding of the details and conditions that you are designing for.

3. The Climate Analogue Tool

The potential benefits to locating a close analogue climate are many, and in the permaculture design process, it is a common tool used by many experienced designers. There are some really useful reasons for locating a similar climate to your own.

1) Locating plant, fungi, and animal species that thrive in your climate and exchange of that genetic material between analogue climates.

Completely different plants, fungi and animals evolved and have been domesticated in similar climates to your own across the world. Domesticated and wild species of plants, fungi and animals have already spread out across the planet, but that does not mean that every beneficial species that can be grown is being cultivated everywhere it can be. Locally adapted varieties of fruits, nuts, vegetables, grains and livestock that are particularly suited to their place may also be particularly suited to yours!

A great example is the cultivation of cold-climate rice by Ben Falk in cold climate Vermont, USA (USDA zone 4). Even though rice is typically grown in warmer regions of the US like the Lower Mississippi river basin in Arkansas and Louisiana, Ben observed that Northern Japan was a climate analogue to Vermont, and that there were traditional rice varieties growing in Japan all the way up to 44 degrees North latitude[1], which is the same latitude that Northern Vermont is located.

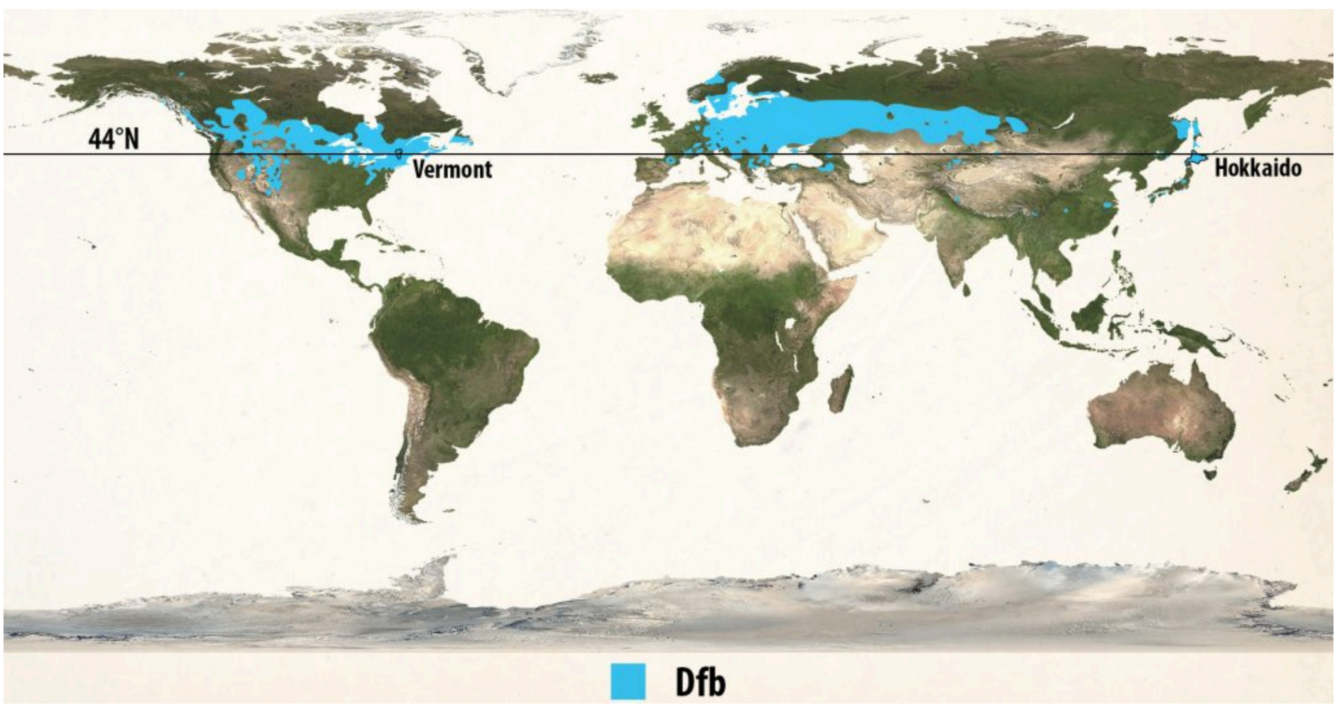

Figure 19: Dfb: Temperate Humid Continental Climate Zone

1. "Japan". Ricepedia. Consultative Group for International Agricultural Research (CGIAR). http://ricepedia.org/japan

Ben began planting Northern Japanese rice on his farm and has been successfully growing it there since 2010. What other useful species are growing in Northern Japan that have never been introduced to Vermont? Much of Eastern Europe, Southern Scandinavia and Southern Russia are also in the same Koppen-Geiger climate classification. What plants, animals, fungi and practices could assist a regenerative agricultural system in the NE USA? These are the questions that the climate analogue tool helps to answer.

Photo 4: Rice from northern Japan growing in Vermont, USA. Taken from Small Farmer's Journal. Permission pending.

2) Understand the climate of a place you've never visited.

This is particularly useful for a professional consultant or designer who is doing work outside of their bioregion. I was recently asked to look at a potential design site in Hangzhou, China. The US East Coast and the Chinese East Coast share a similar latitude and coastline shape in relation to a warm water body to the south: the Gulf of Mexico and the South China Sea.

It was easy for me to figure out that Jacksonville, Florida was a close climate analogue to Hangzhou, with the same latitude, elevation, and proximity to the water where a major river enters the ocean. Finding resources about the region around Jacksonville gives me a really good starting point from which to study Hangzhou because I can see what the major crops, practices and plant and animal species are that are from its analogue. It's not just Jacksonville and Hangzhou. The entire US East Coast and Chinese East Coasts are mirrors of each other in so many ways.

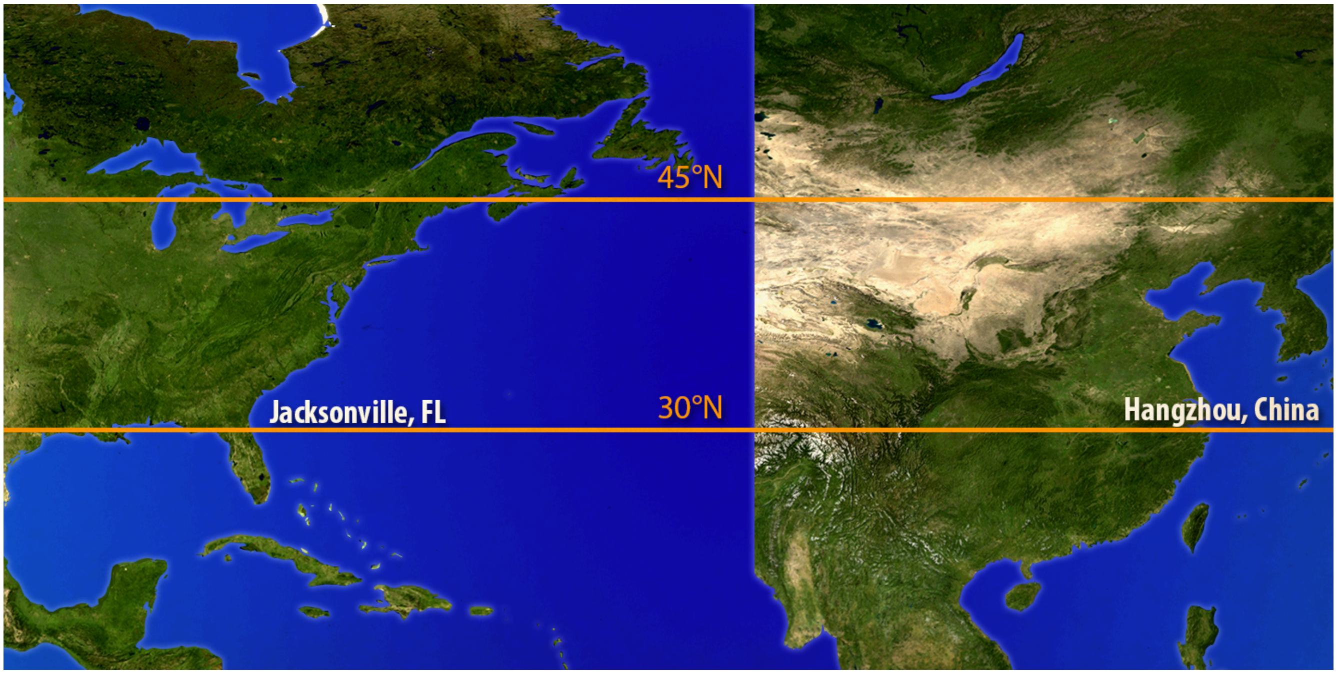

Figure 20: Climate Analogue for Jacksonville and Hangzhou, China

3) Understand horticultural history for plant breeding and microclimate development

When we understand the climatic similarity of different regions, history can suddenly make a lot more sense.

One of the oldest cases of genetic evolution of an Asian fruit variety in North America is the Peach. When Spanish conquistadors arrived in New Mexico and Arizona starting in 1540, they built missions in the Rio Grande river valley and in the Pecos, Hopi and Zuni pueblos.They brought fruits familiar to them: Peaches, Apricots, Apples, Pears and Grapes, and Native Americans became familiar with these at that time.

In 1680, the Pueblos rose up against the Spaniards in the Pueblo Revolt, and drove them out from their lands. The tribes at some point adopted the exotic fruit trees and began planting peach seeds, and have continued planting them to this day, centuries later. These trees have become very adapted to the Bsk Cold Semi-arid climate, famously growing in Canyon De Chelly on the Navajo Nation in NE Arizona where in 1863, the US government led by Kit Carson burned thousands of these trees from the canyon in an effort to force the Navajo out.

Peaches in a high desert canyon aren't the typical images of the Georgia or California crops in lush irrigated agricultural lands. But when we look at the migration route of peaches from their origins in China and along the Silk Road to Europe, we see them becoming established in the walled paradise gardens of the Iranian Plateau. And when the climate types are examined, it becomes apparent that the Iranian Plateau and the Colorado Plateau are strikingly similar in climate type, latitude, elevation, continental positioning, and topographic variation. The canyon walls that shelter trees in the Four Corners of the US are liken to the walls that enclose the gardens of Iran. The peaches found their analogue climate and conditions from earlier on their migration route.

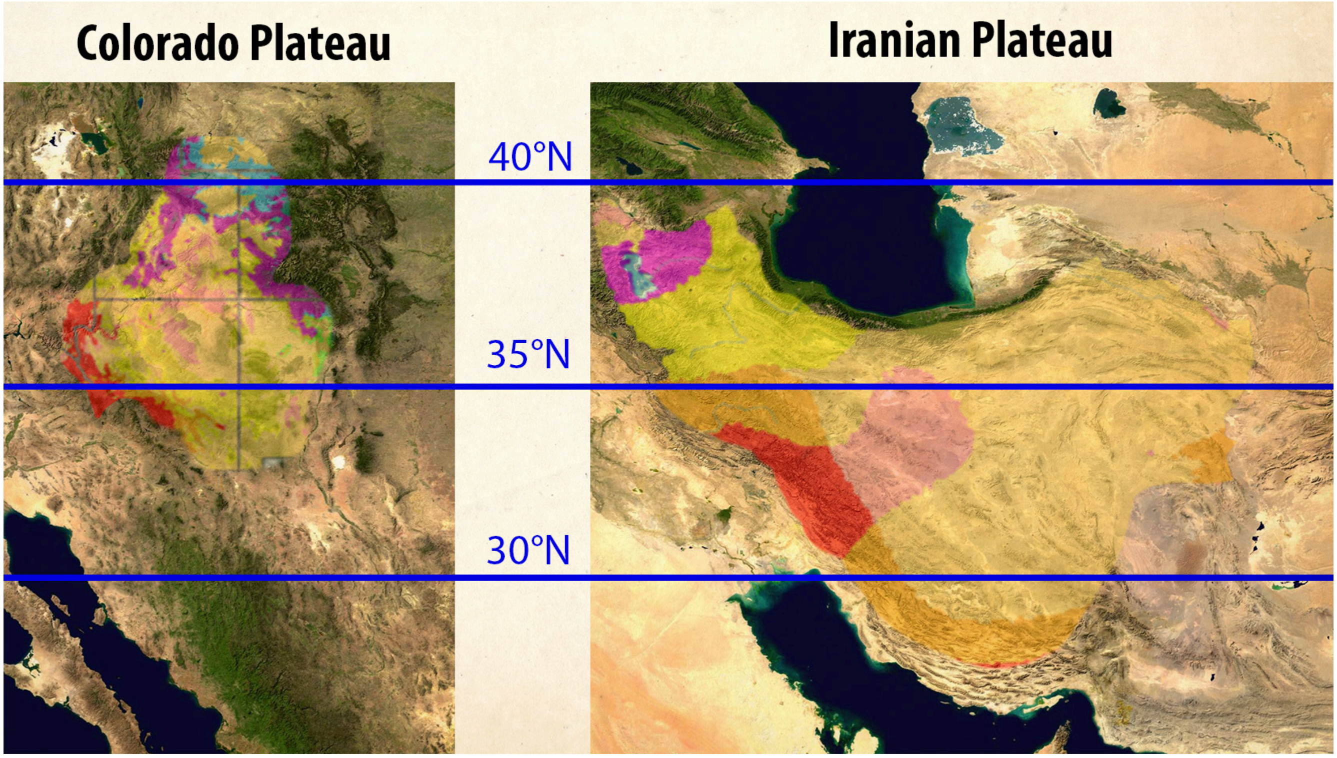

Figure 21: Climate analogue for the Colorado Plateau and the Iranian Plateau.


Photo 5: Canyon De Chelly, Arizona. Photo by Kelsie DiPerna CC BY-NC-SA 2.0

Photo 6: Persian Walled Garden. By Mohsen Rajabpoor. Creative Commons.

4) Vernacular architecture and innovative engineering

Developing climatically appropriate buildings is another area where the climate analogue tool can be very useful. Studying the housing and construction styles of an analogue climate can reveal profound human ingenuity in adaptation to climatic conditions.

A stark example of this takes us to the Al Baydha project in Saudi Arabia and their development of underground housing. The project was initiated by the Kingdom of Saudi Arabia in order to create a viable settled livelihood for the traditionally nomadic Bedouin people, and we will be examining various aspects of this project throughout this book.

The underground homes of the Berbers in Tunisia are well known in modern culture for their influence on Luke Skywalker's childhood home on Tatooine in the movie Star Wars.

Photo 7: Berber Home. By Panegyrics of Granovetter. CC BY-SA 2.0.

Tunisia is Bwh, hot desert, and a climate analogue of Saudi Arabia. The Al Baydha project imported this style while adapting it to modern and available construction techniques and materials like tires, rebar and concrete, and created their version of the Berber house.

Photo 9 and 10: By Neal Spackman

5) Innovative engineering

Irrigation methods is another huge field with knowledge to be gained by studying analogue climates. One common example of a technique now used in North America in hot desert climates is watering through a buried unglazed clay pot where the water trickles through the pot directly into the root zones of adjacent plants. This method was originally developed in North Africa and is still used by traditional farmers in the Middle East and India today[2].

This method for water saving irrigation has been transported from analogue climates in the East over to the Western hemisphere where it is widely practiced among drylands Permaculture practitioners.

There are many more examples of methods that have been copied from their original innovators over to their climate analogues, and there are many possibilities for this technology exchange that have not yet been done. Study of the practices of one analogue can yield very useful methods for another.

6) Cultural practices and Folk Wisdom

Often times, the folk wisdom of a society represents a great deal of trial and error and practical lessons learned in a place that have been passed down for many generations. As practical wisdom is learned, it morphs into written stories and oral traditions over time. Studying the anthropological aspects of cultures of analogous climates is rich with possibilities for learning how to best relate with a given climate type.

2. Bayuk, Kevin. “Ollas: Unglazed Clay Pots For Garden irrigation”. The Permaculture Research institute Australia 26 Sept. 2010. Permaculture News. Web. Jan. 2018

Photo 11: Clay pot irrigation in garden. Andrew Millison

For example, if one looks at the geographic distribution of the “siesta”, or afternoon nap, we see that it is in places where temperatures rise steeply in mid-afternoon. People wake up early, have a big lunch, and then nap during the hottest part of the day, returning to work when temperatures cool down later. So the cultural patterns in areas like Spain and Southern Europe were translated over to analogous climates in North and South America, and the siesta became a cultural practice transferred along analogous climates.

Photo 12: Siesta. Creative Commons.

How-to Find a Climate Analogue

The most basic elements of a climate type are temperature, precipitation, and seasonality of precipitation. All of the other climate ingredients are part of the recipe that brings us to those basic elements. This is what Koppen understood when he developed his climate classification system, so this is an excellent place to start when locating a climate analogue. Not all regions have equal information about them available, and this can be a challenge. Regions that contain good climatic, agricultural and cultural data about them make the task of locating a climate analogue much easier.

1) Identify your Koppen-Geiger climate classification.

What is the 3 letter Koppen-Geiger code of your site and what do the letters represent? You should be able to look at the Koppen-Geiger map and identify the color that represents your climate class. {Hint: on the Koppen-Geiger page of Wikipedia, you can click on each climate class to go to a map that shows only that climate zone on an otherwise white map. Very easy to read.}

2) Look for areas within 10 degrees North or South of your latitude.

Study the map for other locations with the same climate classification as your site that are within 10 degrees latitude of your site, or the mirror image in the other hemisphere. The closer that you can get to your latitude, the better. By this point you should have some options identified to look more closely into for the remaining steps.

3) Look for areas with the same proximity to water; oceanic or continental.

Of the areas that interest you as potential climate analogues, assess their proximity to the ocean or other large body of water. What are the similarities and differences between your site and this potential analogue climate? Are both locations on the same coast East or West, North or South?

4) Compare Koppen-Trewartha classification.

What is the 2 letter Koppen-Trewartha code and what do the letters represent? Cross-reference the Koppen-Trewartha classification map to see if there is any difference between your site and its potential analogue. If the Trewartha map shows that your two comparison sites are in different climate classes, then go back to the beginning and find a new potential analogue to assess.

5) Compare elevation.

What is the elevation, in feet or meters, of your design site and potential analogue site?

6) Compare precipitation amounts.

What is the average annual precipitation, in inches or millimeters?

7) Compare precipitation seasonality.

When during the seasons of the year does precipitation typically arrive?

8) Compare Thornthwaite climate classification.

What is the Thornthwaite climate classification which is based on precipitation and evaporation rates? If these are very different, you may want to reconsider this location and try another.

9) Compare global air circulation and storm tracks.

Are there particular air circulation patterns that affect the timing and qualities precipitation, winds and storm events? (i.e. monsoon, seasonal hurricanes, oceanic jet stream etc.)

10) Compare nearby ocean currents (if applicable).

Are there particular ocean currents that affect temperature and seasonal weather events? (i.e. North Atlantic Current bringing warm water North or California Current bringing cold water South etc.)

11) Compare topographic features and landscape positioning.

Are there mountain ranges or major rivers in the region? What are they called and what are their elevations in feet or meters? If there are topographic features present, what is the proximity of the site and directional relationship to them (North, South, East or West)? Is there a major plateau, delta, are you on an island? Are there other distinctive feature that characterizes the area?

12) Compare average temperatures.

What are the yearly average high or low temperatures of the site in degrees Celsius or Fahrenheit?

13) Compare plant hardiness zones.

What is the plant hardiness zone of the site in degrees Celsius or Fahrenheit? This has to do with the average low yearly temperature.

14) Compare soil types.

More than likely the global soil regions between two analogue sites will be the same because climate strongly dominates the soil forming process.[3] If the soil regions are not the same, that may be something to

3. Bailey, Robert G. “Ecoregions: The Ecosystem Geography of Oceans and Continents” Springer-Verlag New York, 1998, p 39

examine. For instance, if the sites have dramatically different soil regions, with one site having sand dunes and the other clay, this means that geologic forces are a dominant characteristic and it could have an impact on the analogous nature of the sites.

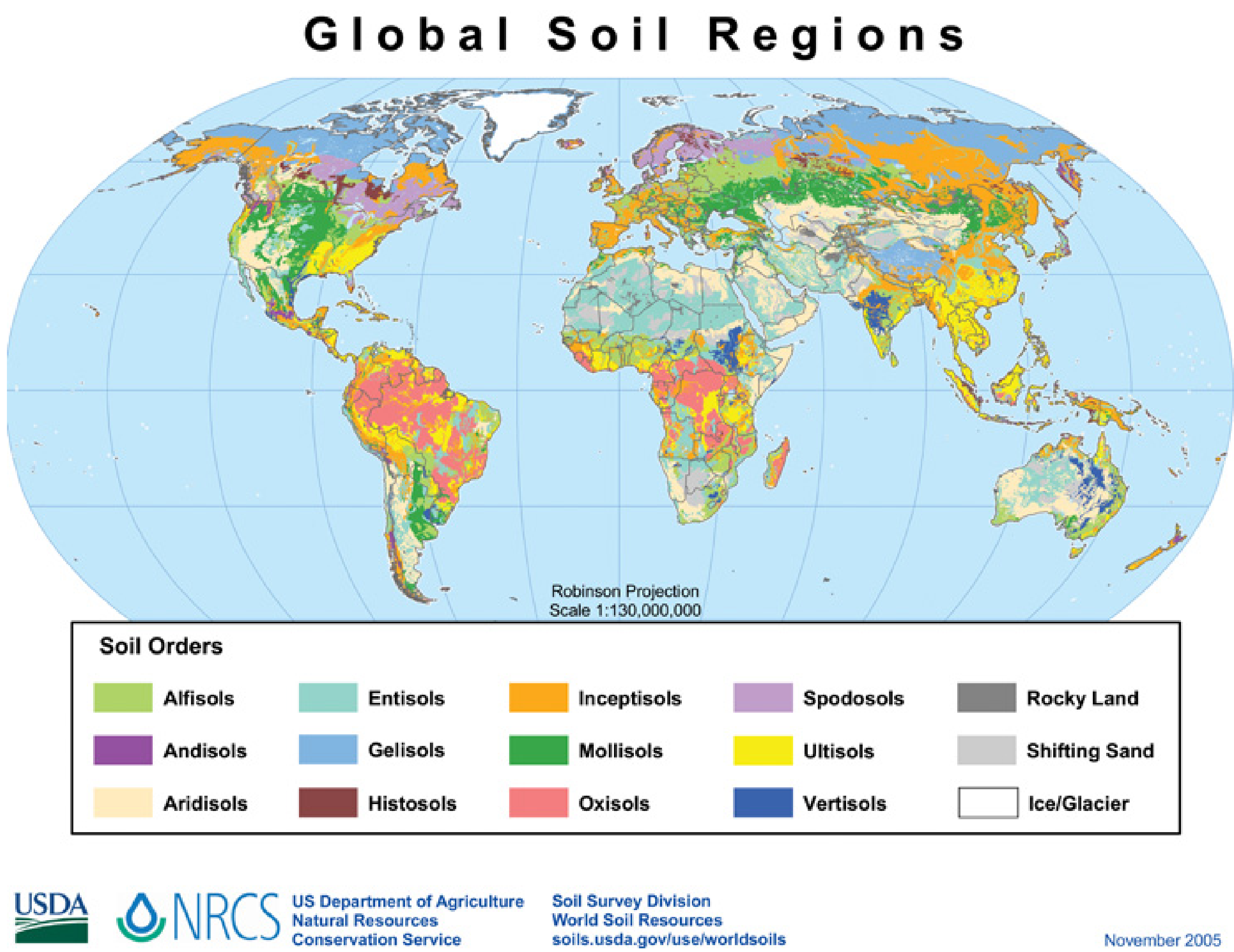

Figure 22: Global Soil Regions. By USDA

At this point, you should be confident about your analogue climate. Ponder what the major differences there are between the two climates. Now it's time to research and really see how things are being done in your climate analogue:

1. What are the major crops grown in the region?
2. What types of interesting plant, fungi and animal species are present?
3. What is the vernacular architecture and building materials used traditionally?
4. What do people use for energy sources?
5. What type of water distribution and irrigation are used?
6. Are there any cultural practices of interest?

4. Climate Analogue Examples

1) Mecca, Saudi Arabia

There are methods to make a quicker climate analogue assessment for a more general search to narrow down possibilities to examine further. One of those methods is by process of elimination using a few easily available pieces of data. This is how a place called Tayib Farm performed a climate analogue study for a location just South of Mecca in Saudi Arabia that was found on their blog on the internet (inactive link as of 05/11/2021). The site is located within the Koppen Geiger classification Bwh, which is "Arid Desert Hot", where precipitation is scant and all months average above 0°C (32°F). That area is pictured below in this map.

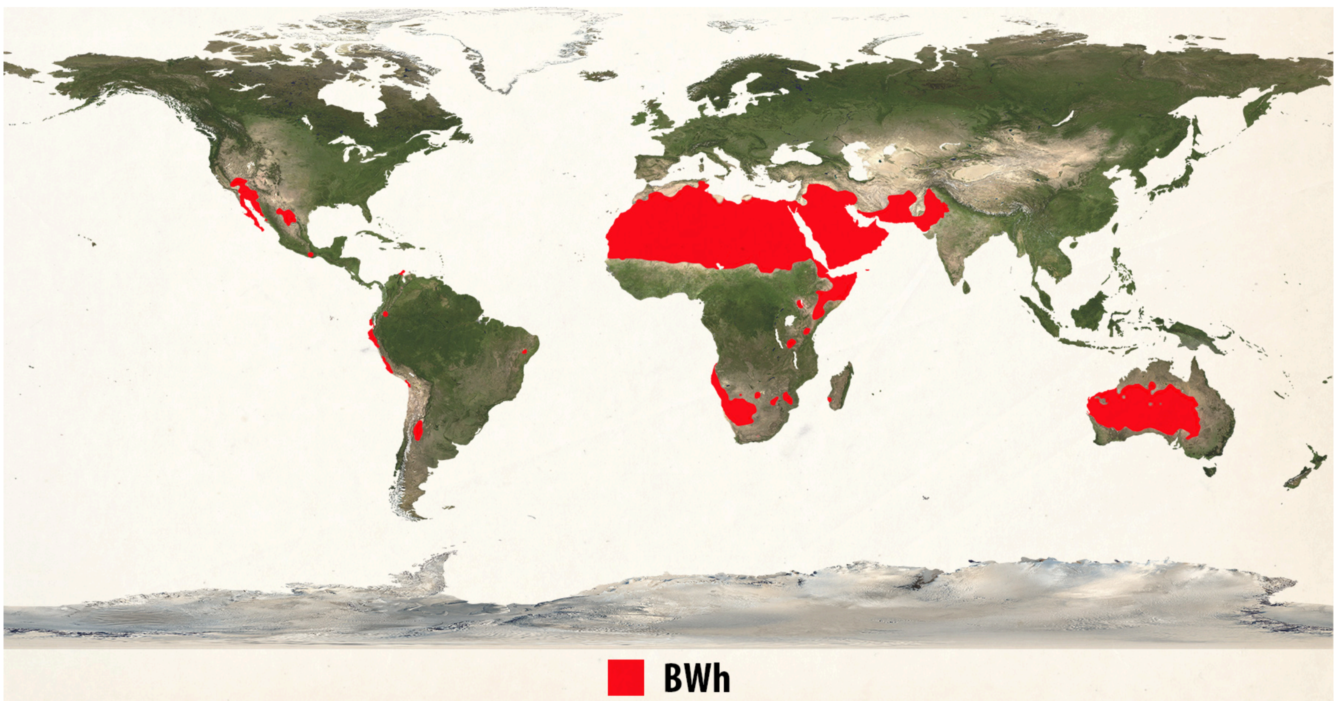

Figure 23: Koppen Geiger BWh "Arid Desert Hot" in red

That is still a very large area within which to narrow down a climate analogue. The next step was to overlay the plant hardiness zone map over the Koppen Geiger map to eliminate areas that had differing average annual extreme low temperatures. The Mecca area has 3 different plant hardiness zones tightly positioned together, zones 10,11 & 12, with average annual lows between 1.7°-12.8°C (35°F-55°F).

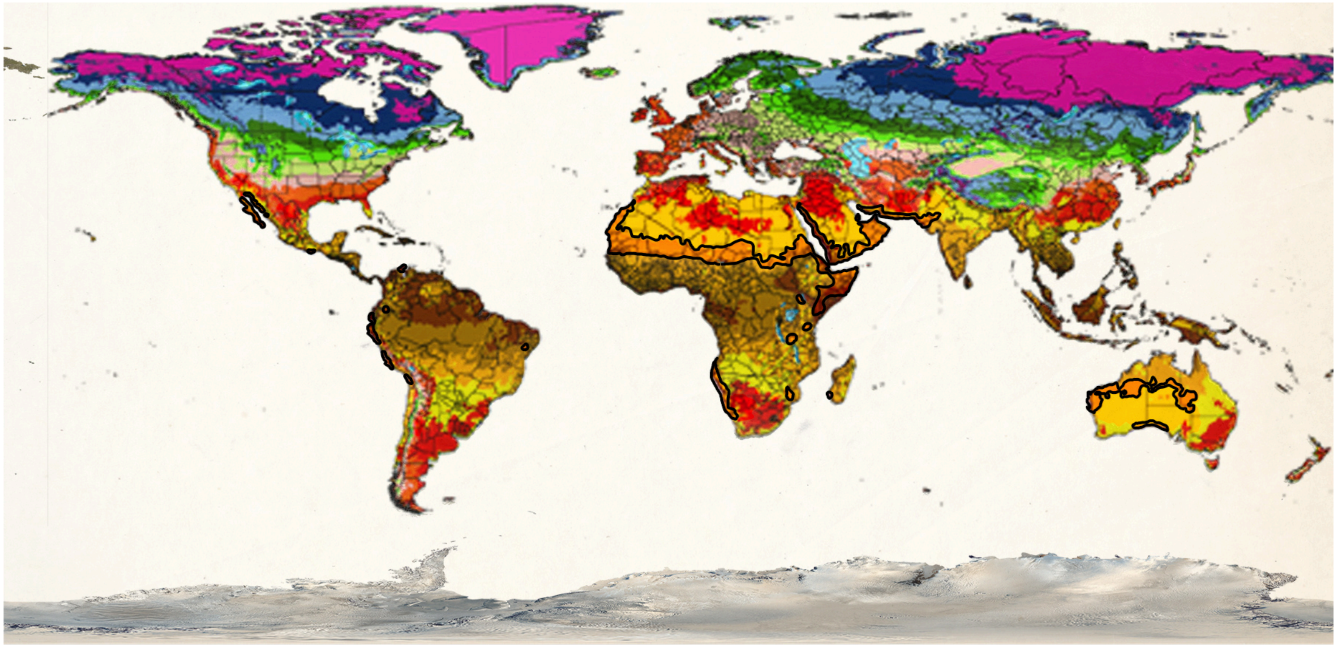

Figure 24: Koppen Geiger map with plant hardiness zones overlayed. Orange areas surrounded by black lines are areas of overlap between the Koppen Geiger classification and the plant hardiness zone.

The next step after that was to overlay a world map of precipitation to further eliminate wetter or drier areas and further narrow down the search. Mecca receives just over 100mm or 4" of rain annually.

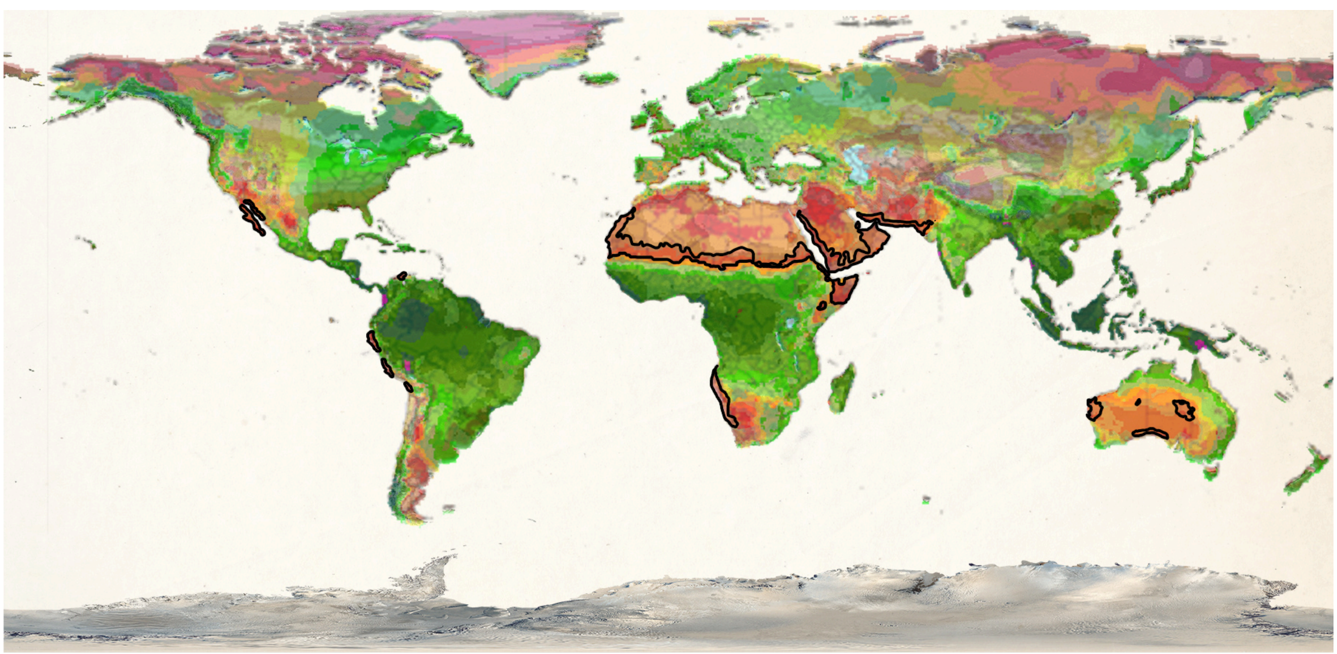

Figure 25: Koppen Geiger with plant hardiness zones overlaid with precipitation zones. Areas within the black line are overlapped between the Koppen Geiger zone, plant hardiness zone, and the annual precipitation.

What is left is a fairly small grouping of areas that have:

1. The same general climate classification
2. The same average yearly low temperature
3. The same yearly precipitation totals.

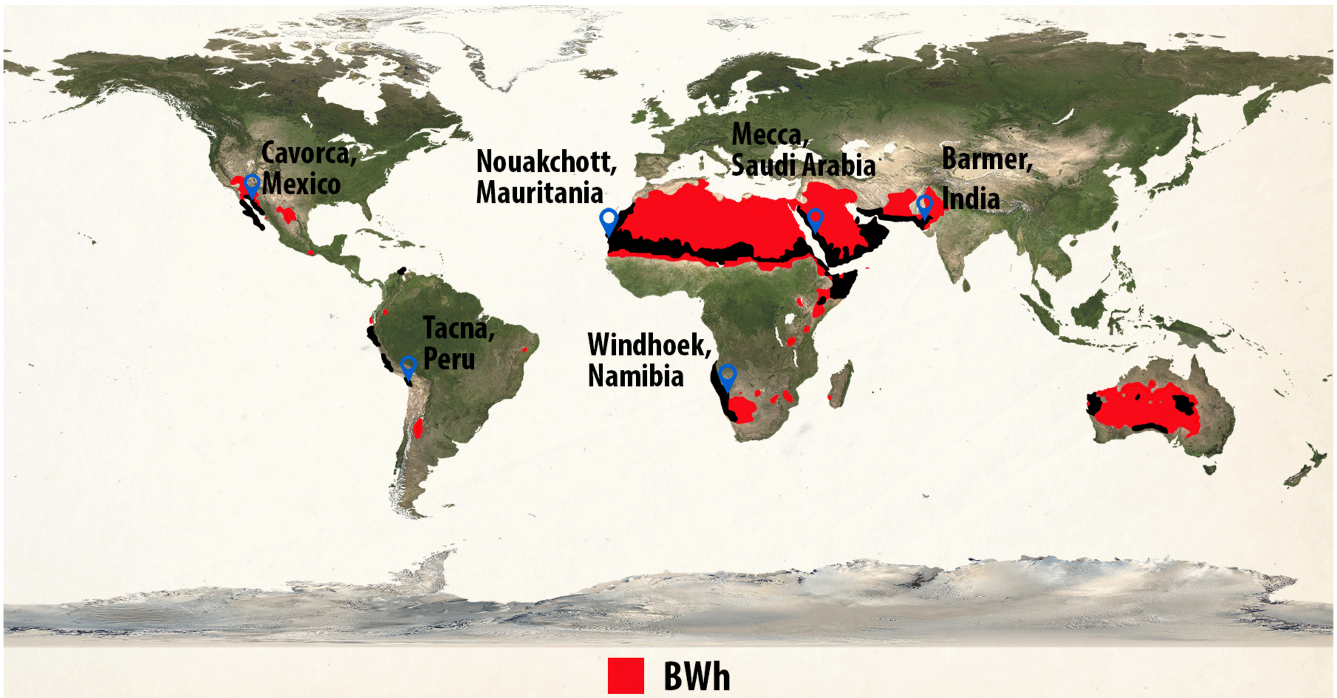

Figure 26: Analogous climates marked in black. These zones have the same climate class, plant hardiness, and precipitation.

From here, each of those areas could then be looked at more carefully with regard to elevation, seasonality of precipitation, proximity to large body of water, soil types, and the other items on the list of how to find a climate analogue. I might look at Barmer, India, Caborca, Mexico, Tacna, Peru, Nouakchott, Mauritania, and Windhoek, Namibia for clues, as they all fall within or very close to the analogue boundary.

Here are some research questions about hot desert climate analogue locations that could prove to be very fruitful with practical information that could assist in the design and development of a site:

1. How is water being accessed and distributed?
2. What trees, shrubs, annual and perennial crops and animals are being utilized?
3. Are people sedentary or nomadic?
4. What materials are buildings built out of and what are the major design features?
5. How is fertility maintained in agricultural systems?
6. How do people cope with the heat and aridity in their daily lives?
7. What is the traditional clothing and diet?

Permaculturist Neal Spackman is the director of the Al Baydha project in Saudi Arabia where they have installed a major water harvesting and reforestation project in order to create a viable settled livelihood for the traditionally nomadic Bedouin people. Bedouin are traditionally nomadic, and have been circulating animals around the Arabian Peninsula for thousands of years. With the rise of the modern nation state, the nomadic way of life was no longer preferable to the central government and they are attempting a new model that provides both economic and ecological vitality for the people and land.

As part of the design process for the 100 acre site, Neal performed a climate analogue assessment in order to select different productive tree species for the project, and came up with some very interesting plant selections[1]:

Photo 13: Neal Spackman and Prosopis glandulosa in Saudi Arabia

Neal Spackman and Prosopis glandulosa in Saudi Arabia

1: Moringa Perigrina is found growing in rocky wadis and cliffs on the Arabian Penninsula. Neal reports that the oil pressed from the seeds is a valuable and popular oil in the Middle East, and views the tree as a potential economically beneficial crop within his system.

1. Spackman, Neal. "How Do You Know What You Can Grow? Building a Climate Analogue". Two Visions Permaculture. 24 March 2015. Web. Jan. 2018 http://www.twovisionspermaculture.com/how-do-you-know-what-you-can-grow-building-a-climate-analogue/

Photo 14: Moringa perigrina in bloom. Creative Commons.

2: Pithecellobium dulce or “Manila Tamarind” is native to Western Mexico, portions of which are analogous to Western Saudi Arabia. The seedpods contain an edible pulp which is high in protein.

Photo 15: Photo by B. Navez. CC BY-SA 3.0

3: Prosopis glandulosa or "Honey Mesquite" is native to the Southwestern US and Northern Mexico, another climate analogue of Saudi Arabia. The Honey Mesquite has pods that can be ground into a flour, and fruits even during drought years. [2]

2. https://en.wikipedia.org/wiki/Prosopis_glandulosa

Photo 16: By Don A.W. Carlson CC BY 2.5

4: Schinziophyton rautanenii or “Mongongo Nut” tree is the staple crop of the Bushmen in the Namib desert. Namibia is a climate analogue to Saudi Arabia and even has matching soil types. The nuts are both flavorful and store well.

Photo 17: Creative Commons

5: Citrullus lanatus var. lanatus is also known as watermelon. Watermelon is another native of Namibia and grows well in Saudi Arabia, and is grown by flooding fields off of flash floods and sowing with watermelon seeds.

6: Various Agave varieties. Agave are succulent plants native to Mexico and the Sonoran Desert in the Southwestern US. One species, Agave murpheyi, was harvested and the basal rosette cooked in a pit for several days to be used as a common food source.

Photo 18: By Forest & Kim Starr CC BY 3.0

Neal combined these and other species to create prototype strip forests positioned in water harvesting swales to develop a climate-adapted diverse food system with economically viable yields to provide new sedentary livelihoods to a formerly nomadic population, pictured below:

Photo 19: By Neal Spackman

Photo 20: By Neal Spackman

5. Climate Change Projections

It is impossible to say exactly what will happen as the global average temperature continues to rise and humans continue to emit carbon and other greenhouse gases, decrease forest cover, increase urban heat islands, and persist in a myriad of other impacts on the biosphere. There are feedback loops that get triggered and complex consequences that are unforeseeable.

In spite of this fact, there are climate models and educated projections of specific impacts on different climate types that are created by scientists from all over the world based on data from weather measurements and inputted into complex computer models. In this next section we will examine some of the likely scenarios that are agreed upon by the majority of models.

The basic summary of the IPCC's (Intergovernmental Panel on Climate Change) 2014 report says this about projected changes in the climate system:

> Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in may regions. The ocean will continue to warm and acidify, and global mean sea level to rise.[1]

General Predicted Trends

1) The Jetstream

As the Arctic and Antarctic heat up, they lose a volume of ice coverage that was formerly reflecting light and heat back out into the atmosphere. Dark ocean and land are left, which more readily absorbs heat. For this reason, the Arctic and Antarctic are heating at a faster rate than the equator.[2]

The temperature differential between the poles and the equator is what pressurizes the jetstreams. The jetstreams are air currents in our atmosphere that move bands of moisture around the planet. The warm equatorial air mass and cold polar air masses meet and the boundary of these air masses become the Polar jetstreams in both the northern and southern hemispheres. These jetstreams wiggle around the globe and move up and down latitudes with seasonal changes. As these jet streams wiggle, on the equatorial side it is warm, and on the polar side it is cold, so the position of the jetstream determines what type of weather is

1. IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups i,ii and iii to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K.Pachauri and L.A.Meyer 9eds.)]. IPCC, Geneva, Switzerland, 151 pp.
2. J. Richter-Menge, J. E. Overland, J. T. Mathis, and E. Osborne, Eds., 2017: Arctic Report Card 2017, http://www.arctic.noaa.gov/Report-Card.

happening in a location. At the mid-latitudes, if one is on the equator side of the jetstream, it is hot. On the pole side it is cold. And within the jetstream it is precipitating.

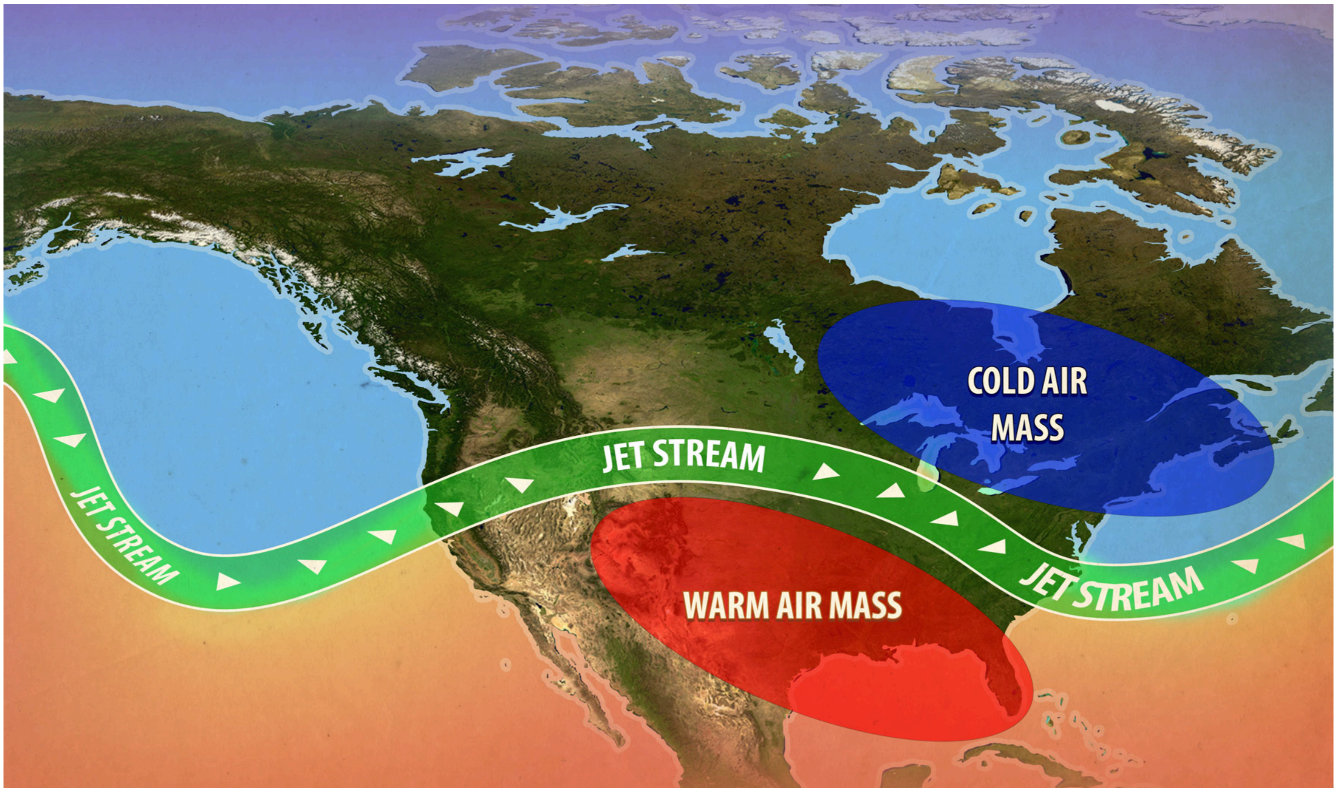

Figure 27: Jet Stream through the US.

When the Arctic and Antarctic heat more than the equator (because of the reflective sea ice melt), then the temperature differential between poles and equator is reduced, and the jetstream becomes depressurized. So instead of wiggling around and moving weather through, it becomes stalled, and it's undulating wave becomes deeper. When the jetstream is stalled and sluggish, weather persists for longer, whether it is rain, snow, heat, drought, or cold. Each one of these conditions becomes expanded. Longer dry spells, fiercer and slower moving storms, and more deeply penetrating cold snaps are all the results of a slowing jet stream.[3]

3. Frances, Jennifer A, and Stephen J. Vavrus. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters. 2015. Web. Jan. 2018

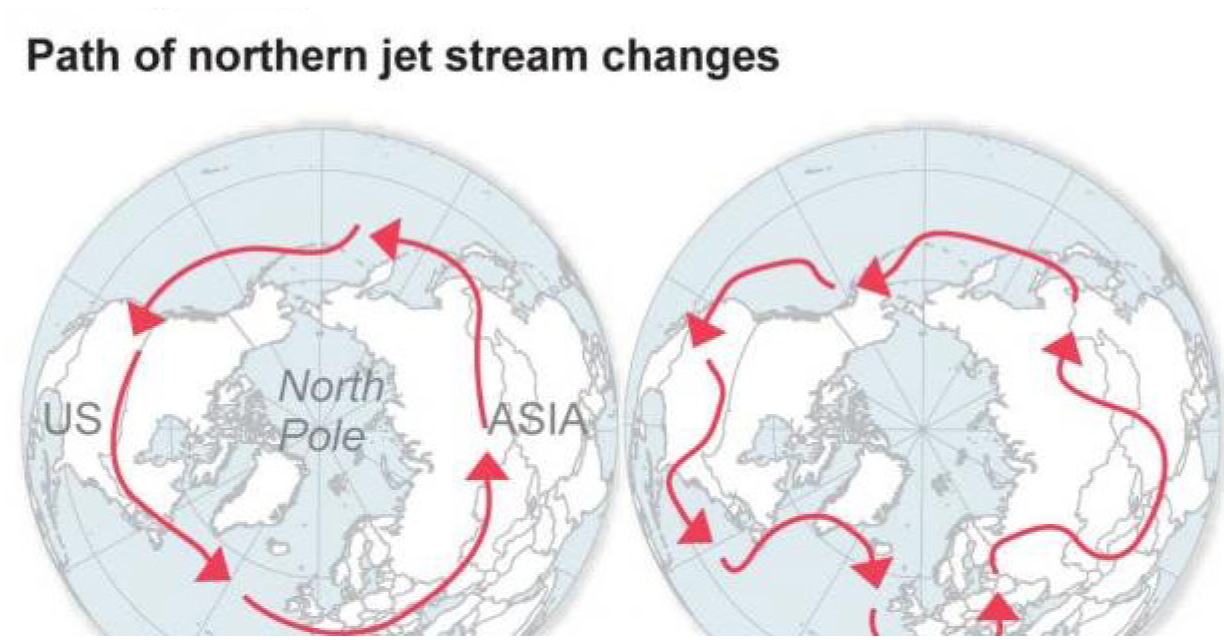

Figure 28: Path of Northern Jet Stream Changes

2) Wetter Tropics

Because of increased temperatures, there is projected to be more water evaporating into the atmosphere. This will lead to changes in precipitation, but they will not be uniform. For the wet tropics and especially the equatorial Pacific, precipitation will likely increase, and extreme precipitation events will very likely increase. This translates to the intensification of hurricanes, typhoons, and monsoon precipitation.[4]

In looking at Koppen Geiger climate projections for 2076-2100 compared to 1901-1925 under the IPCC's A1FI emissions scenario, there is a dramatic expansion of all equatorial humid climate types.

4. IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups i,ii and iii to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K.Pachauri and L.A.Meyer 9eds.)]. IPCC, Geneva, Switzerland, 151 pp. Print.

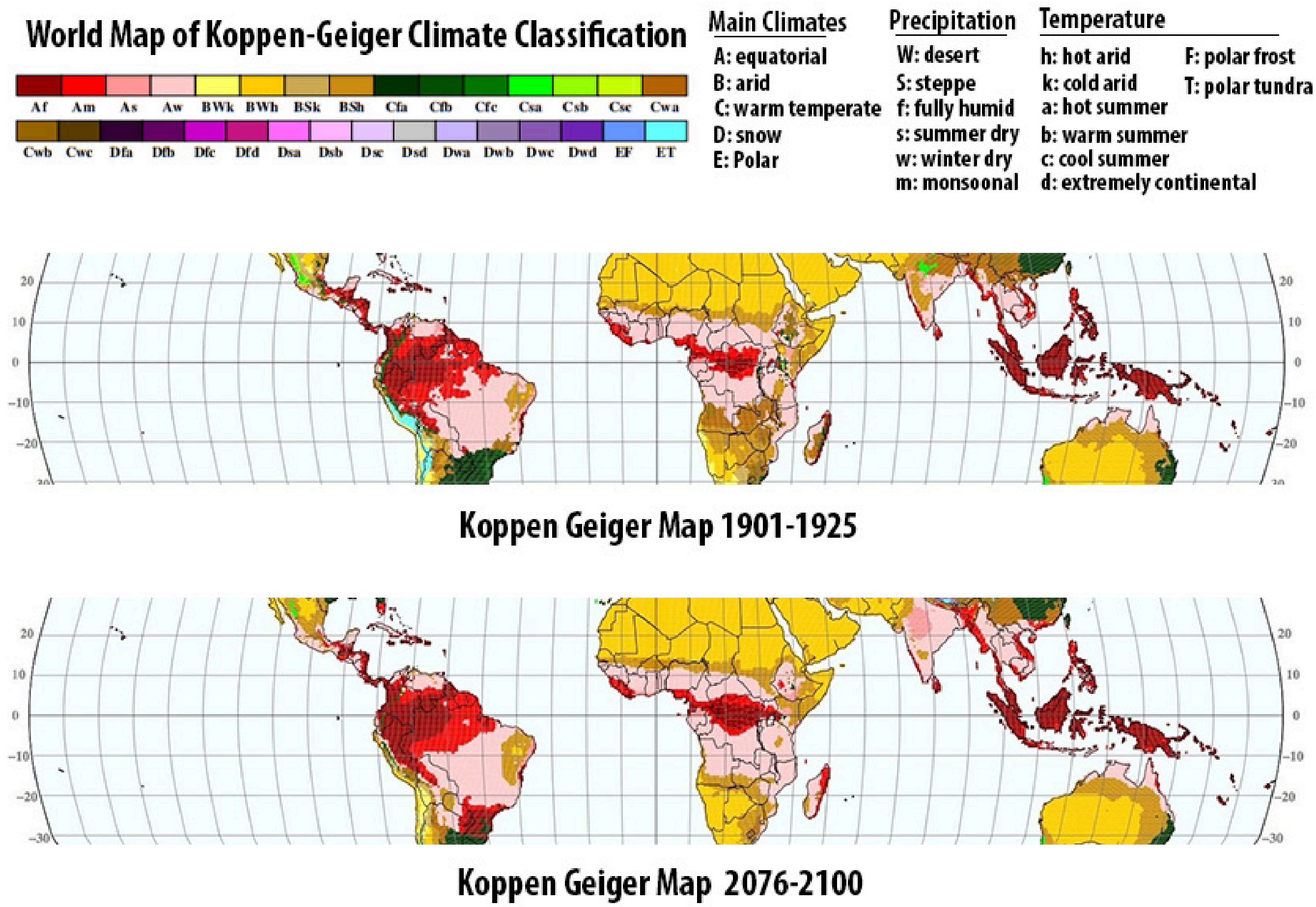

Figure 29: Equatorial Koppen Geiger Map 1902-125 and 2076-2100. Adapted from Observed and projected climate shifts 1901–2100 depicted by world maps of the Koppen-Geiger climate classification.

What will this actually look like? At the time of this writing, hurricane Harvey is dropping an all time record amount of precipitation for a single storm on the US mainland, a full 50" (1.27m) on Houston, Texas and the surrounding areas. This is one aspect of expanding tropical moisture and one that calls for extreme flood and storm surge resilience in equatorial communities.

3) Expanded Dry Areas

The IPCC states that there's "robust evidence" with "high agreement" that the changes in surface and groundwater resources in dry subtropical regions will be reduced, and drought frequency will likely increase. That is coupled with more extreme heat events overall, punctuated by increasing extreme precipitation events when it does rain.[5]

5. IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups i,ii and iii to the

This diagram from that same IPCC report shows areas of projected decreased precipitation in the browns and tans. Also note the increased rainfall in other places, in both equatorial zones as well as higher latitudes.

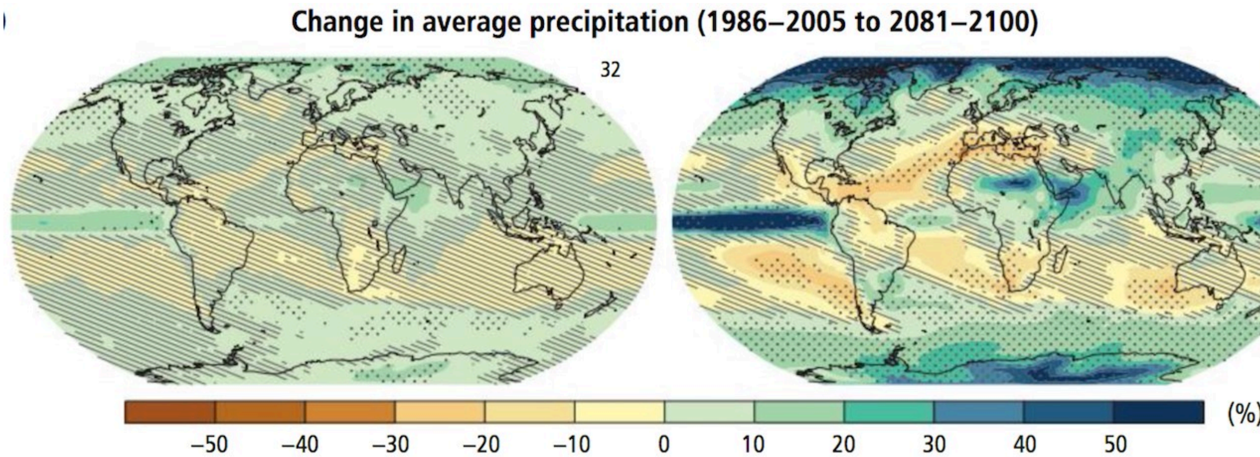

Figure 30: Change in Average Precipitation (1986-2005 to 2081-2100)

This is a very low resolution map without much detail, but notice projections of increased rainfall on the horn of Africa and the Southern Arabian Peninsula. I can't help but wonder if the projection of increased rainfall over that extremely arid area will take the form of devastating storms like Tropical Cyclone Chapala that battered Yemen in 2015 and caused massive flooding throughout that country that is primarily in the Bwh hot desert climate class. Chapala was fueled by record warm water temperatures in the Indian Ocean and dumped several years worth of precipitation.

Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K.Pachauri and L.A.Meyer 9eds.)]. IPCC, Geneva, Switzerland, 151 pp.

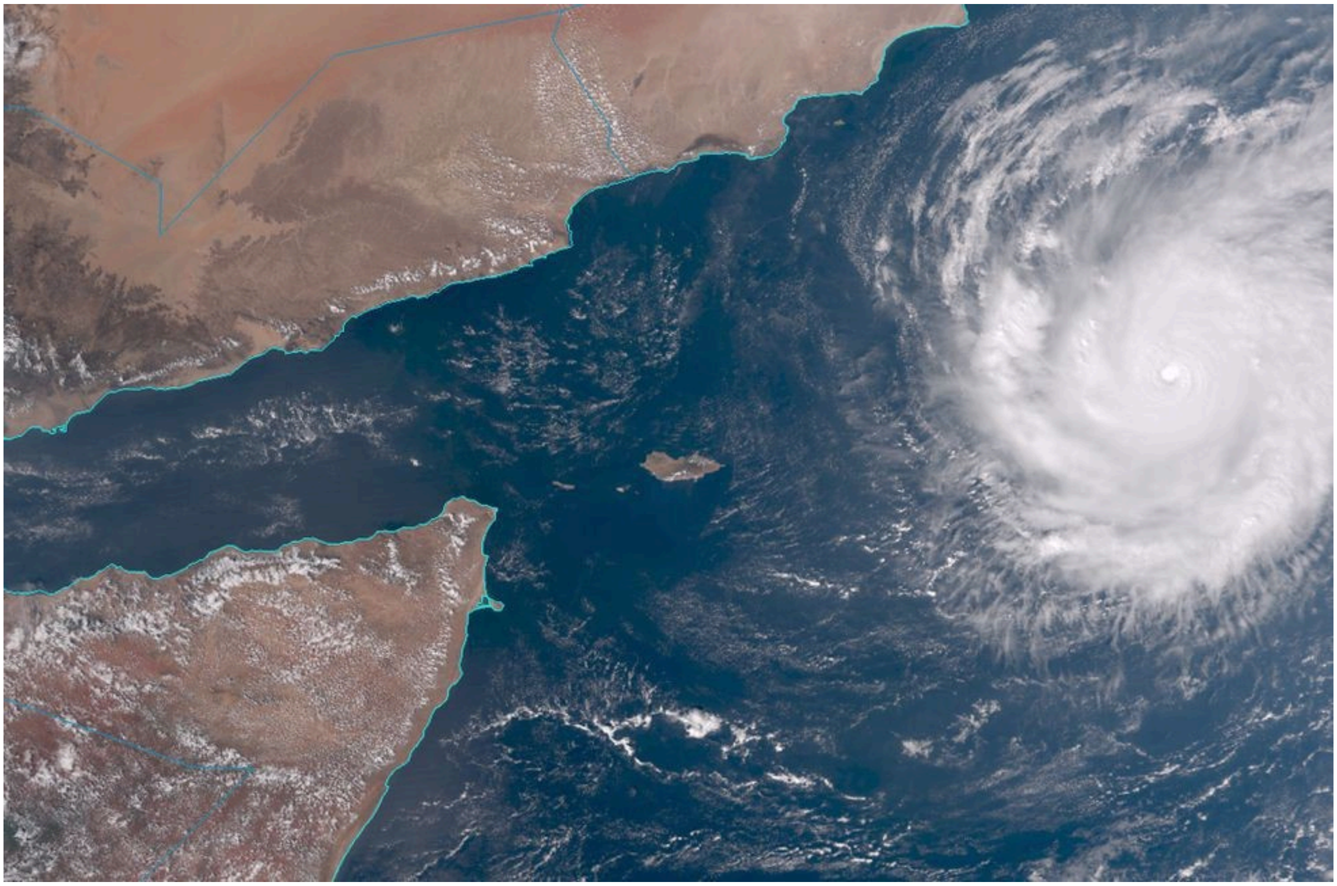

Photo 21: Yemen and tropical Cyclone Chapala. Creative Commons

Either way, with hotter and drier deserts, their edges will naturally expand into the ecosystems at their edges. This map of Australia and the projected shift in climate types is illustrative of this fact. Notice the reduction of the Cfa, Csb, and Cfc climate types (temperate) along with the elimination of the Bwk and Bsk climate types (cold arid) and the expansion of Bwh and Bsh climate types (hot arid). There is however some expansion of Aw (equatorial winter dry) in the north and northeast, which means that region gets some benefit of the trend towards wetter tropics.

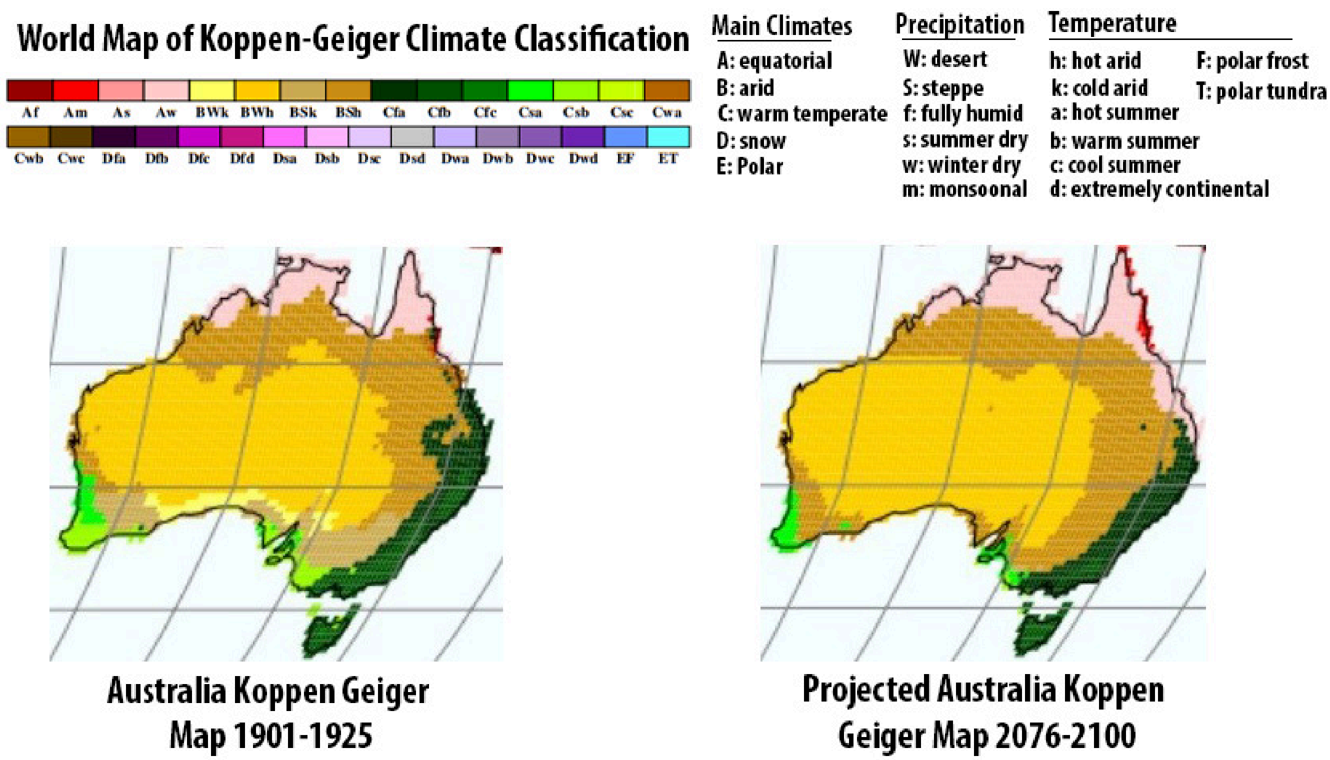

Figure 31: Australian Koppen Geiger map past and projected. Adapted from "Observed and projected climate shifts 1901-2100 depicted by world maps of the Koppen-Geiger climate classification."

4) High Latitude Warming

The higher latitude land masses in the northern hemisphere are projected to warm more than any other place on Earth. This will have a very visible impact on the landscape through the reduction of snow cover, sea ice, and the melting of permafrost. Satellites have already observed a reduction in sea ice concentrations, and some scenarios predict the Arctic to be ice free in summer by 2050[6].

6. Hartmann, Dennis L., Global Physical Climatology. Elsevier, Amsterdam, The Netherlands, 2016. Pg 418

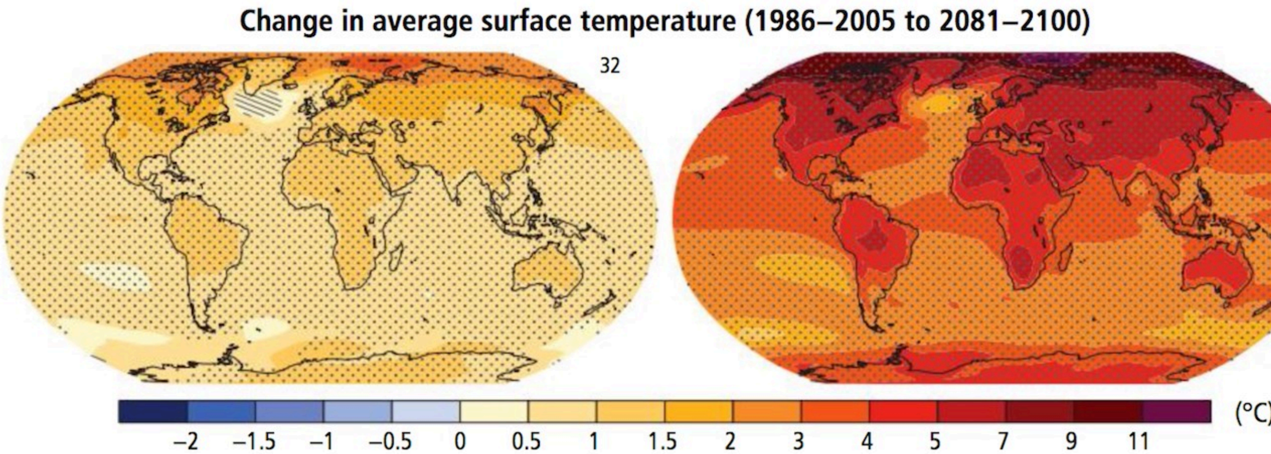

Figure 32: Change in Average Surface Temperature (1986-2005 to 2081-2100)

Overall there will be a reduction of climate zones classified as boreal forest, snow climates and polar climates.[7]

Notice the retreat of the purple and blue colors which are the snow and polar climate types, and the amount of landmass affected by this shift. This will be a different world than it is right now by the end of the century.

In scientist James Lovelock (creator of the Gaia Hypothesis)'s 2006 book The Revenge of Gaia, he speculates that later on in the 21st century, human civilization will be confined to a narrow band of about 200 million people living around the Arctic Circle, as this will be the most expansive area of the temperate climate zone where broadscale agriculture will still be able to be practiced.[8]

That speculation does not match up with the pictured projected change of the Koppen-Geiger map, but it certainly makes one think. Already there is stiff competition for newly accessible fossil fuel resources around the Arctic because of melting ice.[9]

7. Bailey, Robert G. "Ecosystem Geography: From Ecoregions to Sites" Springer, New York 2009, p.121
8. Lovelock, James. The Revenge of Gaia. New York: Basic Books. Print.
9. Macalister, Terry. "The New Cold War". The Guardian. Web. https://www.theguardian.com/environment/ng-interactive/2015/jun/16/drilling-oil-gas-arctic-alaska

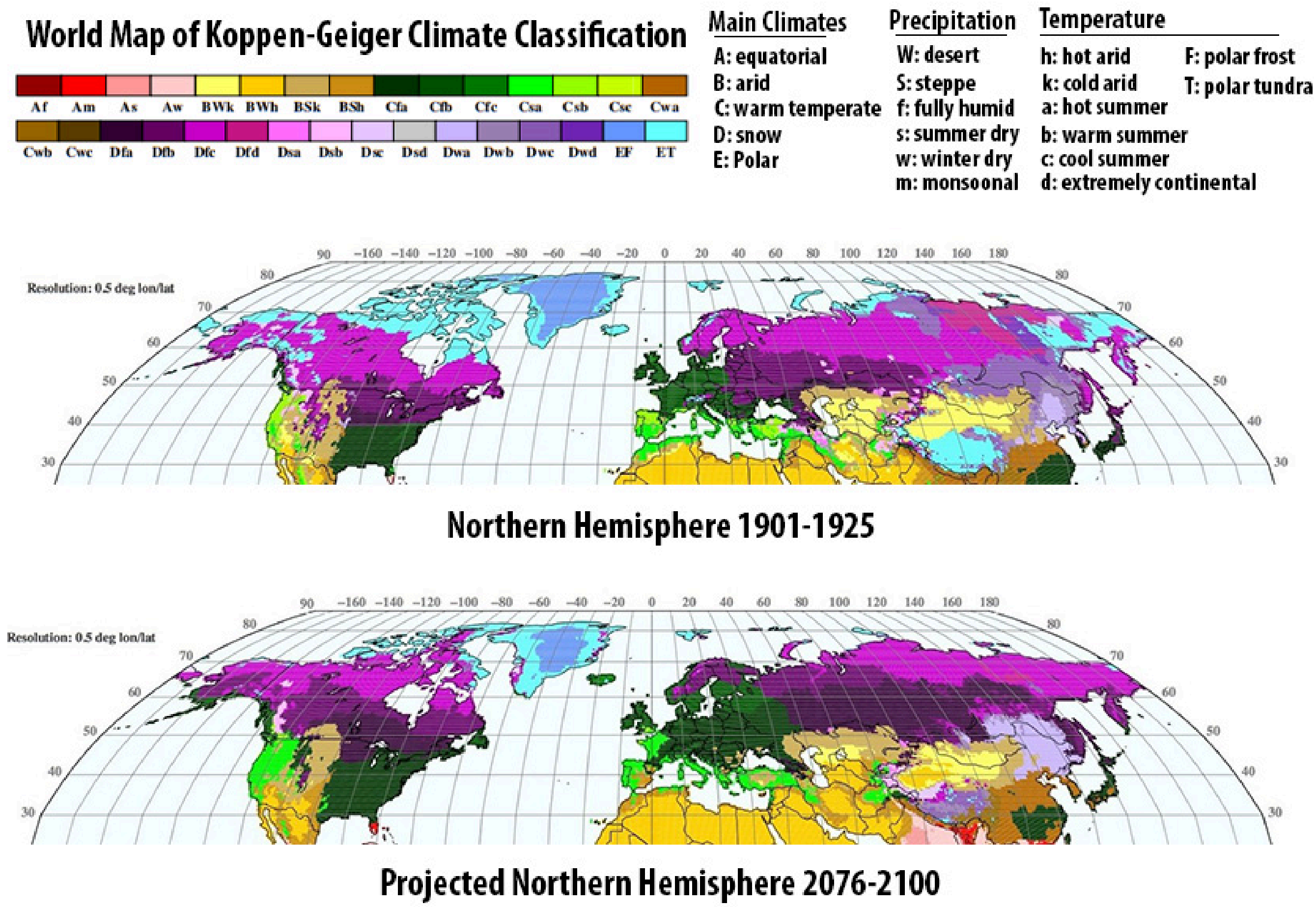

Figure 33: Koppen Geiger Northern Hemisphere Map 1901-1925 and 2076-2100

5) Altitudinal Shifts

Travelling up any mountain range or plateau reveals elevational boundaries between vegetative types. Ecosystems are stratified as one moves through elevation. With climate change projections, that stratification will change, and dramatically in some places.

The elevational shift of climate zones will not be consistent throughout the world because there are so many variations in the number of elevational zones present and at what elevation these zones are found at between various latitudes. [10]

10. Bailey, Robert G. “Ecosystem Geography: From Ecoregions to Sites” Springer, New York 2009, p.122

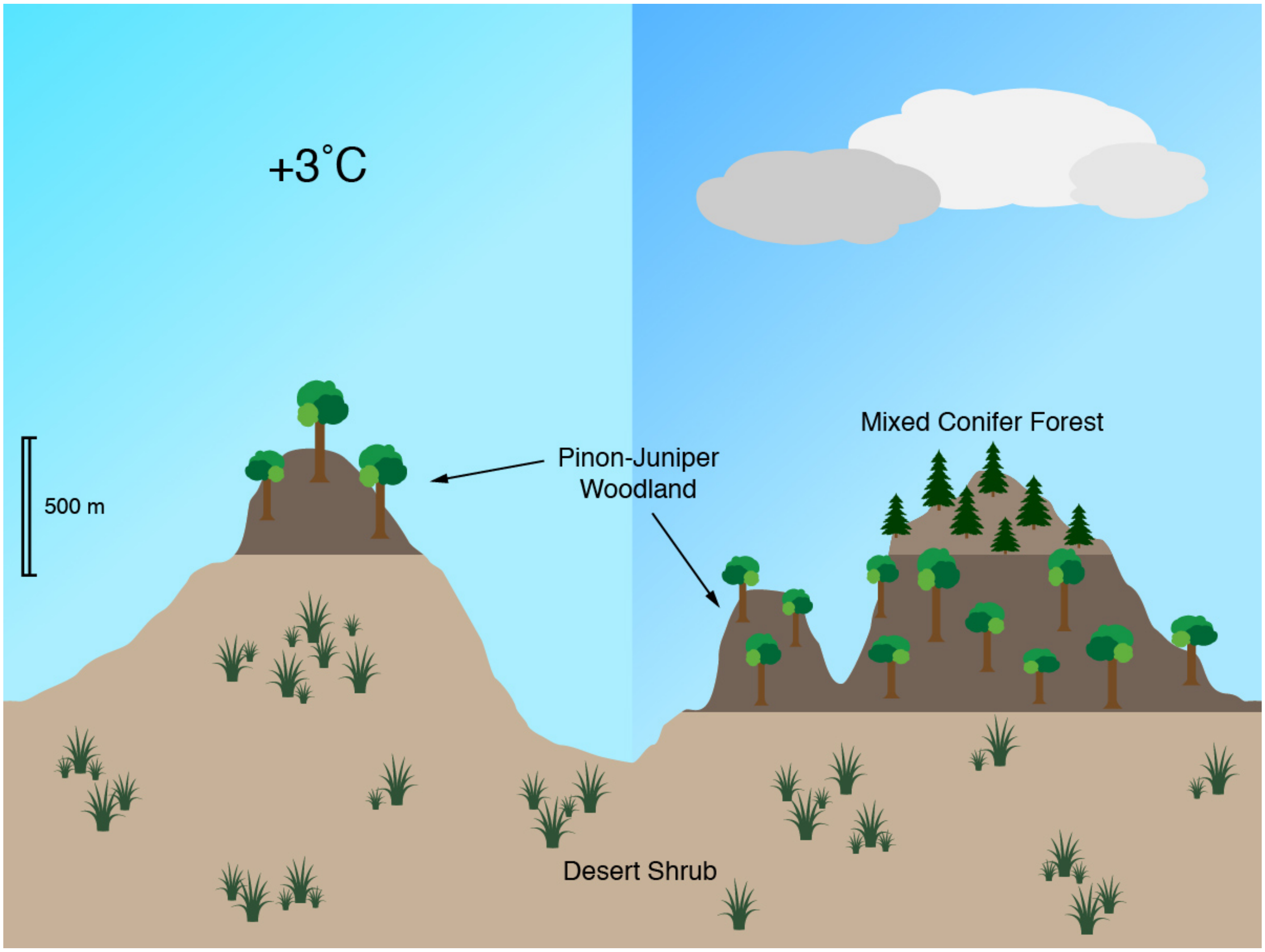

Figure 34: Elevational Boundaries diagram. Adapted from "Ecosystem Geography" by R.J. Bailey

This diagram projects the change of the elevational boundaries of vegetative types in the Great Basin of Nevada, USA in a 3˚C warming scenario. We see an increase in desert scrub vegetation, a raising up of the Pinon-juniper woodland, and the elimination of the coniferous forest from the top in this diagram. One has to wonder how the ecosystem makes a transition like that when a catalyst like a wildfire could reset the whole ecosystem in a flash. The regrowth after the fire would reflect the new ecosystem and climate type.

This altitudinal shift in climate types explains a lot of the changes we see in Figure 15 in the mid latitudes. Notice especially the changes in the Himalayas and Tibetan Plateau. Permaculturists have a unique opportunity to adapt to elevational climate shifts by amplifying microclimates within complex elevational topography to include a maximum diversity of species that represent the greatest elevational range.

6. Climate Change Analogue

As was mentioned at the beginning of this book, in the conventional world of climate science and international development, a climate analogue is the climate that one is set to become with climate change. In this book, we are referring to that as the "climate change analogue", and using "climate analogue" to refer to an area that is similar to another climate currently.

One important point to consider is the timing of any climate change forecasts, and why we would look at one time span over another. It is unknown whether or not the climate will reach some stable state or whether we will continue, decelerate or accelerate human caused climate change. Most of the forecasting maps that are currently available tend to look at the last quarter of the 21st century. The reason that this seems like an appropriate time frame is that by the year 2100, a child born today will be into their 80's, which is considered a full life span in the industrialized world today. So we are planning for the world that a baby today will live through. Seems appropriate, right? But practicality must be taken into account. Introducing species that will thrive at the end of the century could be a failure in the present. The change needs to be incremental and experimental.

Locating climate change analogues is valuable for a number of reasons, and has already been adopted as a practical tool by research organizations like the International Center for Tropical Agriculture (CCAFS), the Consultative Group for International Agricultural Research (CGIAR), and the World Agroforestry Centre (ICRAF). Programs like the Research Program on Climate Change, Agriculture and Food Security are locating climate change analogue locations and actually facilitating farmer trainings between locations and exchange of genetic material. [1]

Many of the reasons that it is beneficial to locate a climate analogue are also relevant for a climate change analogue. Some of the specific goals of the research program mentioned above are:

1) Locating plant, fungi, and animal species that will thrive in your future climate and exchange of that genetic material.

A few excellent examples of the practical use of this tool are highlighted on the website of the Research Program on Climate Change, Agriculture and Food Security:

"Climate models predict a 1°C rise in average temperatures by 2030 during the maize-growing season near the city of Durban, South Africa; this could result in a 20% drop in yield. The analogues tool suggests looking to northern Argentina and Uruguay, where maize farmers are enjoying good yields under average temperatures that are 3°C higher than those around Durban."

"The 2030 climate in a soybean-growing area near Shanghai, China will be similar to current climates in soybean-growing zones in the USA and South America. Farmers in Shanghai can learn from these analogous climates as their own climate shifts."

"An analogue of present day Los Angeles shows that the southeastern USA, France, northern Germany and

1. "Climate Analogues". Climate Change, Agriculture, and Food Security (CCAFS). Web. https://ccafs.cgiar.org/tool-climate-analogue-tool#.Wql8bJPwZBL

the Netherlands might all experience southern California's mild winter climate by 2030, with implications for the agriculture in these regions."[2]

These examples crack open the window of possibility in the creative Permaculture mind for the endless possibilities of learning and systems development that can come from directly visiting and exchanging with one's climate change analogue. For plant breeders, to begin to introduce the genetics of climate change analogue species into regional varieties of plants and animals helps us partner with nature to create a biodiverse and resilient agricultural gene pool.

2) Putting farmers directly in touch with their agricultural futures by taking them to visit their climate change analogues and facilitating an exchange of knowledge.

Again, the Research Program on Climate Change, Agriculture and Food Security actually took a group of farmers from one part of Tanzania over 1,000km away to another part of the nation that represents their climate change analogue. This glimpse at their "future farms" and facilitated exchanges between them and their analogues' farmers left them with a clear sense of what they are facing and a strategy to address that. The group of 15 farmers then returned to their region and shared their findings among their community. [3]

They have also undergone similar tours in Kenya and Nepal, and have conducted workshops and trainings in Costa Rica, Ghana, Vietnam, and other places. This is the sort of tool and perspective that could be very useful to Permaculturists working throughout the world. Permaculture does claim to be the largest decentralized aid organization on the planet, and would do well to become proficient with the Climate Analogue Online Platform interactive tool that the Research Program on Climate Change, Agriculture and Food Security provides. [4]

Aside from agricultural information, there are the other items that can be learned from identifying a climate change analogue similar to those of a current climate analogue. Those include building design and methods, civil engineering related to water systems, infrastructure that's resilient to climate and weather events, cultural practices that enhance comfort and safety in relation to weather and climate, and folk wisdom that can help people cope and make connections in their new climate.

Methodology for Locating Climate Change Analogues

There is more than one computer model that attempts to identify climate change analogues and others that claim to be under development. For the purposes of this writing, we will not rely on any one particular tool, as tools on the internet come and go and it's important to build the capacity to think this through oneself.

2. "Climate Analogues". Climate Change, Agriculture, and Food Security (CCAFS). Web. https://ccafs.cgiar.org/tool-climate-analogue-tool#.Wql8bJPwZBL
3. Mungai, Catherine, and Maren Radeny and Caity Peterson. "One Farmer's Future is Another Farmer's Present: Farms of the Future Hits Tanzania". Climate Change, Agriculture and Food Security (CCAFS). Web. https://ccafs.cgiar.org/blog/one-mans-future-another-mans-present-farms-future-hits-tanzania#.Wql8_JPwZBJ
4. https://ccafs.cgiar.org/tool-climate-analogue-tool#.Wql8bJPwZBL

The goal of this section is to provide a simple and low-tech process for determining a climate change analogue. Below are a series of simple steps. Please see [Appendix B: Climate Change Analogue Survey] for a printable form.

Step 1) Locate the site on a Koppen Geiger climate change forecast map and identify the projected climate classification.

The most common Koppen Geiger climate change projection maps are for the years 2076-2100 [See Appendix E]. That is still nearly 60 years away from the time of this writing, and may or may not be a relevant time frame based on the designer's goals. It also may not be accurate due to so many unforeseen circumstances and unknown climatic feedback loops. But as an exercise in acting on what is considered consensus forecast models, it shows a general direction based on a warming planet.

It is also an important exercise to imagine what the agent of a shift in vegetative types will be. Fire, extreme drought and heat, flooding, extreme cold, and large scale insect damage are all factors that can cause the die-off of species and facilitate replacement of others.

These can be catastrophic events that can threaten the habitability of areas. So if the climate is going to shift to a new ecosystem, it is the role of the Permaculture designer to foresee the potential agent of that shift and design for resilience as a response to that possibility. There is a very complicated series of ecological events that need to happen for those colors to shift on the Koppen maps. It is the role of the climate change designer to lean into that.

Step 2) Research region-specific climate change forecasts.

Previously in this book I discussed major trends that have consensus among climate scientists to be unavoidable. I will summarize them here and add a bit more:

1. A general warming trend over the entire planet. Even though year over year there could be cooling and extreme cold events, statistically the average temperature on Earth is warming and that is a trend that will continue. Much of climate change is a response to this basic fact.
2. Acidification of the ocean. The pH and chemistry of the ocean is changing, and this is having a negative effect on the existing oceanic food chain
3. The stalling and undulating of the jet stream. This is making weather systems persist longer, whether they are precipitation, drought, heat, or cold.
4. The tropics are getting wetter. This is due to greater evaporation in warmer oceans.
5. Dry areas are expanding. Hot places are getting hotter, leading to further evaporation and evapotranspiration, leading to a greater drying of the landscape and the resulting changes in biota and fire danger.
6. High latitude regions are warming the most. This has to do with disappearing sea ice and greater heat absorption by a darker ocean.
7. Warming is causing shifts in the altitudinal stratification of vegetation. This means glaciers are retreating or disappearing, boreal forests are moving up or disappearing, and shrub dominated ecosystems are replacing tree dominated ones, often with fire as the agent of change.

There are many regional and governmental organizations that have distilled information into distinct climate change forecasts. For example, for the Pacific Northwest of the USA, there is a website called the

Northwest Climate toolbox[5] that was created by two different entities within the National Oceanic and Atmospheric Administration (NOAA). It is an interactive site addressing issues of agriculture, climate, fire, and water with loads of information and specific projections aimed at people who seek to understand how to adapt and prepare.

So do your best to locate what information exists out there and summarize the projections in as simple terms as is possible. See [Appendix F: Resources for predictions and climate models]

Step 3) Using a climate data chart, see how close the area is to shifting climate zone classifications.

When studying the forecasted Koppen maps, there are many areas that do not change their climate classification and many which do. Just because an area does not shift its climate classification does not mean that the climate does not experience a dramatic shift. It's important to recognize how close or far a given location is to the next classification.

Here we revisit the parameters that define the Koppen Geiger classification system: specific average temperatures for a certain amount of months combined with the seasonality of precipitation determine the classification. In the Appendix C & D of this book, you'll find the specific temperature and precipitation parameters for each Koppen Geiger and Koppen Trewartha classification.

The next step is to locate a climate data chart for your location, or find one for the closest analogous area if none exists. Examine the climate data chart alongside the Koppen Geiger or Koppen Trewartha climate type parameters, and discern how the climate data validates the classification.

If your climate is projected to be hotter, then look at the parameters of the next hotter climate type, and see how close the climate data is to it. If your climate is projected to get wetter, then find the next wetter climate type. The information about what the general projections are for the study area will inform which climate type is examined as the potential climate change analogue.

Step 4) Find regions that are located now within the projected new climate type.

Following some of the same methodology from the climate analogue identification process, there are some specifics to examine. The two main areas to begin searching are areas of either different latitude, elevation, or both. Whether or not you are more likely to find your analogue by changing latitude or elevation depends on the landscape positioning of the site.

Here are actions from the climate analogue identification process adapted to finding a climate change analogue:

a) Look for areas within 10 degrees North or South of your latitude.

The closer to the site's latitude that can be located as a climate change analogue, the better. This is because both sites will have similar seasonal sun cycles. In fact, the closer the site is period, the closer the conditions will be an accurate analogue.

b) Examine Thornthwaite climate classification.

If the climate for a location is projected to get drier or wetter, looking on the Thornthwaite climate map could be an easy way to identify another area with the forecasted moisture index.

c) Look for areas with the same proximity to water; oceanic or continental.

What are the similarities and differences between your site and this potential climate change analogue? Are both locations on the same coast East or West, North or South?

5. "The Northwest Climate Toolbox". Climate Impacts Research Consortium and NOAA Regional Integrated Sciences and Assessments. Web. www.climatetoolbox.org

d) Compare elevation.

A change in elevation may be the easiest way to find a nearby analogue. It could be that dropping elevation 1000 ft or 300 m is the easiest way to locate the closest analogue.

e) Compare precipitation amounts.

Is precipitation forecasted to go up or down for the area? Can you find a location with the projected new precipitation trend?

f) Compare precipitation seasonality.

Are dry or rainy periods forecasted to lengthen or shorten, increase or decrease in volume or intensity? Is it possible to find a climate that already exhibits these projected qualities.

g) Examine global air circulation and storm tracks.

Are there particular air circulation patterns that reflect the forecasted climate change?

h) Examine nearby ocean currents (if applicable).

Are there particular ocean currents that affect temperature and seasonal weather events? (i.e. North Atlantic Current bringing warm water North or California Current bringing cold water South etc.)

i) Compare topographic features and landscape positioning.

Are there mountain ranges or major rivers in the region? What are they called and what are their elevations in feet or meters? If there are topographic features present, what is the proximity of the site and directional relationship to them (North, South, East or West)? Is there a major plateau, delta, are you on an island? Are there other distinctive feature that characterizes the area?

j) Examine plant hardiness zones.

How is the plant hardiness zone of the site projected to change in degrees Celsius or Fahrenheit? Looking at areas that have the new forecasted zone could be a quick way to locate potential climate change analogues.

k) Compare global soil regions.

If the sites have dramatically different soil regions, with one site having sand dunes and the other clay, that means that geologic forces are a dominant characteristic and it could have an impact on the analogous nature of the sites.

7. Climate Change Analogue Examples

I will now go through the process of locating a climate change analogue for two places I am intimately familiar with: my current home in Corvallis, Oregon and my previous home in Prescott, Arizona.

Case study #1: Corvallis, Oregon, USA

Photo 22: Corvallis in the Willamette Valley, Oregon. Creative Commons.

Step 1: Locate the site on a Koppen Geiger climate change forecast map and identify the projected climate classification.

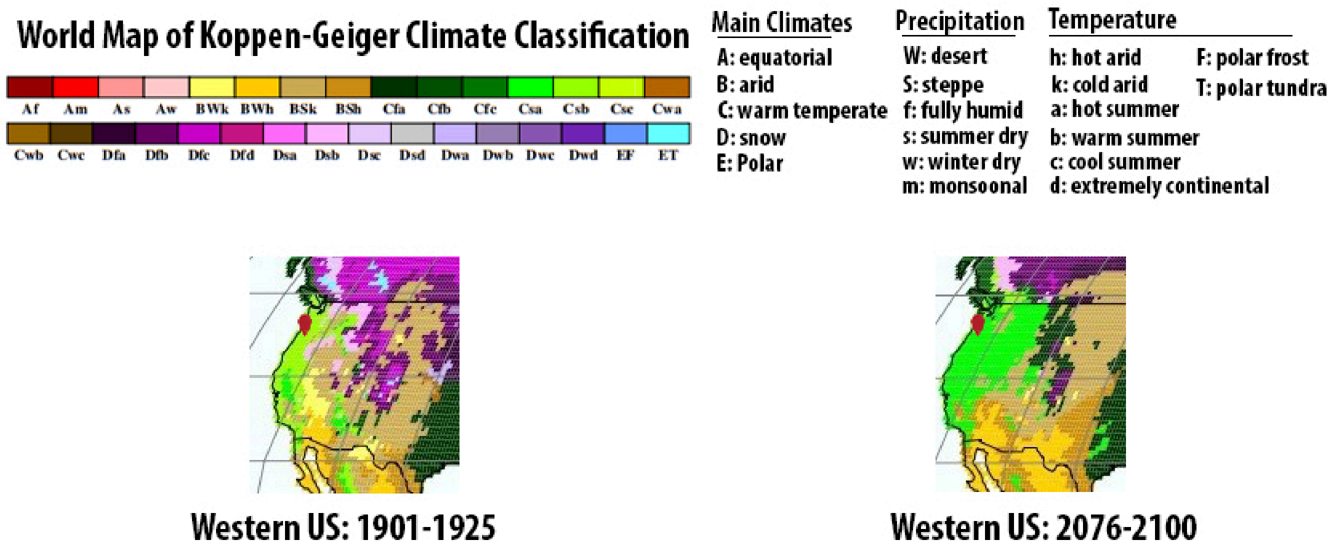

Figure 36: Corvallis on the Koppen Geiger Map 1901-1925 and 2076-2100

In short, Western Oregon is projected to go from a Csb climate type to a Csa, meaning from a Warm Summer Mediterranean climate to a Hot Summer Mediterranean Climate

Step 2: Research region-specific climate change forecasts.

The Pacific Northwest of the US is fortunate to have top-notch climate change research going on and easy-to-digest forecasts for the various biomes within the region. To get a well-summarized forecast, I just needed to look to Oregon State University's state funded Oregon Climate Change Research Institute and their publication "The Third Oregon Climate Assessment Report January 2017".[1]

In the legislative summary at the beginning of the report, they broke down the general trends for the state, and then specific forecasts for the Willamette Valley in which Corvallis is located. It reads:

> Oregon will continue to warm Under continued increasing greenhouse gas emissions, Oregon's climate is projected to warm on average 3–7°F by the 2050s and 5– 11°F by the 2080s. If greenhouse gas emissions level off by mid-century, warming would be limited to 2–5°F by the 2050s and 2–7°F by the 2080s. Annual precipitation is projected to increase slightly, although with a high degree of uncertainty. Summers are expected to warm more than the annual average and are likely to become drier. Extreme heat and precipitation events are expected to become more frequent.
>
> In the Willamette Valley, declining snowpack, earlier snowmelt, and greater summer water demand may increase summer water scarcity; and wildfire activity is expected to increase.

So in summary, warmer and drier in summer with extreme heat and extreme precipitation events during the rainy season.

1. Dalton, M.M., K.D. Dello, L. Hawkins, P.W. Mote, and D.E. Rupp (2017) The Third Oregon Climate Assessment Report, Oregon Climate Change Research Institute, College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR. Print.

Step 3: Using a climate data chart, see how close the area is to shifting climate zone classifications.

Here is a climate data chart for Corvallis, Oregon, home of Oregon State University:

Climate data for Corvallis, Oregon (Oregon State University) [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °F (°C)	66 (19)	68 (20)	76 (24)	85 (29)	96 (36)	102 (39)	105 (41)	108 (42)	103 (39)	92 (33)	72 (22)	66 (19)	108 (42)
Average high °F (°C)	47.0 (8.3)	51.0 (10.6)	56.1 (13.4)	60.7 (15.9)	67.1 (19.5)	73.4 (23)	81.2 (27.3)	82.4 (28)	77.1 (25.1)	65.4 (18.6)	52.9 (11.6)	46.4 (8)	63.39 (17.44)
Average low °F (°C)	33.6 (0.9)	35.4 (1.9)	37.6 (3.1)	39.9 (4.4)	44.0 (6.7)	48.5 (9.2)	51.8 (11)	51.5 (10.8)	48.2 (9)	41.8 (5.4)	38.0 (3.3)	33.8 (1)	42.01 (5.56)
Record low °F (°C)	−1 (−18)	1 (−17)	12 (−11)	24 (−4)	28 (−2)	33 (1)	38 (3)	37 (3)	27 (−3)	22 (−6)	14 (−10)	−7 (−22)	−7 (−22)
Average precipitation inches (mm)	6.46 (164.1)	5.71 (145)	4.59 (116.6)	2.98 (75.7)	2.30 (58.4)	1.46 (37.1)	.57 (14.5)	.73 (18.5)	1.47 (37.3)	3.02 (76.7)	6.94 (176.3)	7.43 (188.7)	43.66 (1,109)
Average snowfall inches (cm)	1.2 (3)	2.2 (5.6)	.1 (0.3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.2 (0.5)	1.4 (3.6)	5.1 (13)
Average precipitation days (≥ 0.01 in)	19.7	18.0	18.8	16.3	12.7	7.8	3.6	3.9	7.1	12.4	20.1	20.8	161.2
Average snowy days (≥ 0.1 in)	.9	1.1	.2	0	0	0	0	0	0	0	.1	.8	3.1
Source #1: NOAA (normals, 1971–2000),[20]													
Source #2: Weather.com (extremes) [21]													

Figure 37: Climate Data Chart for Corvallis, Oregon. Click for the high resolution image.

The monthly average high and low temperatures and the average monthly precipitation amounts are the pieces of data that will help to see how solidly in one climate class or another a site is. Commonly available charts may or may not include the daily mean temperature, which is different than the average high and average low. So for the purposes of seeing where a site sits within the range of a climate type, the average monthly low and high temperatures will need to be added and then divided by 2 to get the daily mean temperature if it is not provided in the climate data chart.

average monthly low + average monthly high

————————————————————— = daily mean temperature

2

I find these charts easily by searching a city name on Wikipedia. This method can only be done for sites where this climate data is available.

Corvallis falls in the Koppen Geiger class Csb. The Csb description has been broken down with comments about Corvallis' climate data:

Csb = Warm-summer Mediterranean climate

1) Coldest month averaging above 32 °F (0 °C)

Yes. January is the coldest month and the average temperature is 40.3°F (4.6°C)

2) All months with average temperatures below 71.6 °F (22 °C).

Yes. August has the highest monthly temperature at 66.95°F (19.15°C)

3) At least four months averaging above 50 °F (10 °C).

Yes. 7 months average above: April 50.3F (10.15°C), May 55.55°F (13.1°C), June 60.95°F (16.1°C), July 66.5°F (19.15°C), Aug 66.95°F (19.4°C), Sept 62.65°F (17.05 °C), Oct 53.5°F (12°C)

4) At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 1.2 in (30 mm).

Yes. The wettest month is Dec with 7.43" (188.7mm) of precipitation, and the driest month is July with .57" (14.5mm) of precipitation.

Now we'll look at Corvallis' climate data in comparison to the next hotter climate classification:

Csa = Hot-summer Mediterranean climate

1) Coldest month averaging above 0 °C (32 °F)

Yes. January is the coldest month and the average temperature is 40.3°F (4.6°C)

2) At least one month's average temperature above 71.6 °F (22 °C)

No. The average highest monthly temperature is in August at 66.35°F (19.05°C)

3) At least four months averaging above 10 °C (50 °F)

Yes. 7 months average above: April 50.3F (10.15°C), May 55.55°F (13.1°C), June 60.95°F (16.1°C), July 66.5°F (19.15°C), Aug 66.95°F (19.4°C), Sept 62.65°F (17.05 °C), Oct 53.5°F (12°C)

4) At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).

Yes. The wettest month is Dec with 7.43" (188.7mm) of precipitation, and the driest month is July with .57" (14.5mm) of precipitation.

The only place where Corvallis deviated from the Csa climate class is in the average highest monthly temperature. These averages are typically measured over a 30 year period. But individual years have already started deviating into Csa temperature ranges. For example, August 2017 had an average monthly temperature of 22.85°C (73.13°F), where high temperature records were set throughout the state. [2]

This led to an extremely active fire season, as vegetation adapted to Csb conditions met Csa temperatures. The results in the Pacific Northwest were literally choking.

2. "August Weather 2017". Accuweather. Web. https://www.accuweather.com/en/us/corvallis-or/97333/month/330142?monyr=8/01/2017

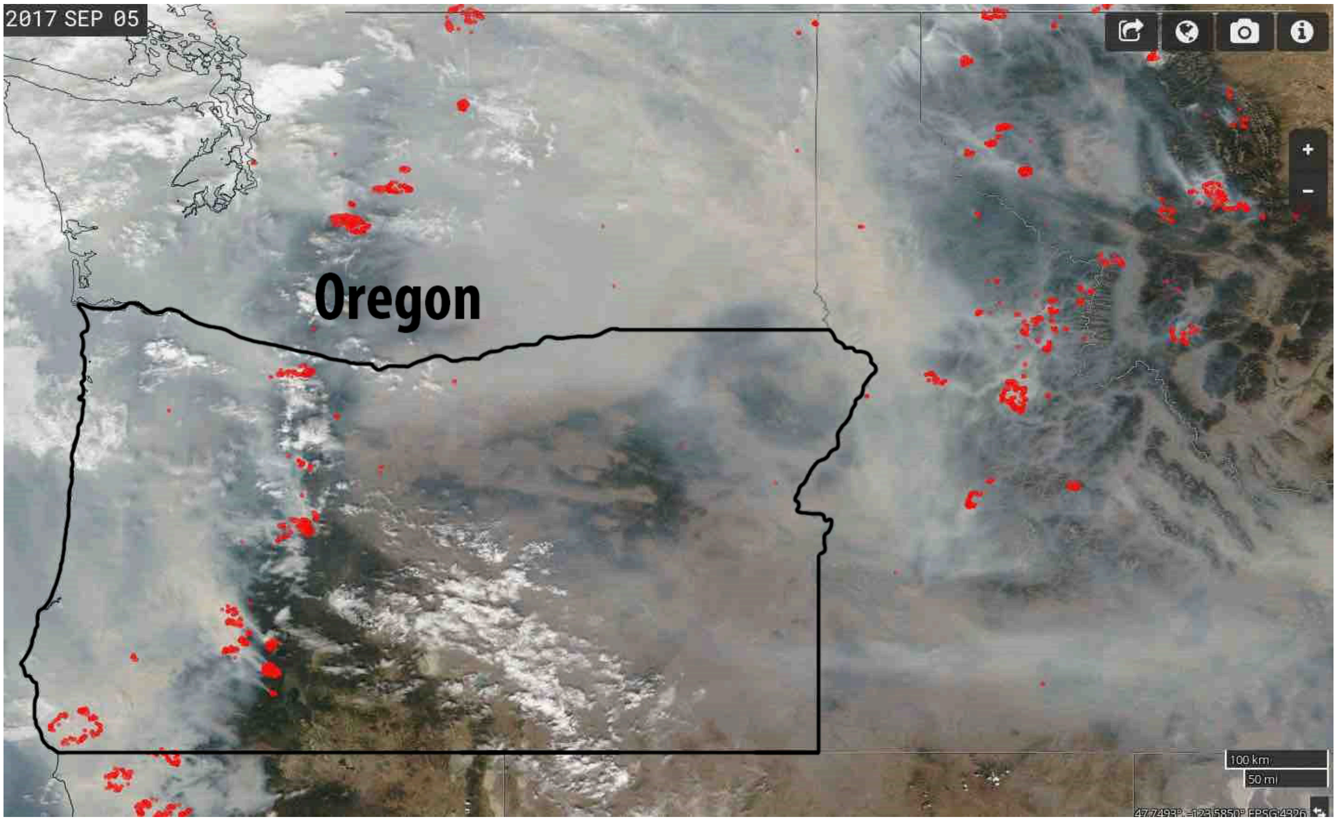

Photo 23: Fire Season in Oregon 2017.

A quick check of average August temperatures in Corvallis over the last 10 years show that 7 of them saw temperatures above average, although only 2017 had a high enough average to fall within Csa range.

To expand on the impact of the warm season heat of 2017, when we go further South into the Csb and Csa climates of Central California, at the height of landscape dehydration before the rains arrive, we see massive and catastrophic wildfires there as well. This is after San Francisco received it's all time record high temperature of 106°F (41°C) on September 1, 2017.

Photo 24: Images of California 2017. NASA Earth Observatory Image by Joshua Stevens using MODIS data from LANCE/ EOSDIS Rapid Response.

Image Source: NASA Earth Observatory images by Joshua Stevens, using MODIS data from LANCE/EOSDIS Rapid Response

Is this just an extreme deviation from the norm, or a glimpse into the new norm? Personally I'm taking it as a wake up call, and my Permaculture design and education work is now factoring more extreme heat events and wildfire scenarios into the equation.

Step 4: Find regions that are located now within the projected new climate type.

The obvious first place to look in finding a climate change analogue for the Willamette valley in Oregon is to head South and find the closest valley area with a Csa designation. This is because Corvallis and the Willamette Valley is close to sea level, below 500 ft (150m), and when we look at the West Coast of the US, there are a lot of areas of low elevation in a similar proximity to the coast both up and down in latitude. So going down latitude looking at areas with a similar elevation and landscape positioning should yield a close climate change analogue.

Luckily an internet search found a Koppen map of the United States that has higher resolution than most, put together by the PRISM Climate Group of Oregon State University.[3] That lead me to look first in Southern Oregon, in the Upper Rogue River Valley around Medford and the Middle Rogue Valley around Grants Pass, as those are the closest valley-bottom locations within the Csa climate class. Further South than that I'd like to look in the northern Central Valley of California in the region between Reading and Chico. So I will examine each of those four locations to see if one stands out as a more likely climate change analogue.

One important point to make is that there will not be one perfect climate change analogue. There will be components of different locations that are relevant to study and that will represent climate types at different points in the future. But in order to obtain specific climate data, it is necessary to pick specific locations for analysis.

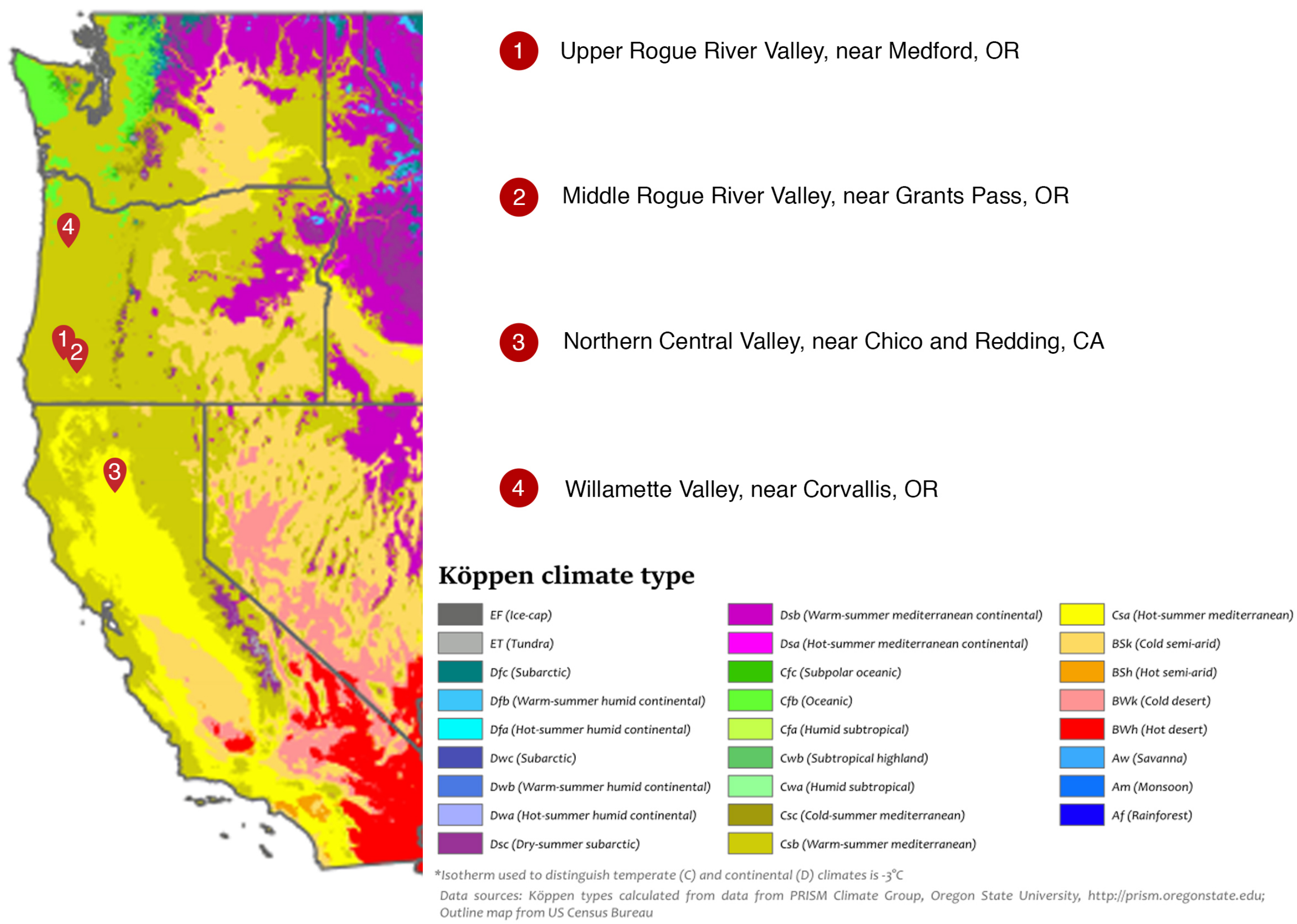

Figure 38: Koppen Climate Map with climate analogues pinpointed.

Recall step 4 in the methodology for locating climate change analogues. The first two actions were to "Look for areas within 10 degrees North or South of your latitude.", **"Look for areas with the same proximity to**

3. "Köppen types calculated from data from PRISM Climate Group". Oregon State University. Web. http://prism.oregonstate.edu

water; oceanic or continental." That was what I did by looking south along the West Coast.We will now go step by step through each item. I created a chart for easy comparison of some of the major measurements:

Location	Avg Temp	Avg Temp hottest month	Hardiness zone	Elevation	Annual Rainfall & Seasonality	Landform
Corvallis, OR	52.7°F (11.5°C)	66.95°F (19.4°C)	8b Low 15-20°F (-9.4 to -6.7°C)	235' (72m)	43.66" (1,109mm) Dry June-Sept	Valley 40 mi. from coast
Medford, OR	55.6°F (13.1°C)	74.1°F (23.4°C)	8b & 8a Low 10-20*F (-12.2 to -6.7°C)	1380' (420m)	18.31" (465.1mm) Dry June-Sept	Valley 80 mi. from coast
Grants Pass, OR	54.8°F (12.7°C)	71.8°F (22.1°C)	8b Low 15-20°F (-9.4 to -6.7°C)	942' (287m)	30.98" (786.9mm) Dry June-Sept	Valley 40 mi. from coast
Redding, CA	62.27°F (16.82°C)	82.2°F (27.9°C)	9a & 9b Low 20-30°F (-6.6 to -1.2°C)	560' (170m)	34.62" (879.5mm) Dry June-Sept	Valley head 100 mi. from coast
Chico, CA	61.2°F (16.25°C)	77.35°F (25.2°C)	9b Low 20-25°F (-3.8 to -1.2°C)	Chico: 200' (60m)	Chico: 26.67" (677.4) Dry June-Sept	Valley w foothills. 104 mi. from coast

Figure 39: Possible Climate Analogue Comparrison Table

Here are the things not covered on the chart:

Examine global air circulation and storm tracks.

Jetstream comes from the West and is same for all locations. However, the further South the location, the less impact of the Polar jetstream and the greater impact of tropically derived "atmospheric river" events.

Examine nearby ocean currents.

Same for all locations. Cold California current moves water from poles towards equator.

Compare topographic features and landscape positioning.

Corvallis: Mid-Valley between river and foothills, on East side of Coastal Mountains. 40 miles (64 km) from coast

Medford: Middle valley bottom, 80 miles (129 km) from coast

Grants Pass: East side of valley with river running through. 56 Miles (90 km) from coast

Redding: Head of valley with river running through, edge of foot hills and valley bottom. 100 miles (161 km) from coast

Chico: East side of valley. Edge of foothills and valley. 104 miles from coast

Compare global soil regions.

Corvallis: Mollisols

Medford: Mollisols

Grants Pass: Inceptisols

Redding: Inceptisols

Chico: Entisols

For my climate change analogue, I decided to look at both long and short term possibilities. The short term analogue is the town of Grants pass on the Rogue River in Southern Oregon. Here are some pertinent points:

1. Grants Pass is in a Csa climate class and is located about 150 miles (240 km) to the South of Corvallis
2. It's about 700' (213m) in elevation higher than Corvallis.
3. It is only 16 miles (26km) further from the coast than Corvallis.
4. That distance between Grants Pass and the Pacific Ocean is filled with multiple mountains above 4000' (1200m), which seem to have the effect of making Grants Pass drier than Corvallis by around 12.5" (350mm) of precipitation per year.

Photo 25: People in Grants Pass tend to think they have a nice climate. By Joseph Novak. Creative Commons.

So this is not a perfect analogue, because Corvallis is set to get wetter during the winter, and Grants Pass has significantly more sunny days (196 as opposed to Corvallis' 159), but temperature-wise, Grants Pass is 2.1F (1.2°C) warmer on average and 4.85°F (2.5°C) degrees warmer during August, the hottest month. It also has the same hardiness zone as Corvallis, 8b. This makes Grants Pass an excellent place to look at plant species in terms of temperature and the future plant palette for a warmer climate.

One important thing to note is that the Douglas Fir forest type does not extend into Southern Oregon, which is in the Siskiyou mixed-conifer forest zone. Does this mean that the Douglas Fir forest will possibly be retreating North? Will higher winter rainfall be enough to compensate for higher summer temperatures with less summer precipitation? Is fire the most likely agent of the Douglas Fir range moving North? Can the Permaculture design perspective help to avoid catastrophe?

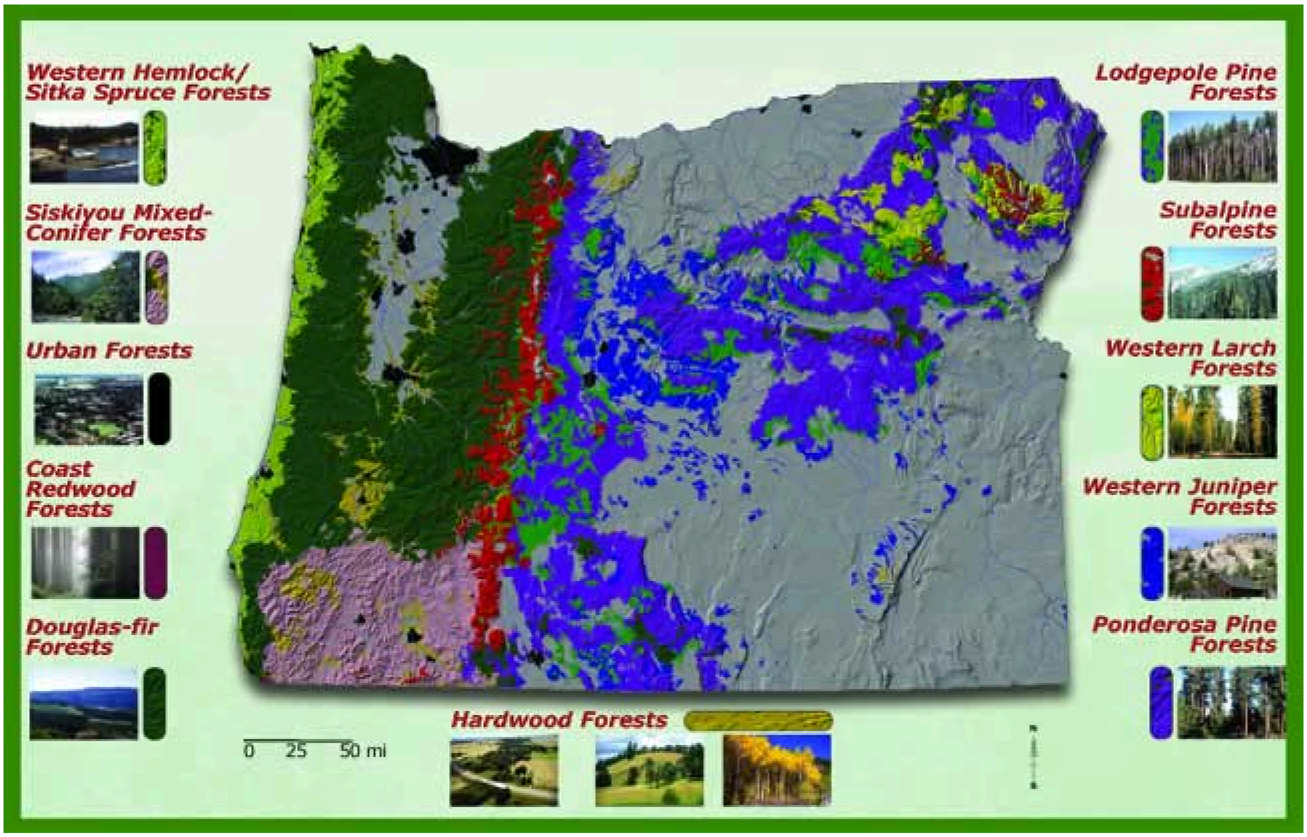

Figure 40: Oregon Forest Distribution Map. Image by Oregon State University's College of Forestry and the Oregon Forest Resources Institute (inactive link as of 05/12/2021)

These are huge questions whose answers affect the lives of millions of people, wildlife, and the entire economy and vitality of the region. Any comprehensive solution will need to involve government and institutions at all levels.

For the pessimistic longer term runaway-climate-change outlook of what the Central Willamette Valley may resemble into the next century, I went 280 miles South to the Northernmost city in California's Central Valley, Redding.

Photo 26: Redding in California's Central Valley. Photo Copyright Aaron Walker.

Redding stood out as a long term climate change analogue for these reasons:

1. It is close in elevation to Corvallis at 225' (68.5m) higher.
2. It is close in rainfall, only 9" (228mm) lower than Corvallis.
3. Corvallis and Redding have a similar topography where river meets foothills
4. Redding's average temperature is about 9.4°F (5.3°C) warmer than Corvallis.
5. Redding's average temperature during the hottest month of the year is 15.25°F (8.5°C) hotter than Corvallis.
6. Redding's yearly low temperatures are about 5-10°F (9-18°C) higher than Corvallis.

When we examine the differences in the average annual temperatures and the average temperature during the hottest month, this is a pretty extreme warming scenario. The Oregon Climate Change Research Center's says that "Under continued increasing greenhouse gas emissions Oregon's climate is projected to warm on average 3–7°F by the 2050s and 5– 11°F by the 2080s. If greenhouse gas emissions level off by mid-century, warming would be limited to 2–5°F by the 2050s and 2–7°F by the 2080s".[4] By these standards, Redding fits into their models as a potential analogue by the end of the century.

Here are some other issues to consider in this scenario:

1. Rainfall in Western Oregon is set to increase, so rainfall gap may widen.
2. With undulating jetstream, there's also the possibility of more extreme periodic cold waves, like the one seen in 2013 when Corvallis hit -1°F (-18°C), and nearby Willamette Valley city Eugene reached -10°F (-23°C).

Overall, it looks like a pretty good fit, and I'm going to be paying a lot more attention next time I go through there! Here are some interesting things learned from doing further research on Redding:

1. Olives are grown there. Olives die at 10°F (-12°C) but there are attempts to grow cold-adapted varieties in the Willamette Valley now. This could be a potential new crop with a warming climate.
2. California's Central Valley is known for its almonds, however there is not significant acreage grown in the Redding area. Is is a matter of temperature, soils or water? This requires further research.
3. Aside from olives, the other top crop items are wild rice, pasture, nursery stock, and barley for grains.
4. The ecosystem type is Oak Woodland, with the absence of Douglas Fir, the predominant tree in Western oregon. The map below shows the current range of Coast Douglas Fir (in green). Douglas fir does not extend into the Central Valley in California. This brings up the same questions from the

4. Dalton, M.M., K.D. Dello, L. Hawkins, P.W. Mote, and D.E. Rupp (2017) The Third Oregon Climate Assessment Report, Oregon Climate Change Research Institute, College of Earth, Ocean and Atmospheric Sciences, Oregon State University, Corvallis, OR. Print.

assessment of Grants Pass, about the Douglas Fir range retreating northward and the possibility of massive tree die-off and wildfire.

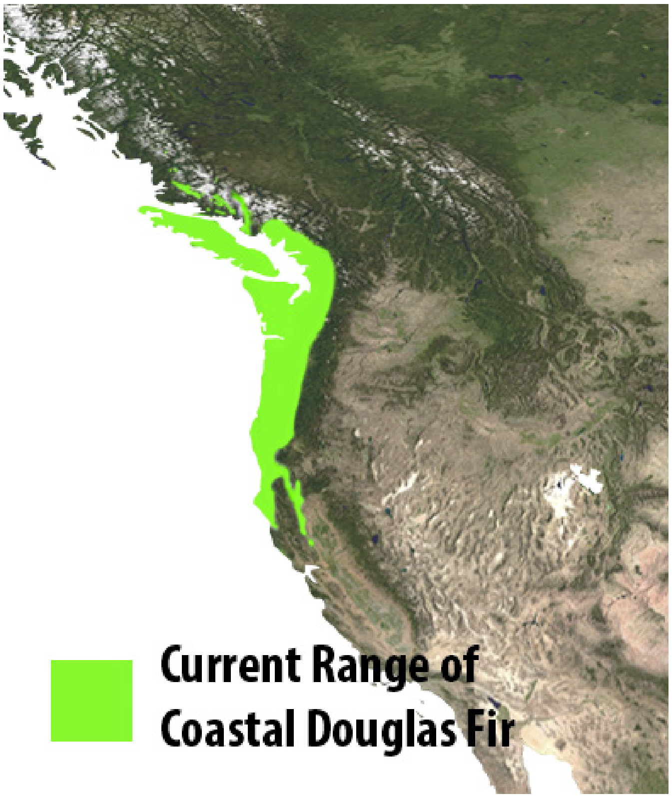

Figure 41: Current Range of Coastal Douglas Fir

One key point of observation to learn the most about the potential climate shift from Csb to Csa is to look at other places in the world where the Csb and Csa climate classes border each other. These are areas that we will find similar temperature, precipitation, and precipitation seasonality. In nearly every one of these locations, the Csb is also bordered by the Cfb, which is an oceanic climate similar to Csb but with summer rainfall.

Those regions that have similar geography to Western Oregon, located on the west coasts of continents in temperate climate latitudes are of particular interest because of similarities in weather patterns, solar influence, and relationship to the ocean. If we as Permaculturists are going to help develop new ecosystems for new climatic conditions, then studying the edge between climate zones analogous to our own could yield some very innovative techniques and valuable species that could be of great assistance. Below are some places of interest in the world to do more research on:

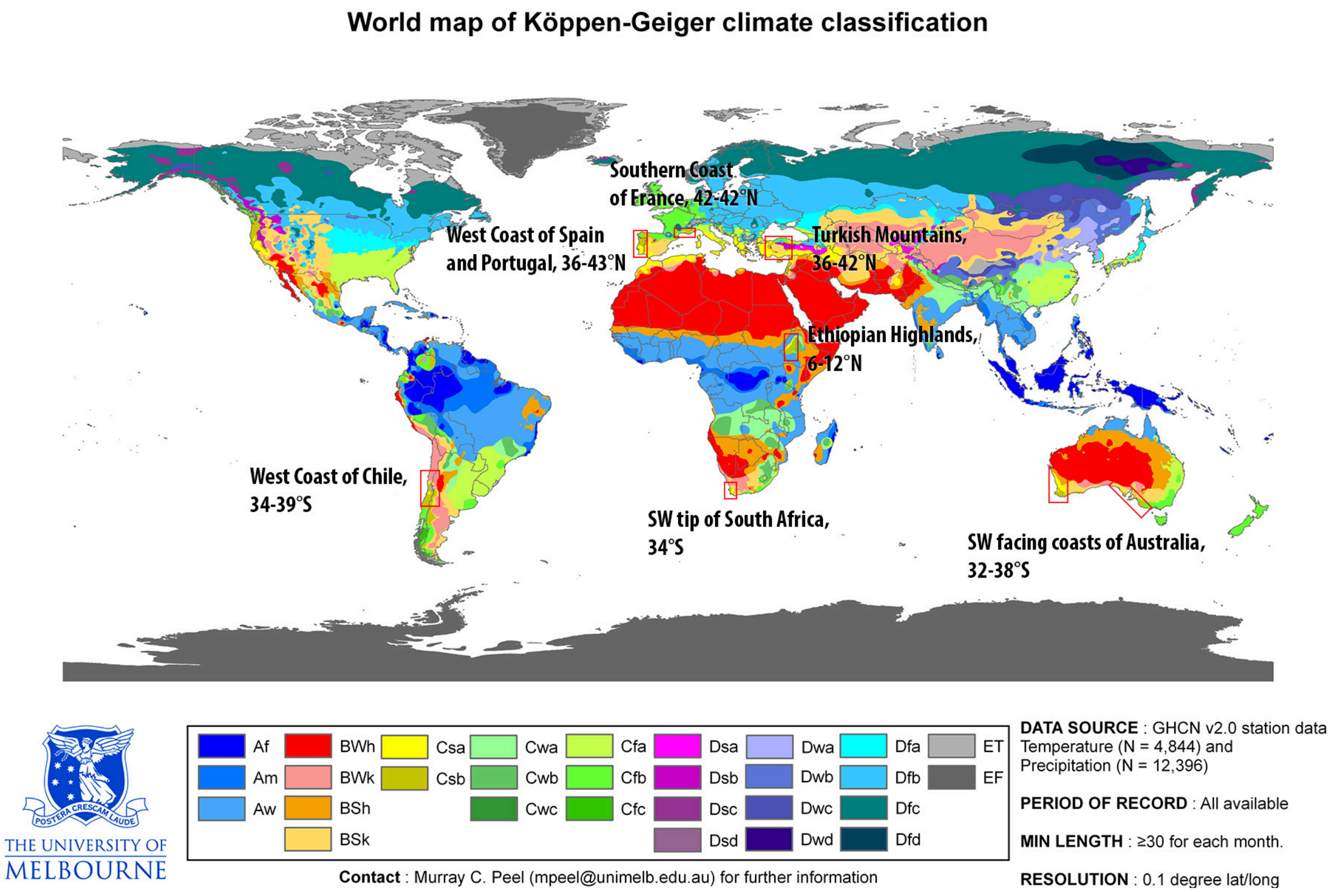

Figure 42: Climate analogues worth investigating.

Case study #2: Prescott, Arizona, USA

Photo 27: Prescott, Arizona, USA. Photo by LunchboxLarry CC BY 2.0

Step 1: Locate the site on a Koppen Geiger climate change forecast map and identify the projected climate classification.

For the current climate classification, I was able to locate a more detailed Koppen climate map of Arizona with higher resolution put together by the PRISM Climate Group at Oregon State University. This map shows Prescott sitting right on the edge between Csb Warm summer mediterranean and Csa Hot summer mediterranean, yet also in very close proximity to Bsk Cold semi-arid. We'll sort out which classification it is in by examining the climate data.

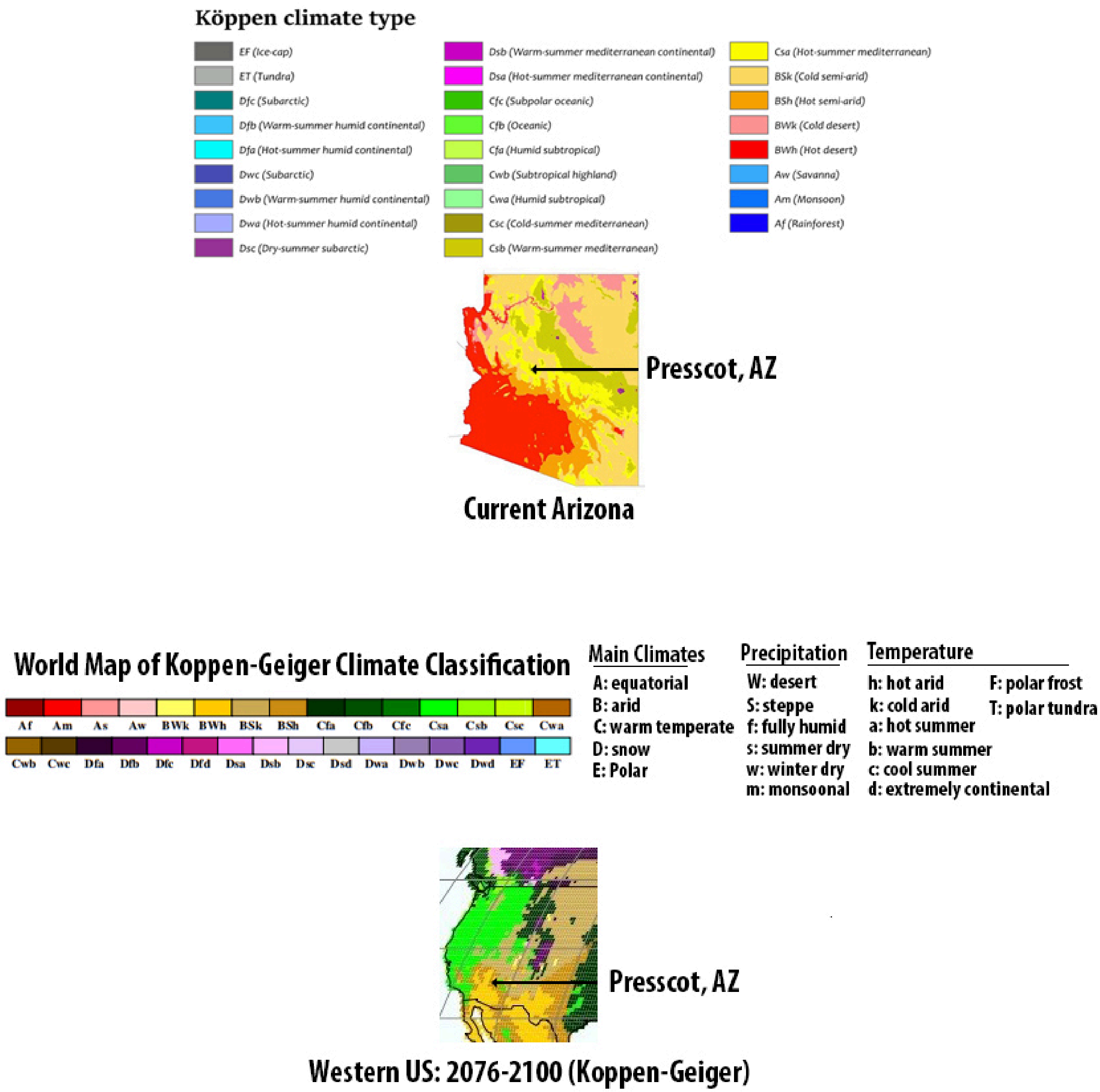

Figure 43: Prescott, AZ on Koppen Climate Map and Projected Climate Map

On the climate change forecast model, although the resolution is low, Prescott is placed in Bsh Hot arid steppe. The low resolution does not account for the microtopography shown on the current Arizona map, where Prescott is tucked into a North facing bowl with water runoff from tall adjacent mountains, but it's a good guide from which to start.

Step 2: Research region-specific climate change forecasts.

Arizona is set to warm disproportionately more than other places, along with extended droughts, decreasing snowpack, and hence increasing wildfires. The US Environmental Protection Agency (EPA) had this to say about Arizona's overall climate outlook:

"Arizona's climate is changing. The state has warmed about two degrees (F) in the last century. Throughout the southwestern United States, heat waves are becoming more common, and snow is melting earlier in spring. In the coming decades, changing the climate is likely to decrease the flow of water in the Colorado River, threaten the health of livestock, increase the frequency and intensity of wildfires, and convert some rangelands to desert."[5]

Another article talks about the climate future of Flagstaff, Arizona in reference to the climate of Prescott. Flagstaff is located about 2,000ft (610m) higher than Prescott and the projected rise in temperature of about 7°F (3.9°C) could likely be the same for Prescott by 2100.

"The area around Prescott provides a good visual for what areas around Flagstaff will likely look like by the end of the century, Kolb said. The city is an average of 7 degrees warmer than Flagstaff, which is about the temperature increase this area is expected to experience by 2100, according to climate change predictions. Prescott is mostly surrounded by grasses and shrubs, but there are still patches of forest in cooler, wetter areas."[6]

Another recent study shows that Arizona's monsoon rains are increasing in intensity, while at the same time daily average precipitation is falling throughout the state.[7] This goes along with the general climate change trend where monsoonal rainfall is becoming more intense and erratic.

In summary, Prescott is set to get significantly hotter, punctuated by extreme heat events and extreme monsoon rain events, with less snowpack and likely a transition to a more grass and shrub than tree based ecosystem. Hopefully wildfire will not be the primary agent of the shift in vegetative type.

Step 3: Using a climate data chart, see how close the area is to shifting climate zone classifications.

Here is a climate data chart for Prescott, Arizona:

5. "What Climate Change Means for Arizona". United States Environmental Protection Agency. Aug.2016. Web. Stolte, Daniel. "Arizona's Future Climate: Temps Rising, Water Disappearing". University Communications. 24 Mar. 2014. University of Arizona. Web. https://uanews.arizona.edu/story/arizona-s-future-climate-temps-rising-water-disappearing
6. Cowan, Emery. "Bleak Future for Warming Forest". Trees. 11 Jan. 2015. Arizona Daily Sun. Web. http://azdailysun.com/news/local/bleak-future-for-warming-forest/article_21fe9e42-7585-5a84-b4d2-31d6c65c3ee7.html The Nature Conservancy's "Climate Wizard" program "Climate Wizard". The Nature Conservancy. Web. Dec. 2017 http://www.climatewizard.org/ puts heating for the Prescott region at around 6°F by 2080.
7. Magill, Bobby. "Global Warming is Fueling Arizona's Monstrous Monsoon". Climate Central. 4 Aug. 2017. Web. http://www.climatecentral.org/news/warming-fueling-arizonas-monstrous-monsoons-21679

Climate data for Prescott, Arizona (1981–2010 normals)													[hide]
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °F (°C)	73 (23)	77 (25)	83 (28)	88 (31)	97 (36)	104 (40)	105 (41)	102 (39)	98 (37)	92 (33)	83 (28)	78 (26)	105 (41)
Average high °F (°C)	52.0 (11.1)	54.6 (12.6)	59.6 (15.3)	67.0 (19.4)	76.3 (24.6)	85.7 (29.8)	88.9 (31.6)	86.1 (30.1)	81.4 (27.4)	71.7 (22.1)	60.5 (15.8)	51.5 (10.8)	69.6 (20.9)
Average low °F (°C)	23.8 (−4.6)	26.4 (−3.1)	31.0 (−0.6)	36.9 (2.7)	45.0 (7.2)	52.8 (11.6)	60.1 (15.6)	58.9 (14.9)	51.3 (10.7)	39.7 (4.3)	29.5 (−1.4)	23.4 (−4.8)	39.9 (4.4)
Record low °F (°C)	−21 (−29)	−12 (−24)	2 (−17)	11 (−12)	20 (−7)	28 (−2)	34 (1)	32 (0)	26 (−3)	13 (−11)	−1 (−18)	−9 (−23)	−21 (−29)
Average precipitation inches (mm)	1.57 (39.9)	1.78 (45.2)	1.60 (40.6)	.76 (19.3)	.49 (12.4)	.30 (7.6)	2.71 (68.8)	3.09 (78.5)	1.95 (49.5)	.98 (24.9)	1.08 (27.4)	1.44 (36.6)	17.75 (450.7)
Average snowfall inches (cm)	2.9 (7.4)	3.9 (9.9)	2.8 (7.1)	.6 (1.5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.7 (1.8)	1.9 (4.8)	12.8 (32.5)
Average precipitation days (≥ 0.01 in)	5.7	5.9	5.9	3.4	2.9	2.0	9.5	9.9	5.8	4.0	4.2	5.0	64.2
Average snowy days (≥ 0.1 in)	1.1	1.1	1.0	.3	0	0	0	0	0	0	.3	1.2	5.0
Source: NOAA (extremes 1898–present)[20]													

Figure 44: Climate Data for Prescott, AZ. Click for high resolution version.

Prescott falls in the Koppen Geiger class Csa. The Csa description has been broken down with comments about Prescott's climate data:

Csa = Hot-summer mediterranean climate

1) Coldest month averaging above 0 °C (32 °F)
Yes. Average lowest monthly temperature is December at 37.45°F (3°C)
2) At least one month's average temperature above 22 °C (71.6 °F)
Yes. Average highest monthly temperature is in July, at 74.5°F (23.6°C)
3) At least four months averaging above 10 °C (50 °F).
Yes. 7 months average above: April 51.9F° (11.05°C), May 60.15°F (15.9°C), June 69.25°F (20.2°C), July 74.5°F (23.6°C), Aug 72.5°F (22.5°C), Sept 66.35°F (19.05 °C), Oct 55.7°F (13.2°C)
4) At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).
Yes. Wettest month is Aug with 3.09" (78.5mm); Driest month is June with .30" (7.6mm).
Equation: 3 x .30 = .90″, .90″<3.09″

Now we'll look at Prescott's climate data in comparison to the two next hotter climate classifications. The original low-resolution Koppen climate change prediction map has Prescott as BSk, Hot semi-arid climate. But in looking at the more detailed PRISM Climate Group map of current Koppen Geiger classes, there is greater resolution, and thus more thought needs to be put into this. There is such diversity of topography, solar aspect, and soil and vegetation conditions in this region, that it was helpful to overlay the PRISM map on a Google Earth image to see the subtleties of how climate types interact with topography. It helps that I am intimately familiar with the landscape, soils and vegetation types in this region.

There are areas where the Csa climate type borders both the BSh (Hot semi-arid) and BSk (cold semi-arid) climate types. So in order to make an accurate prediction, both need to be examined in relation to Prescott's current climate.

BSh & BSk = Hot and cold semi-arid climates

1) Multiply the average annual temperature in Celsius by 20, then add

Average high (20.9°C) + Average low (4.4°C) ÷ 2 = 12.65°C average annual temperature.
12.65 x 20 = **253**

(a) 280 if 70% or more of the total precipitation is in the spring and summer months (April–September in the Northern Hemisphere, or October–March in the Southern), or

No. 52% of annual precipitation falls between April-September.
Equation:
April (19.3mm) + May(12.4mm) + June(7.6mm) + July (68.8mm) + August(78.5mm) + Sept(48.5mm) = 235.1mm
Total precipitation = 450.7mm
235.1 ÷ 450.7 x 100 = 52%

(b) 140 if 30%–70% of the total precipitation is received during the spring and summer, or

Yes. 52% of annual precipitation falls between April-September. So **140** + **253** = **393**

(c) 0 if less than 30% of the total precipitation is received during the spring and summer.

No

2) If the annual precipitation is less than 50% of this threshold, the classification is BW (arid: desert climate); if it is in the range of 50%–100% of the threshold, the classification is BS (semi-arid: steppe climate).

No. It is neither

Annual precipitation = 450.7mm. That is not less than 50% of **393**

3) A third letter can be included to indicate temperature. Originally, h signified low-latitude climate (average annual temperature above 18 °C (64.4 °F) while k signified middle-latitude climate (average annual temperature below 18 °C), but the more common practice today, especially in the United States, is to use h to mean the coldest month has an average temperature above 0 °C (32 °F), with k denoting that at least one month's averages below 0 °C.

Average annual temperature is 12.65°C, below 18 °C (64.4 °F)

Average temperature of coldest month is average high (10.8°C) + average low (-4.8°C) ÷ 2 = 3°C, which is above 0 °C (32 °F).

Summary:

In order for Prescott to get into the B climate classes, there would need to be a combination of reduced precipitation and increased temperature because of how the B classes are calculated. For instance, if the rainfall reduced to 15" (381mm) annually and the temperature went up by 9.81°C (17.66°F) then Prescott could be BSh. But that is more extreme than the highest emissions scenarios which puts annual temperature rise by the end of the century at around 8°F (4.4°C), so it's most likely that even by the end of the century, Prescott will stay within the Csa range, although it will move closer to BSh.[8]

Step 4: Find regions that are located now within the projected new climate type.

Because there is not a distinct transition to a different Koppen Geiger climate type, I chose to investigate nearby areas. I began by looking at the average annual temperature, elevation, precipitation and landform of surrounding cities and comparing them to Prescott:

8. Cayan, D., M. Tyree, K. E. Kunkel, C. Castro, A. Gershunov, J. Barsugli, A. J. Ray, J. Overpeck, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala, and P. Duffy. 2013. "Future Climate: Projected Average." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 101–125. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Location	Avg Temp	Avg Temp hottest month	Hardiness zone	Elevation	Annual Rainfall & Seasonality	Landform
Prescott, AZ	54.75°F (12.65°C)	60.1°F (15.61°C)	6b & 7a -5 to 5°F (-20 to -15°C)	5,400′ (1,646m)	17.75″ 450.7mm	NW facing bowl @ base of mountains
Sedona, AZ	60.75°F (16°C)	81.3°F (27.39°C)	8b 15 to 20°F (-9.4 to -6.7°C)	4500′ (1.370m)	19.01″ (482.9mm)	SW facing bowl @ base of mountains
Jerome, AZ	59.5°F (15°C)	79.8°F (26.55°C)	8b 15 to 20°F (-9.4 to -6.7°C)	5000′ (1525m)	18.56″ (471.5mm)	Steep west facing slope
Wickenberg, AZ	65.95°F (18.9°C)	86.4°F (30.22°C)	9a 20 to 25°F (-6.7 to -3.9°C)	2065′ (629m)	12.15″ (308.6mm)	Valley bottom

Figure 46: Climates comparable to Prescott, AZ

Figure 47: Climate Analogue for Prescott, AZ

Climate Change Analogue: Sedona, Arizona

Photo 28: Sedona, AZ. Creative Commons.

After this short analysis, I'm going to look further into Sedona as a realistic near-term (mid-century) climate change analogue. This is principally because it is 6°F (3.3°C) hotter than Prescott on average, and is located in a bowl at the base of a mountain with many rock features and undulating topography within the town. Where Prescott is located in the transition between Csc, Csb, and Csa, Sedona is located in the transition between Csa and BSk. Both locations are between mountain and valley ecosystems with varied topography. Both towns are also built around a waterway, although Prescott's is an intermittent creek and Sedona's is perennially flowing.

Climate data for Sedona, Arizona [hide]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °F (°C)	77 (25)	88 (31)	89 (32)	93 (34)	104 (40)	110 (43)	110 (43)	110 (43)	104 (40)	100 (38)	88 (31)	77 (25)	110 (43)
Average high °F (°C)	56.5 (13.6)	60.6 (15.9)	65.1 (18.4)	73.4 (23)	82.2 (27.9)	93.3 (34.1)	96.6 (35.9)	94.2 (34.6)	88.1 (31.2)	77.2 (25.1)	64.3 (17.9)	56.6 (13.7)	75.7 (24.3)
Average low °F (°C)	30.5 (−0.8)	33.3 (0.7)	36.8 (2.7)	41.9 (5.5)	49.3 (9.6)	57.9 (14.4)	64.0 (17.8)	63.4 (17.4)	57.7 (14.3)	47.9 (8.8)	36.4 (2.4)	30.7 (−0.7)	45.8 (7.7)
Record low °F (°C)	0 (−18)	10 (−12)	9 (−13)	18 (−8)	24 (−4)	36 (2)	43 (6)	45 (7)	28 (−2)	23 (−5)	11 (−12)	0 (−18)	0 (−18)
Average precipitation inches (mm)	2.10 (53.3)	2.16 (54.9)	2.47 (62.7)	1.16 (29.5)	0.71 (18)	0.36 (9.1)	1.65 (41.9)	1.90 (48.3)	1.94 (49.3)	1.67 (42.4)	1.38 (35.1)	1.51 (38.4)	19.01 (482.9)
Average precipitation days (≥ 0.01 in)	5.9	5.5	6.9	3.9	3.8	2.2	7.7	8.6	5.7	4.4	3.5	4.0	62.1

Source #1: NOAA[18]

Source #2: The Weather Channel (record temps)[19]

Figure 48: Sedona, AZ Climate Data. Click for high resolution version.

Even though Sedona is 900' (274m) lower than Prescott, the precipitation is slightly higher. This is atypical because normally in this region precipitation is reduced with lowered elevation. A quick look at the climatograms from each location show that Sedona gets more precipitation than Prescott January-April but less rainfall during the monsoons in July and August. I do not understand the dynamics of that. But regardless, the higher temperatures and subsequent increased evapotranspiration of plants means a dramatic change in the ecosystems between Sedona and Prescott. Sedona has a lot of unvegetated monolithic rock features which have a high runoff coefficient during storm events, so the landscape characteristics combined with higher temperatures mean Sedona is overall a drier landscape than Prescott.

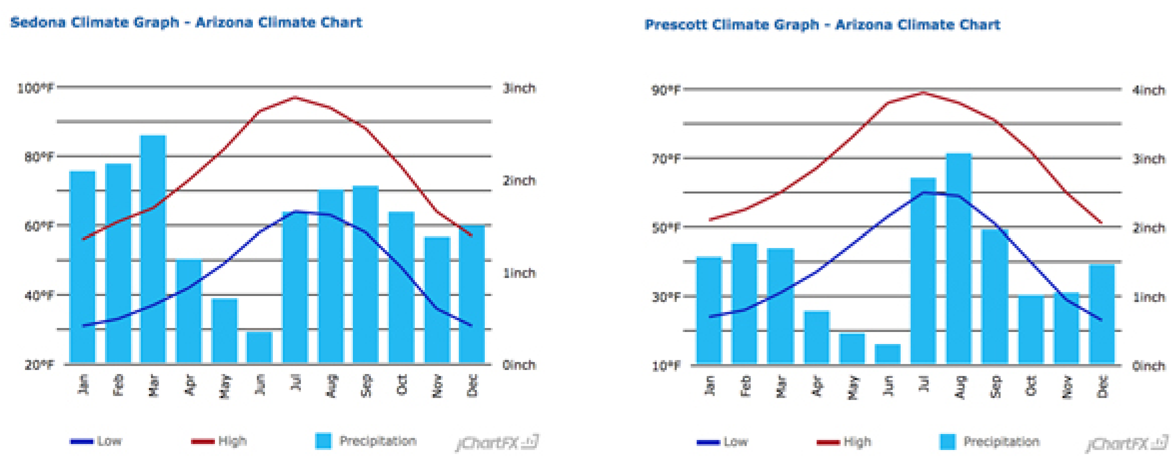

Figure 49: Sedona and Prescott Climate Charts

One result of this greater heat and aridity in Sedona is that it is dominated by different tree species than Prescott. The iconic tree of Prescott is the Ponderosa Pine (Pinus ponderosa), found within the city and its outskirts. The dominant trees in Sedona are species primarily found in hotter drier areas: several varieties of Juniper (Juniperus spp.) and Pinyon Pine (Pinus edulis), along with desert chaparral species like Velvet Mesquite (Prosopis velutina) and Catclaw acacia (Acacia gregii). Sedona also has excellent peaches and apricots which are missing in cooler Prescott where blossoms freeze in spring.

Many of the native plants present in Sedona like the Pinon Pine and Velvet Mesquite are actually traditional native food plants that have a high value as perennial staple crops that are adapted to the heat and drought of Arizona. This could be a silver lining from the Permaculture perspective, and could inform future plantings as the Ponderosa Pine forest retreats to higher elevations. There are Pinon Pine trees growing now in the Prescott basin, which could be propagated and planted on the hotter solar aspects. Velvet Mesquite seeds could be collected from the highest elevation they are found at and could also be planted on hotter aspects within the basin.

Photo 29: *Pinon Pine with Edible Nuts. Photo by Toiyab. CC BY-SA 3.0*

Photo 30: Velvet Mesquite Pods. Creative Commons

Both landscapes are fairly fire-prone and have experienced catastrophic fires in the vicinity in recent years. If the Ponderosa Pine forest is retreating to higher elevations, than tree mortality and wildfire are likely agents of that change. Controlled burning is currently practiced within the main fire sector outside of the town of Prescott, and that is a strategy for ecosystem management and fire mitigation that is encouraged from the Permaculture perspective.

PART II

PART 2: DESIGN STRATEGIES FOR CLIMATE RESILIENCE

Climate Change design for extreme events

Through part one of this book, the reader should have gained a familiarity with climate zones and gained the knowledge to foresee different extreme weather and climate events that need to be designed for if climate resilience is to be attained. Part two of this book looks at four major effects of climate change and some design strategies and examples of projects that are addressing those effects. The effects examined are:

1. Drought, Heat, and Erratic Rainfall
2. Wildfire
3. Tropical Cyclone Effects
4. Sea Level Rise and Flooding

For each climatic effect, we will examine five topics: threat summary, extreme event survival, site mitigation plan, regional mitigation, and recovery.

8. Drought, Heat, and Erratic Rainfall

Threat Summary

The impacts of drought, heat, and erratic rainfall are varied, and have differing effects on urban and rural populations. In this section we will primarily focus on the effects on agriculture because maintaining food production through extreme climatic events is critical to the existence of stable societies.

One of the main effects of climate change apparent in many different climate zones is the change in regular rainfall patterns[1]. This is especially impactful for farmers who depend on rainfall to determine sowing and harvesting periods. Correctly timing rainfall based agricultural activities is even more critical in arid and semi-arid climates with very short cool and wet seasons.

Erratic rainfall patterns can mean both an increase and decrease of precipitation amounts. Decreased rainfall and drought can cause low yields and crop failure, depletion of surface and groundwater irrigation supplies, depletion of domestic water supplies, and an increase in wildfire potential (which will be discussed in a later section). Drought is a slow motion disaster, as water resource depletion is not a singular event; it builds as rains fail, heat increases, and supplies are exhausted.

Extreme rainfall events are also on the rise, and can be more of a fast motion disaster, with flash flooding and the resulting soil erosion. In rainfall dependent dryland agricultural systems, rapid loss of topsoil from an extreme rain event can prove catastrophic. If a farmer is not prepared for the undulation between extreme heat, drought, and extreme episodic rainfall events, then it can spell disaster through crop failure, topsoil loss, and infrastructure damage.

A change in the length of seasons also creates risk because certain crops require particular temperature thresholds to survive and thrive. A rise in temperature can mean both a shortening of cool seasons and lengthening of warm seasons. This affects sowing and harvesting times as well as the general viability of certain crops.

With the combination of irregular extreme heat spikes, varied season length, and erratic rainfall patterns, farmers who have historically relied on predictable planting calendars and irrigation schedules can find themselves in unfamiliar new conditions that are hard to predict and plan for. Data from the US has seen a steady increase in the length of the growing season for the contiguous 48 states, and the influence on planting times is obvious. [https://www.epa.gov/climate-indicators/climate-change-indicators-length-growing-season]

One region that we will be examining in this chapter is the Thar Desert in Rajasthan, India, where it's been measured that the cool season is decreasing while the warm season is lengthening. At the same time the

1. Paige Ogburn, Stephanie. "Climate Change is Altering Rainfall Patterns Worldwide". Climate Wire. 12 Nov. 2013. Scientific American. Web. https://www.scientificamerican.com/article/climate-change-is-altering-rainfall-patterns-worldwide/

length of the monsoon season is decreasing while the total rainfall amount is increasing with greater deluges from monsoon rains[2].

For communities to survive these sorts of complex changes, solutions have to be deeply integrated as well as widespread throughout a region to make any impact on overall food and water security.

Extreme Event Survival

Surviving the acute effects of drought, extreme heat, and erratic rainfall is something that communities located in extreme climate conditions have to deal with on a regular basis, so there is a lot to learn by studying their habits, practices, and rules. The Thar Desert in Rajasthan, India, is the most densely populated area with a Warm Desert Climate (BWh) on the planet, with a population of around 25 million people and a population density of 83 people per square mile. Traditional knowledge and practices are adapted to the extreme conditions and have lead to a historically stable agricultural system in this marginal region.

In Rajasthan, there is a local saying about what climate conditions can be expected over long time periods. This was related to me by Rajendra Kumar, the senior program coordinator of the NGO GRAVIS Jodhpur, whose mission is to work with desert communities for the empowerment of the poor. The saying is that in a century of 100 years, there are 27 years of good rainfall. Another 63 years are mixed with some production. There are 7 years of drought, and 3 of extreme drought when even mothers and children separate, never to meet again[3].

In the Thar desert it is considered a good year when rainfall is greater than 20% of normal, so greater than 250mm (10”). A mixed year is when rainfall is between 150-250mm (6-10”). A drought year is between 100-150mm (4-6”), and the severe drought is below 100mm (4”), possibly down to 0 if rains fail completely.

This extreme drought condition is known locally as Trikal and is characterized by lack grain for food, fodder for livestock, and water for basic domestic needs. When it is said that if mother and child become separated they will never meet again, it is representing complete societal breakdown, where people are wandering in search of food and water to avoid dying of thirst and starvation. This condition is said to happen three times in a century, so you can only imagine the cultural memory of those years and how much that shapes the conservation and stockpiling of resources during good years. The Thar Desert area has been continually inhabited since it became a desert between 4,000-10,000 years ago[4], so this 100 year breakdown is coming from very real long standing observation.

2. Poonia, Surendra, and A.S. Rao. Climate Change and its Impacts on Thar Desert Ecosystem”. Journal of Agricultural Physics. 16 May 2013. Indian Society of Agrophysics. Web. Jan 2018 http://www.agrophysics.in/Published/2013/S-Poonia.pdf
3. Katiyar, Sudhir. Rainfed Agriculture in Thar. Jodhpur: Gramin Vikas Vigyan Samiti (GRAVIS). 1990. Print http://www.gravis.org.in/images/Books/Rain%20fed%20Agriculture%20in%20Thar.pdf
4. Sanyal, Sanjay. Land of the Seven Rivers: A Brief History of India’s Geography. London: Penguin. 15 Nov. 2012. Print.

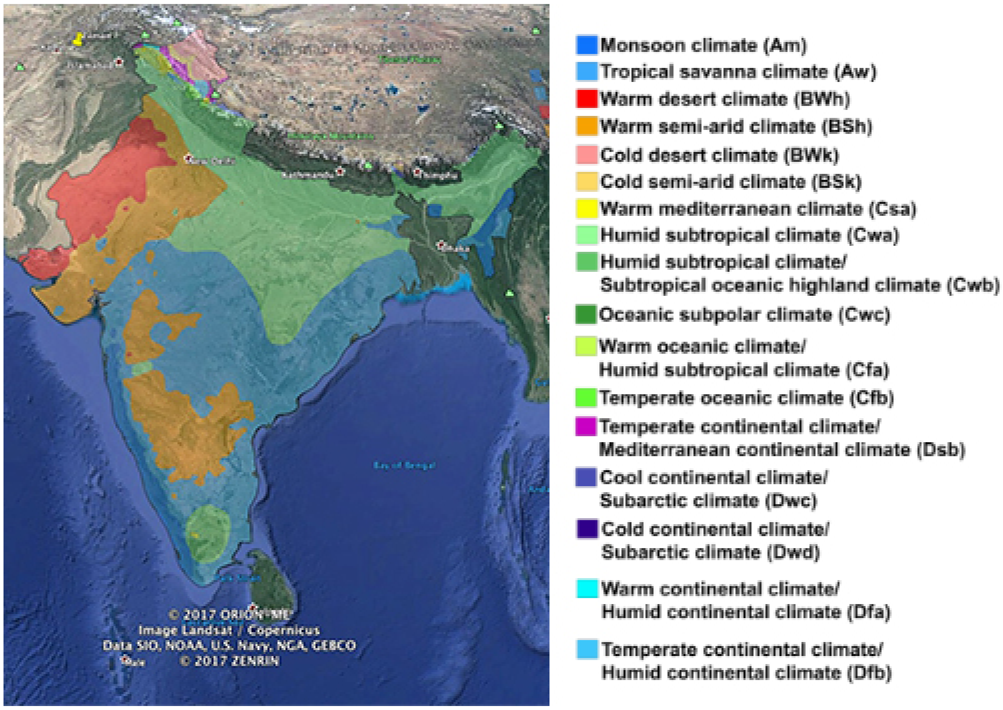

Figure 50: Koppen Climate Map of India

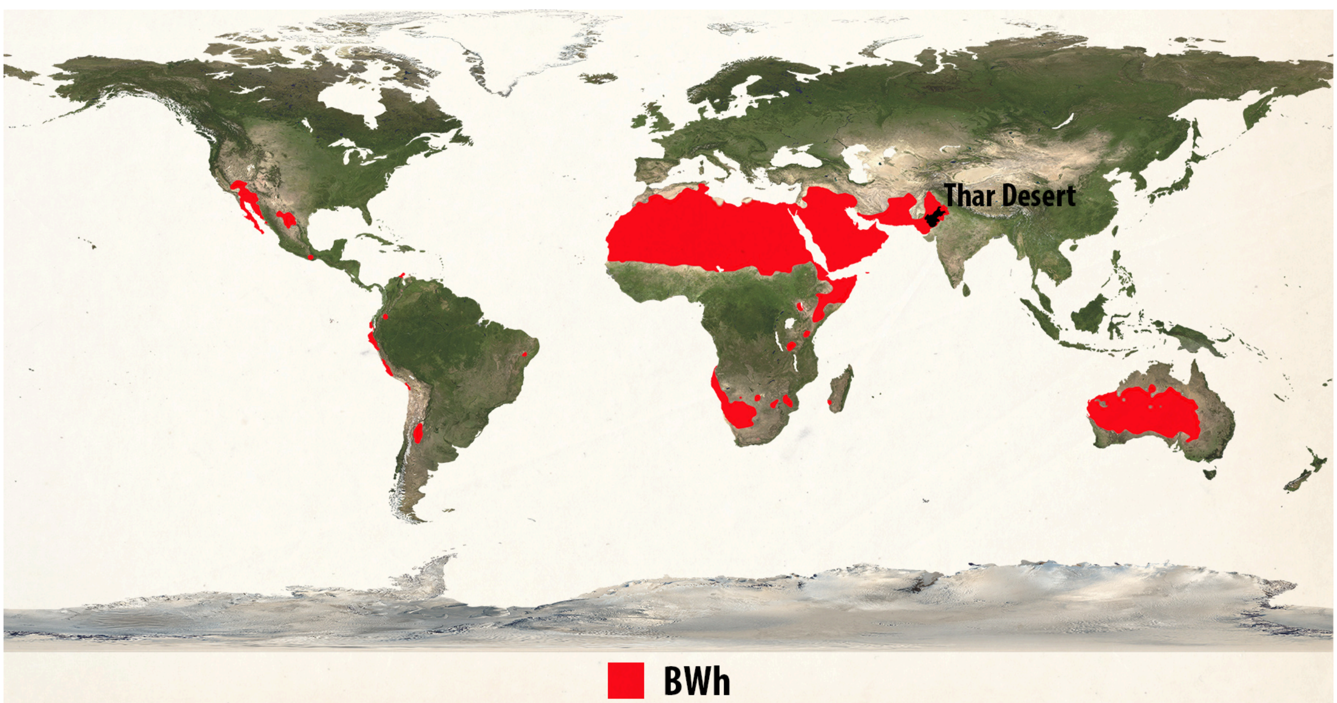

Figure 51: Thar Desert on Koppen World Map Hot Desert Climate Type. Adapted from image by Peel, M. C., Finlayson, B. L., and McMahon, T. A.(University of Melbourne) CC BY-SA 3.0

Because of the extremely harsh conditions in the Thar Desert, the culture is built for survival with long term vision, strategy, and coping mechanisms. They manage both private and community resources for survival, and have developed a Common Property Resources bank (CPR). This bank is not full of money, although villagers have also developed their own financial systems. It is comprised of the essential elements for their survival.

The types of resource storages listed below demonstrate the way in which one society has coped with extreme conditions. The details will change in different regions, but the principal of stockpiling resources for survival during lean times remains the same:

1. Grain bank: This is surplus grain storage on a community level.
2. Fodder bank: Fodder is cut and stored in large piles at each village hamlet.
3. Firewood bank: Wood is gathered and stockpiled at the family and community level.
4. Water bank: Water resources are developed and are stored at both the community and the family level. Water is stored in home reservoirs for domestic use, as well as in larger wells and ponds developed with community labor and financial resources. The wider water resource that is developed as the accumulation of many small and medium scale water harvesting projects is groundwater, where water is pulled out for irrigation.
5. Vegetable bank: Vegetables are cultivated in irrigated lands where the water table has been built up enough to provide water even in dry years.
6. Seed bank: Climatically appropriate seeds are saved at the domestic and community levels.
7. Tree and shrub banks: There are five keystone tree and shrub species that represent the foundation of indigenous survival which are conserved as a rule throughout the Thar Desert. These are trees that provide essential food, fodder, medicine, fuel or material for the people, and as perennials, are plants that remain productive throughout drought and extreme drought years. The species are the sacred Khejri Tree (Prosopis cineraria), Ker Tree (Capparis decidua), Gum Acacia (Acacia Senegal), Phog Shrub (Calligonum polygonoides), and Rohida Tree (Tecomella undulata). Reverence and protection for these species is a matter of religious significance, and they are conserved on both community lands as well as private farms, insuring a base level of food security during drought years.


Photo 31: Khejeri Tree. Photo by Andrew Millison

The sacred Khejeri Tree (Prosopis cineraria) is pruned each year for fodder, building the bank that will feed animals into dry seasons.

Site mitigation plan

The below list of simple drought resilience strategies represents an excellent collection of guiding directives to follow in adapting a site to drought, extreme heat and erratic precipitation. This list was provided by Ardhendu S. Chaterjee, who is the executive director of an NGO called Development Research Communication and Services Centre located in West Bengal, India, where they have impacted over ¼ million rural villagers since their work began in 1982. I have provided an expanded explanation for each topic heading. Overall, this is a design checklist for a site mitigation plan.

1. Store water from all precipitation and surface flows.

This brings us back to permaculture site analysis 101. What is the watershed of your design site? What are the impermeable surfaces and places where water is running off? Where does water enter and leave the site? Where can water be slowed, spread, sunk and stored?

2. Reduce irrigation with pumped up deep level groundwater.

Groundwater may or may not be a renewable resource. It depends on if water within the basin is being infiltrated in a healthy watershed. If the hydrologic cycle is broken, then pumping deep groundwater can deplete aquifers and degrade water resources.

3. Reduce areas under crops requiring frequent & intensive irrigation.

This is about the appropriate choice of plant types and varieties. The world over, people are growing water intensive crops in places that do not have the long term water resources to support those crops. This is how aquifers collapse!

4. Select plants and animals accustomed to heat stress and occasional dry spells.

Locally and regionally adapted species and varieties, or varieties of plants and animals that are regionally adapted within an analogous climate are the best bet to planting and rearing appropriate species and cultivars.

5. Reduce the use of petro-chemicals & other fossil fuel based machinery used in the farm for tilling soil, lifting groundwater, post-harvest processing etc. both in and around the farm.

Reducing the energy footprint of farm operations lessens dependence on fossil fuels, which may be imported from far away and be a weak link in overall resilience due to distant supply lines. Reducing fossil fuel usage also lowers the carbon footprint of operations, lessening global climate change.

6. Reduce soil erosion by physical and biological means.

Soil erosion is caused by wind and water flow, as well as mechanical and biological means, like hoof action from grazing animals. Soil is the basis of terrestrial agriculture and conserving and building soil is a foundation of successful agriculture.

7. Reduce exposed soil surfaces.

Covered soil is more biologically active, and can thus hold more moisture. Soil that is exposed to the sun, wind, and falling raindrops is more prone to erosion and dehydration.

8. Enhance the water holding and carbon sequestration capacities of soil to improve productivity, soil structure, and reduce the need for tillage and aeration.

A healthy soil biology will accomplish all these things. Covering soil and protecting it from erosive forces is the first critical step to building and maintaining healthy soil biology.

9. Diversify sources of income based on agro-residues and byproducts.

The permaculture principle "Produce no waste" is about seeing waste as a resource. Agricultural residues and byproducts could be potential income generating materials if viewed as resources and used innovatively.

10. Cultivate various tree products and parasitic/pollinating insects.

Perennials are more resilient overall to yearly fluctuations of water availability because of their established root systems, especially if those trees, shrubs, herbs and grasses are climatically appropriate species. As we saw in the section "Survival" above, in the Thar Desert, five species of native perennial trees and shrubs make up the foundation of food security during drought years.

Another strategy to add to this list that is being implemented in the Thar desert relates not to increasing heat and drought, but to increasing intensity of storms and the threat of flash flooding. Although the rural landscape is fully designed for water harvesting and water infiltration to build groundwater resources, flooding is also accounted for through several strategies:

1. Overflows on water harvesting structures are robust and sized for large scale rain events.
2. Water flow within farm fields is channelized so flood flow does not spread out within fields and damage crops. Although channelizing water can be dangerous in many circumstances because of the erosive power of concentrated water, stabilizing the channels is critical when water is being channelized.

Figure 52: Water Flow Channelized Through a Field

3. Water flows are sometimes brought into a field at the embankment at the bottom of the field, so water can backflood into the field, to avoid damaging flows from the top to bottom of the field

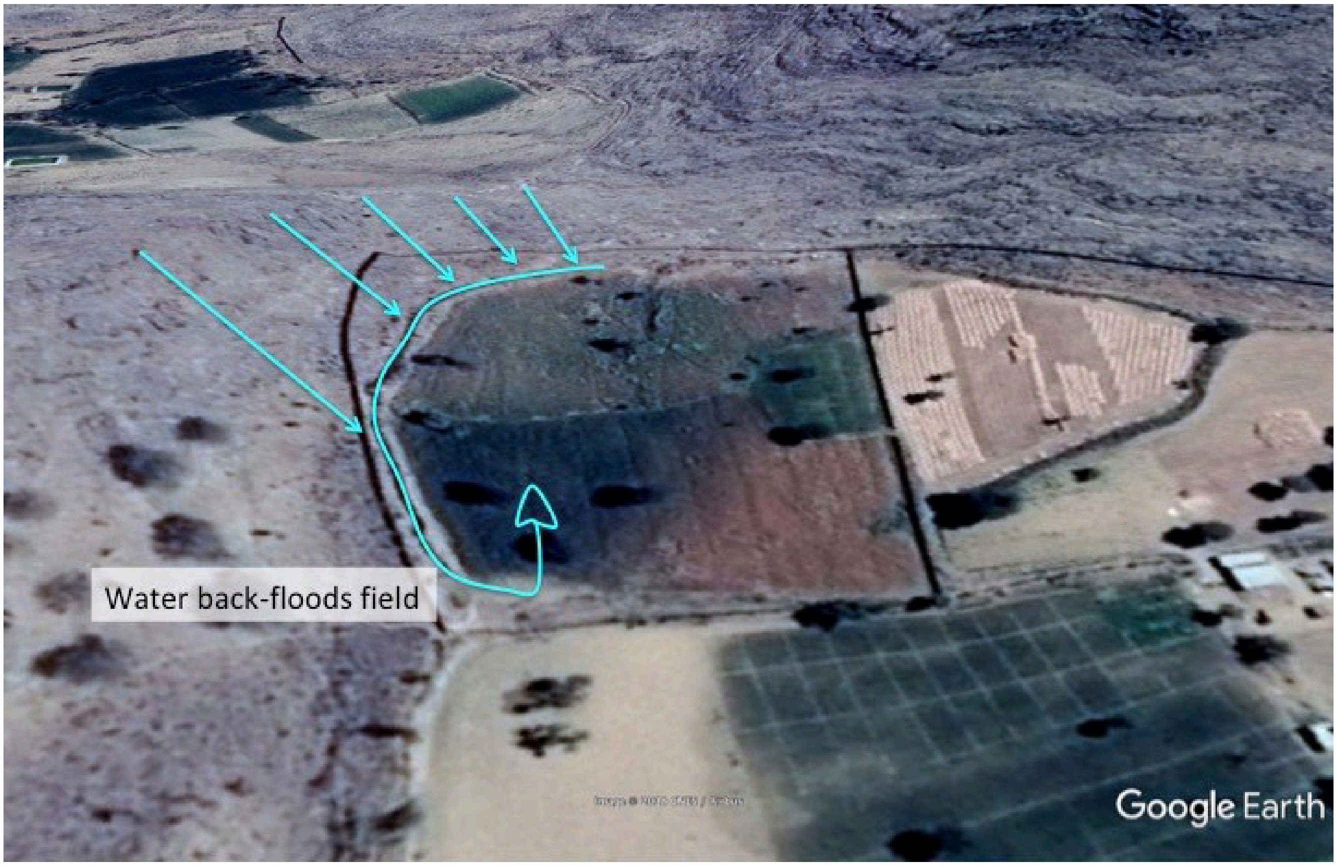

Figure 53: Water Back-floods Field

Designing a site to be resilient to the many faces of climate change is complex. Doing so requires accounting for drought and intense heat, as well as intense storms and flooding, and then fire. To design communities to withstand the multiple layers of threats demands an integrated and multi-faceted design system like permaculture. First natural forces are assessed, and then the design responds to those forces for both protection and utilization. But true resilience does not happen within the boundaries of one site. It happens by planning at the scale of communities and regions.

Regional mitigation

It's important to expand out to regional scale planning, because that's really where a community and region will become resilient. Working at the individual site level is important, but if civilization is to weather the storm of climate change and actually transition to life in an altered climatic system, then work will need to happen at the highest levels of governments and organizations to cooperate in regional and national strategies.

Watershed-scale planning

The perspective that needs to be adopted is water resource development at the **watershed scale**. When food and water security are addressed at that level, then planning can lead to actual resilience. Take some of the work in Rajasthan for example:

The NGO GVNML based in the village of Laporiya has been working on village scale water harvesting projects since their inception in 1977. They have now created water harvesting projects in 58 villages, affecting the livelihoods of over 115,000 people and managing nearly 450 square miles with water harvesting structures. In many cases, water harvesting structures are interlinked between villages, sometimes in chains of up to eight villages, where the overflow from one village's structures are channeled into the next village. They have literally built the groundwater resources over an entire region, where they now pull out stored groundwater for irrigation and grow a winter crop in addition to the summer crop planted with the monsoon rains.

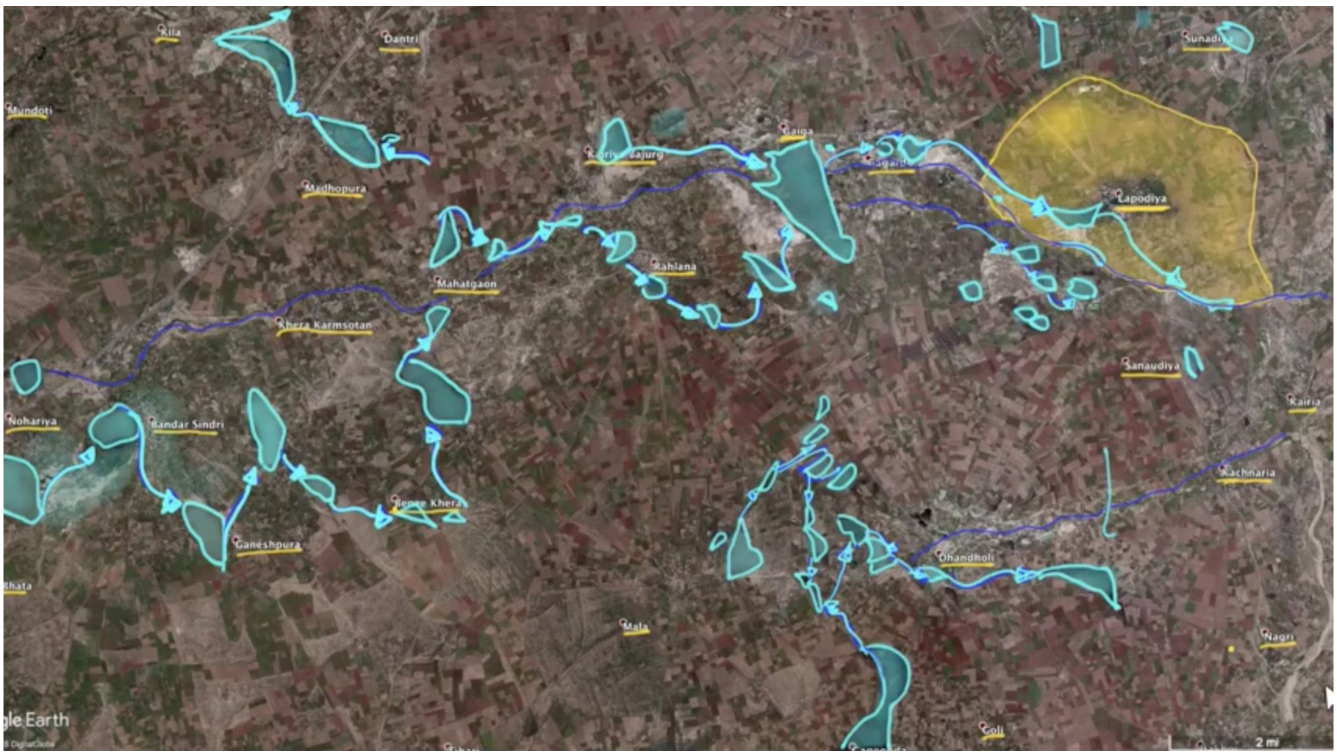

Figure 54 Interconnected ponds overflow from one to the next between multiple villages within a watershed.

Water harvesting structures are interlinked between villages to harvest intense monsoon rains during 2 months of the year for use during the 10 dry months. Satellite photo is from after the monsoons, where major water harvesting structures are full and visible.

Groundwater resource development

At that scale, they are undertaking **groundwater resource development.** Jagveer Singh, the executive director of GVNML and the brother of its founder states that if they have one good year of rains and fill their extensive water harvesting structures in his village of Laporiya, then they will store enough groundwater to last through three dry years. They have rules about conservation and what crops can be grown during dry years, as well as rules about maintaining tree cover and setting aside land for wildlife. The rules are posted throughout the village to remind everyone of their agreements.

GVNML is working in 58 villages in a warm semi-arid climate (Bsh), and estimates the amount of land that they have under water management to be 450 square miles (1150 square kilometers). With interconnected village water harvesting systems at this scale, it is at the level of regional groundwater recharge. The work of GRAVIS Jodhpur is at an even larger scale in a warm desert climate (Bwh), where they the area around 1,200 villages under water management. Both of these organizations working at this scale have literally altered the hydrology, agriculture, and culture of their regions through their work. That's true permaculture!

Reforestation

Along with regional groundwater recharge and improving the soil's capacity to hold water comes another important aspect of restoring the hydrologic cycle and stabilizing climate, and that is reforestation. As previously mentioned, trees and shrubs can provide food security in arid lands, and can also help to increase rainfall. This occurs by trees transpiring water into the atmosphere which then combines with atmospheric moisture to produce precipitation. The effects of deforestation on precipitation are well established[5], and this trend can be reversed by establishing forests on degraded and desertified lands. Establishing new forests goes along with conserving existing forests and strategically blocking desertification through water harvesting, erosion control, and reforestation.

Some well known examples of this are Africa's Green Wall, where the aim is to establish a belt of trees at the Southern border of the Sahara Desert[6].

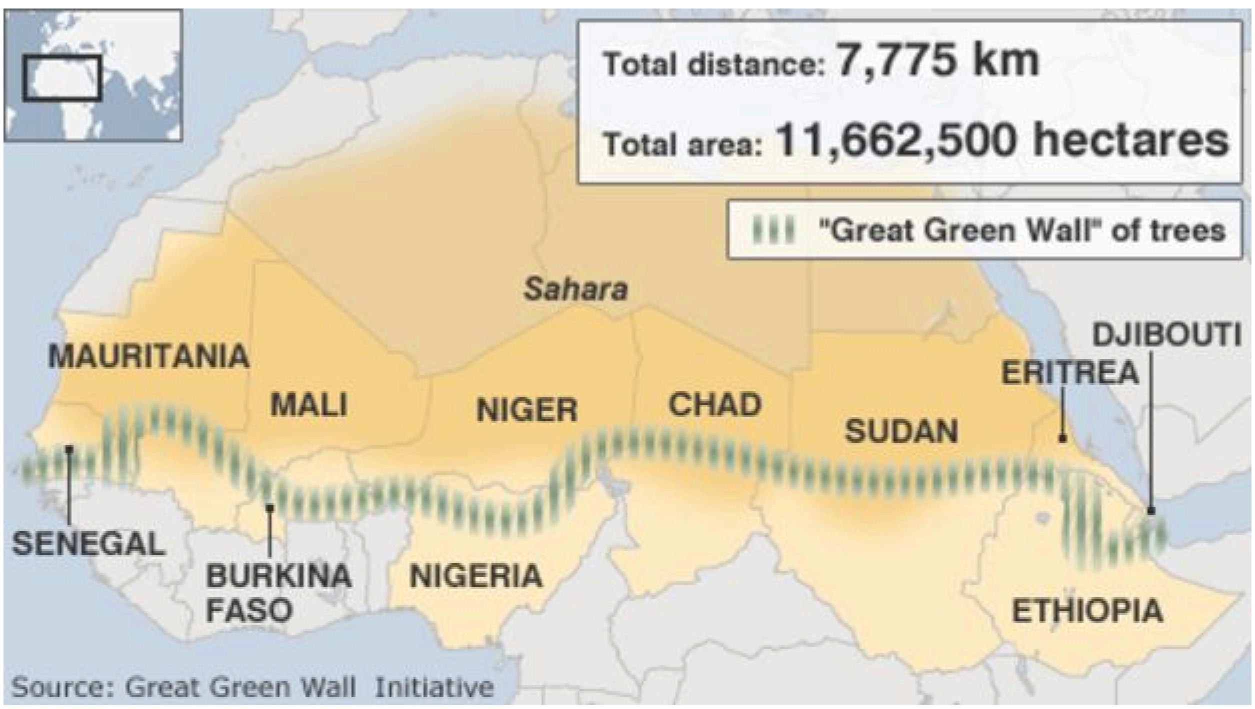

Figure 55: The Great Green Wall Initiative

5. Webster, Bayard. "Forests Role in Weather Documented in Amazon". New York Times. 5 July 1983. Print. http://www.nytimes.com/1983/07/05/science/forest-s-role-in-weather-documented-in-amazon.html?pagewanted=all
6. "Push for 'Great Green Wall of Africa' to Halt Sahara". BBC News. 12 Jun. 2010. Web. Jan. 2018. http://www.bbc.com/news/10344622

China's regreening of the Kubuqi Desert, which was born from the business need to transport salt across a blowing sandy desert that was constantly making roads impassable for transport.

Photo 32: A satellite view of the Kubuqi Desert from Google Earth reveals rows of trees planted throughout the sand dunes.

The reforestation of the Loess Plateau is another massive scale reforestation project, popularized by filmmaker John D. Liu that has had a huge impact on the agriculture and hydrology of the region.

Photo 33: Loess Plateau revegetation. Creative Commons.

Forests are not however the answer for every arid ecosystem on the planet, and each situation needs to examined individually. There are ecosystems where it appears more appropriate to manage for soil cover using perennial grasses than trees. One example is the Western Juniper (*Juniperus occidentalis*) woodlands covering areas in eastern and central Oregon, and the situation is similar in much of the arid western United States. Junipers used to be confined to rocky ridges, and as they spread down into slopes and lowlands since the 1880's, springs dried up and low growing grasses and forbs disappeared. It was measured that the evergreen Western Junipers in that instance were intercepting 70% of the rainfall and it never hit the ground. When the trees were removed and the ecosystem transitioned to perennial grasses, soil moisture increased, as well as the amount of water flowing through streams and springs. [7] So encouraging every arid ecosystem towards a climax forest as a blanket strategy is not wise. There are unique dynamics to every ecosystem and species which need to be studied, considered, and tested.

Recovery

Drought is not a singular destructive event that a region would recover from, like a wildfire or hurricane. It is more of a persistent long term disaster that needs to be permanently adapted to. Areas that are prone to drought should be consistently building and storing essential resources as mentioned above to be ready to endure through the next dry spell or heat wave.

There are particular events within droughts that have an element of disaster, like extreme heat waves. Often times extreme heat threatens the lives of people, livestock, and wildlife. They also create the conditions for wildfire, which will be discussed in the next section.

Extreme heat events are disastrous, and make headlines like this image when Australia had to add a new color to the temperature map:

7. Herring, Peg. "Taking the Pulse of Water in Western Juniper Woodlands." Oregon's Agricultural Progress. Winter, 2017. Oregon State University. Web. http://oregonprogress.oregonstate.edu/winter-2017/taking-pulse-water-western-juniper-woodlands. Mar. 2018.

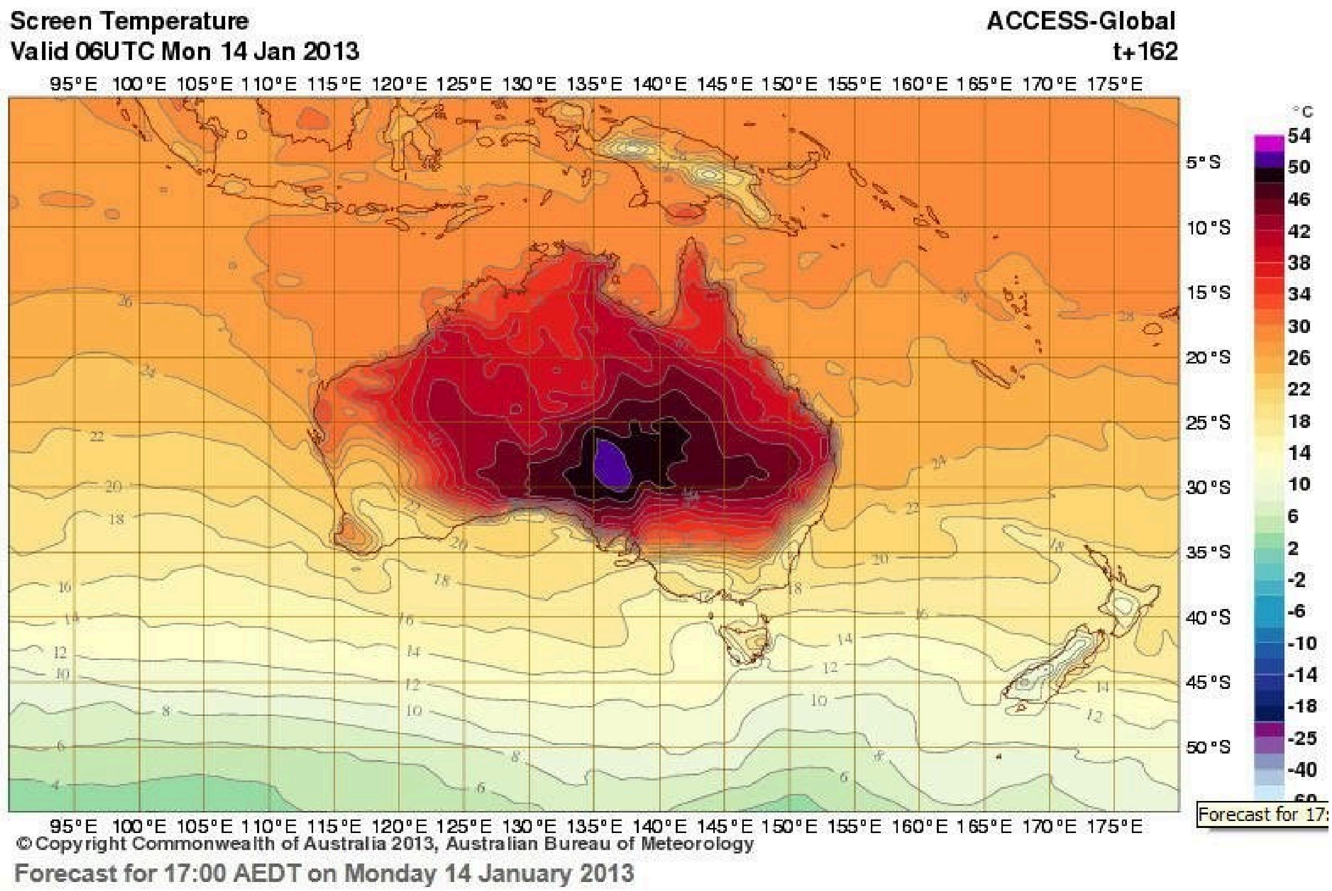

Figure 56: Australian Temperature Map

They can lead to crop failure, road and equipment damage, and tree and shrub mortality. There is not a quick fix for recovery from intense heat events besides future planning choices of species and developing infrastructure to handle such events.

Erratic rainfall events are also disastrous if water harvesting systems are not designed for heavy storm flow, with properly sized channels and overflows to handle epic storm events. Recovery from topsoil loss, crop destruction and infrastructure damage will take time and resources, and the only real recovery is to be ready to capture, store, and utilize the next massive water flow episode.

New areas of soil deposition and a total saturation of the landscape could provide opportunities to get a crop in a location or at a time that was not previously anticipated, and having seed to plant after a devastating flash flood could lessen the losses from crop failure.

9. Wildfire

Threat Assessment

Climate change is forecasted to increase the likelihood of "very large fires", which are the largest 10% of wildfires that burn the majority of the land area in the United States. This is primarily due to the lengthening of fire seasons with the overall rise in temperature. The United States National Oceanic and Atmospheric Administration (NOAA) predicts that by 2042 in the Great Plains and Northwest portions of the fire-prone Western US, the number of weeks that a very large fire could occur will go up between 400-600%! In other areas of the Western US, it still goes up between 50-400%[1]. You can bet that if fire season is lengthening within the Western US, then it is also lengthening in other analogous climate zones throughout the planet.

Much of the most important work of mitigating this threat is in the initial assessment phase, and ideally would be on the permaculture practitioners mind at the time of site selection. If a location sits within an area with major fire danger, and a design site is located within topography and vegetation types that will inevitably burn someday, then it will take a huge amount of infrastructure planning to avoid the threat. Sometimes the best defense is a good offense, and selecting a location that is not in an area with extremely high fire danger could be the best choice to make. So that being said, this next section will look at assessing the threat and mapping the "fire shed".

Wildfire Season

The first thing to do is assess the time of year that is most likely for a wildfire to spread. As stated above, with rising temperatures, fire seasons are expected to lengthen very significantly in some areas. Fire season is when the confluence of heat and moisture is at its highest; the greater the heat and the lesser the moisture, the greater the fire danger. Fire season in many areas is also determined by critical weather events, such as seasonal downslope winds, or periods of dry lightning strikes. Fire season also has a typical end date, when fire spread is no longer likely or possible due to temperatures, day length, relative humidity, and weather patterns. There are also fire stopping events, like significant rain, which can abruptly put an end to the season[2].

Mapping out the fire season therefore becomes an equation. The "Fire Behavior Field Reference Guide" put out by the National Wildfire Coordinating Group breaks fire season assessment into 5 primary elements: climatology, fire activity, critical weather events, fire slowing or stopping events, and fire growth potential indicators.

In 'climatology', each season is assessed for its temperature, precipitation, and relative humidity. A

1. Leavell, Daniel et al. "Fire Science Core Curriculum". Oregon State University Extension Service. Aug. 2017. Oregon State University. Web. Jan.2018 https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9172.pdf
2. "Fire Season Climatology". Fire Behavior Field Reference Guide. Dec. 2017. National Wildfire Coordinating Group. Web. Jan. 2018 http://www.fbfrg.org/weather/fire-season-climatology

seasonal narrative is produced for the year which identifies the weather patterns that bring on the start and end of fire season.

In 'fire activity', a narrative is produced that describes fire's response to the seasonal conditions that are described in the 'climatology' section. When and why fire season peaks, and why it dissipates are addressed in this section.

In the 'critical weather events' section, any weather systems that set up the start or intensification of fire season are described. This often includes a katabatic or downslope wind. These winds are often named, like the famed Santa Ana winds in Southern California that roar over the mountains from the East, down into the coastal basin, bringing strong hot wind from wooded mountains into human settlements located in the urban-wildlands interface.

For 'fire slowing or stopping events', this is also signified by a weather event. This weather event is also often a change of wind direction, influx of precipitation and humidity, as well as cold air.

The 'fire growth potential indicators' are particular measurements that signal the start of or intensification of fire season. In the United States, there are a number of different measurements done by weather monitoring organizations like the US drought monitor for example. Other examples are given below in this sample fire assessment given for the Northwest. Similar assessments for all fire prone regions of the US can be found here[3]:

Northwest

Climatology

- Winter/Spring – Cool & moist with frequent & abundant precipitation, especially western portion of area. Relatively dry east.
- Summer – Some windy & dry season potential early, then becomes generally warm & dry with infrequent wind events due to dry cold fronts.
- Fall – Return of cooler, more moist conditions ushered in by a period of windy, dry conditions with cold frontal passages. Potential for dry offshore wind events behind storm systems.

Fire Activity

- Fire activity peaks in summer due to increasingly warm & dry conditions and potential for wind and lightning with dry cold frontal passages.
- Rapid decrease in activity in fall with Pacific moisture on the increase, though this the peak period for dry offshore wind events and a few dry cold front passages are still possible.
- Little to no activity late fall through spring

3. "Fire Season Climatology". Fire Behavior Field Reference Guide. Dec. 2017. National Wildfire Coordinating Group. Web. Jan. 2018 http://www.fbfrg.org/weather/fire-season-climatology

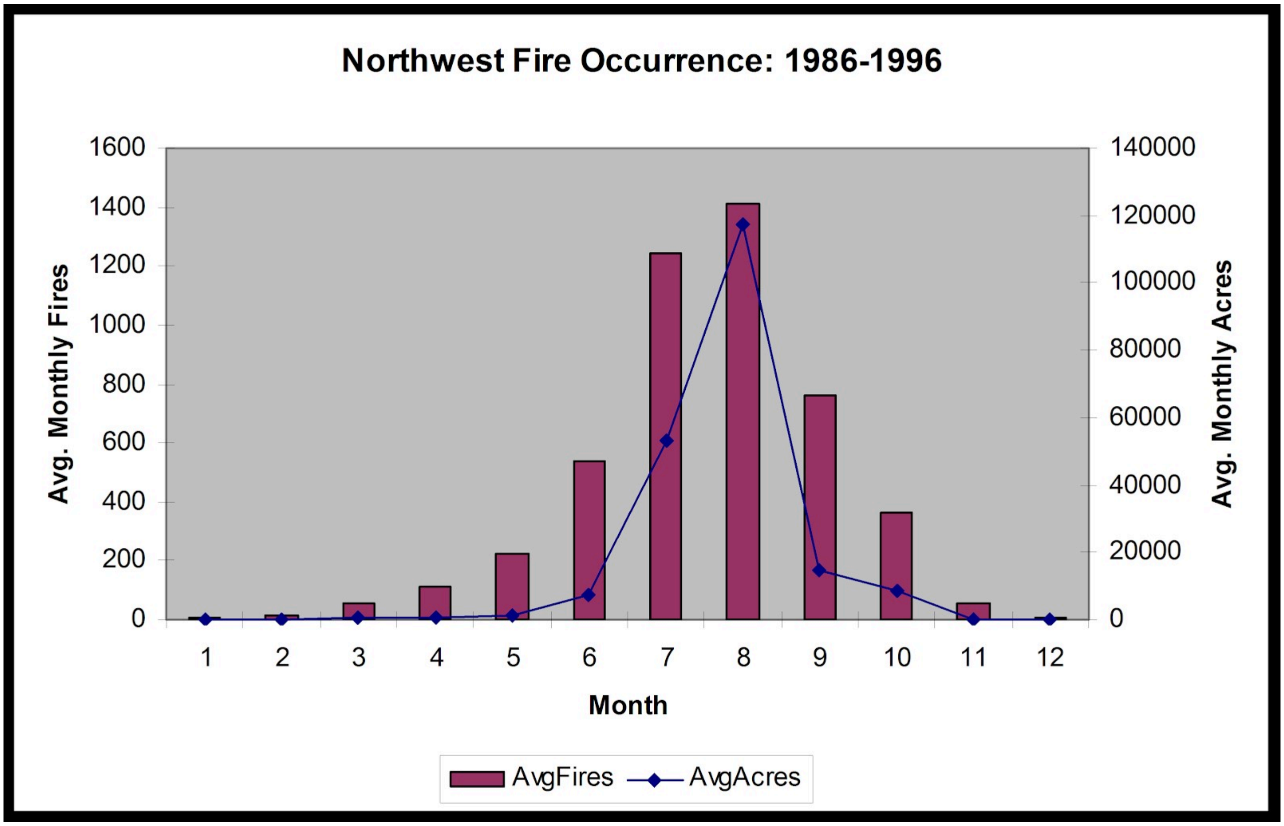

Figure 57: Northwest Fire Occurrence: 1986-1996

Critical Weather Events

- Thermal Low/Subtropical Ridge
- Breakdown of the Upper Ridge and Passage of a dry cold front
- Foehn or Downslope Wind (East Wind west slopes of Cascades and Chinook Wind east slopes of the Cascades)

Fire Slowing or Stopping Events

- Closed Lows/Wet Cold Front
- Marine Layer/Onshore flow
- Smoke Events

Fire Growth Potential Indicators

- Energy Release Component
- 100 hr fuel moisture
- AVHRR satellite NDVI DA and RG
- NWS QPE (30-60 days)
- Drought Monitor

An important permaculture principle to revisit right now says that we design from “patterns to details”. The fire season is the larger pattern of assessing fire danger for a region. As we move in closer to examining and assessing the danger for a particular site, we move to another tool which is the fire behaviour triangle. The three sides of the triangle are topography, weather, and fuel.

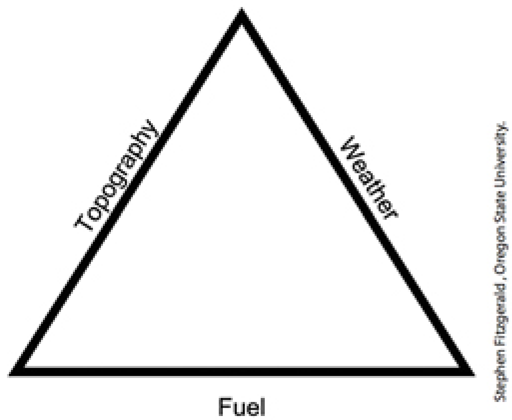

figure 58: The Fire Behavior Triangle. By Stephen Fitzgerald, OSU.

Topography

There are several elements to consider in assessing the fire danger based on topography. Those are slope, landform, and solar aspect.

The steeper the slope, the faster a fire can move, as it preheats and pre-dries the terrain above it. Fire typically moves up, so looking downslope from a location is a good first step in estimating where a likely fire will come from.

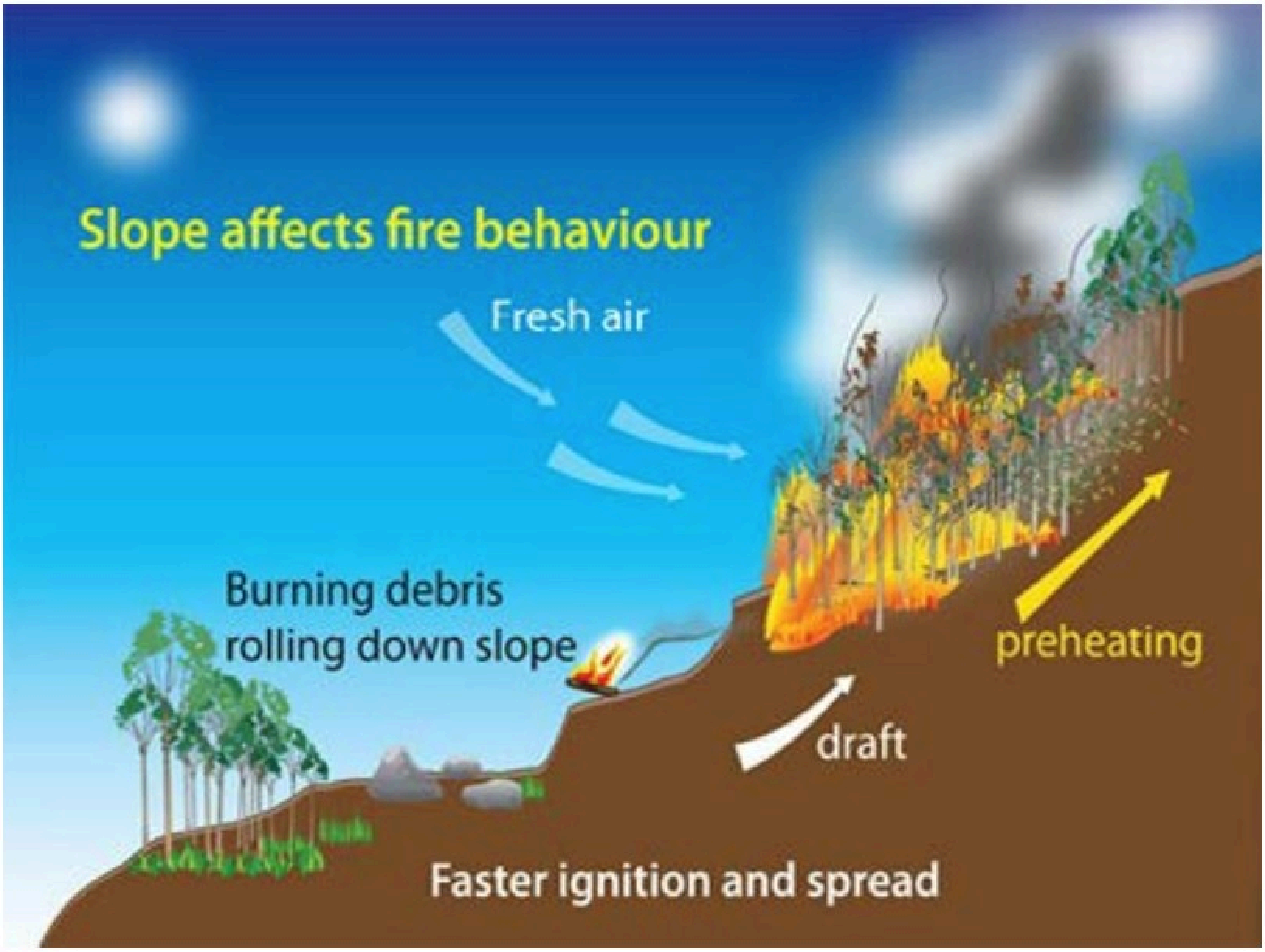

Figure 59: Slope effects on Fire Behavior. Image by the National Wildfire Coordinating Group

Landform also has a lot to do with the potential spread of fire, as topographic features like a canyon or drainage can create a funnel for fire to move through at an accelerated speed. A "chimney", which is a canyon or drainage can serve as a pathway for fire to move both up and down slope, depending on wind direction. We cannot just look at topographic features without overlapping with the other sides of the fire behavior triangle like weather and fuel.

Solar aspect is another topographic element that overlaps on the triangle with vegetation. A slope with greater solar exposure, like southern and western slopes in the northern hemisphere, will be drier because of the increased solar radiation. A drier slope will be more flammable, so you can make assumptions about the potential fire behavior on a slope based on it's directional orientation.

Weather

The whole 'fireshed' assessment activity becomes somewhat of a process of elimination. The first thing that was examined was determining the fire season, where parts of the year where conditions are not conducive to the spread of fire can be eliminated from planning. Next we examined topography and the slopes, aspects, and landforms where fire is more and less likely to spread quickly, where certain areas can be eliminated as hazardous. The next piece to look at in our process are several aspects relating to weather.

Weather has to do with a number of factors including wind direction, wind speed, temperature, humidity, and critical weather events. Each factor within the weather heading has a seasonal association, and some weather patterns can be eliminated as having any relation to determining fire risk due to their seasonal occurrence. We really want to examine the wind direction, speed, and temperature during the fire season.

It was mentioned that fire season is set to lengthen in many areas of the world. Will the lengthening fire season begin to overlap with wind patterns that are not typically present during fire season? That's impossible to say right now, but that possibility should be considered in the name of precaution.

It's really interesting to look at satellite images of the direction of wind driven smoke during periods of greatest spread of regional wildfires. This image from September 1st, 2017 is really informative to the nature of hot continental air moving from the northeast and creating a general Katabatic downslope fire situation that was extremely explosive in the region:

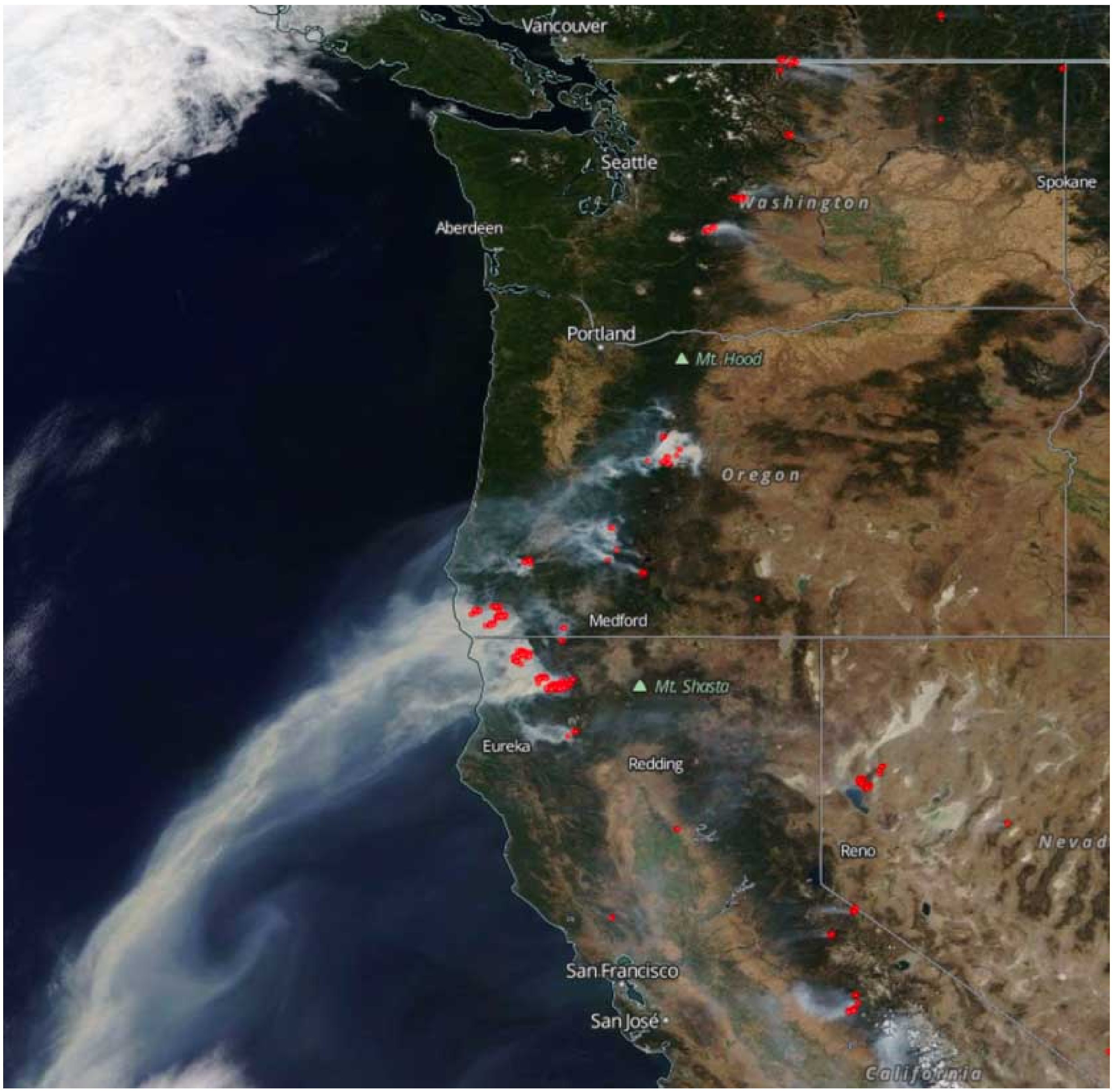

Photo 34: Northwest Wildfires September 1, 2017. Image from wildfiretoday.com

The same goes for the catastrophic fires in Northern and Central California in October of 2017.

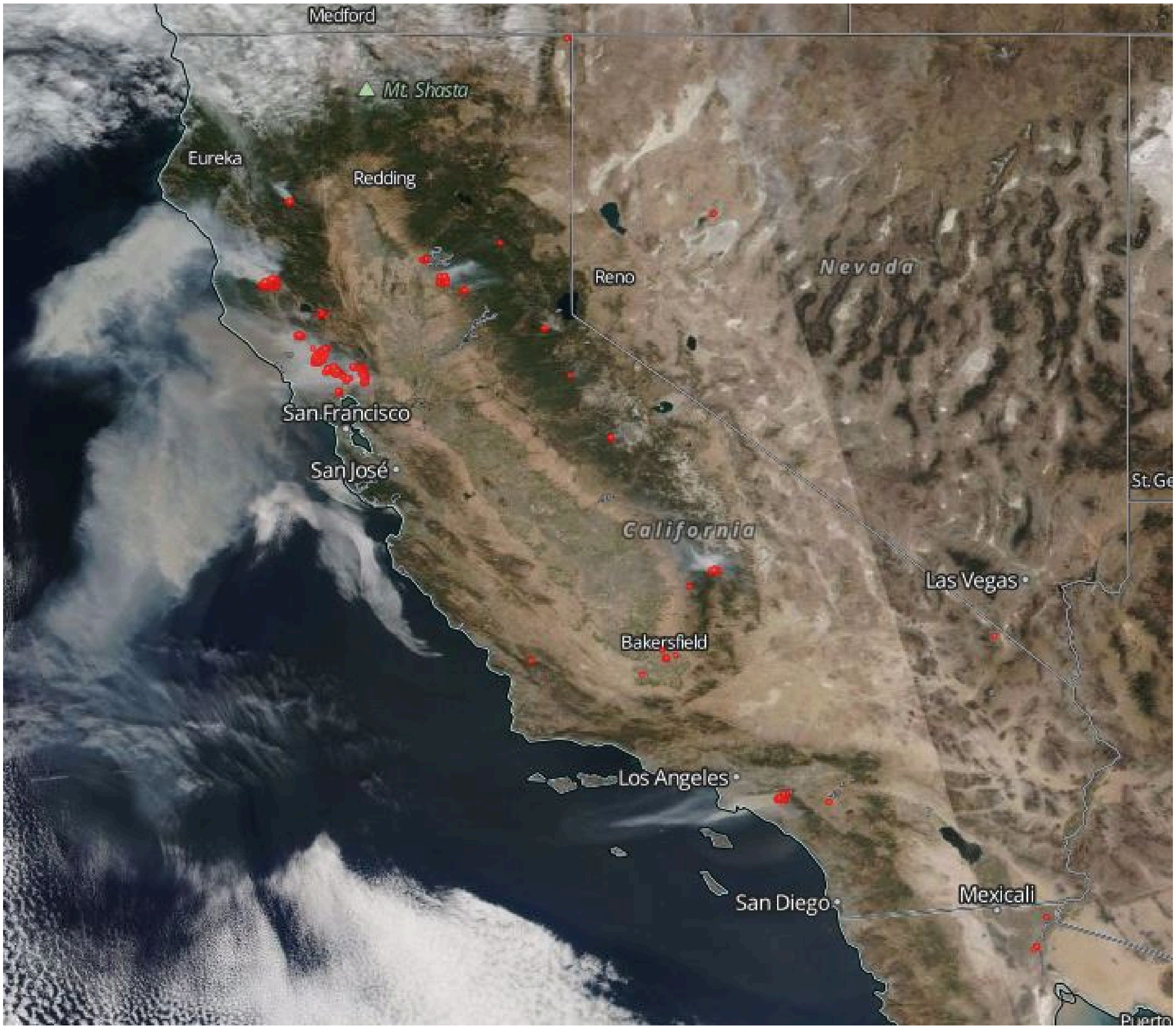

Photo 35: California Wildfires October 9th, 2017. Image by NOAA.

The Eagle Creek fire that occurred in the Columbia River Gorge in Oregon in the summer of 2017 was a perfect example of where topography and katabatic wind combined to funnel the fire through the gorge at an explosive speed.

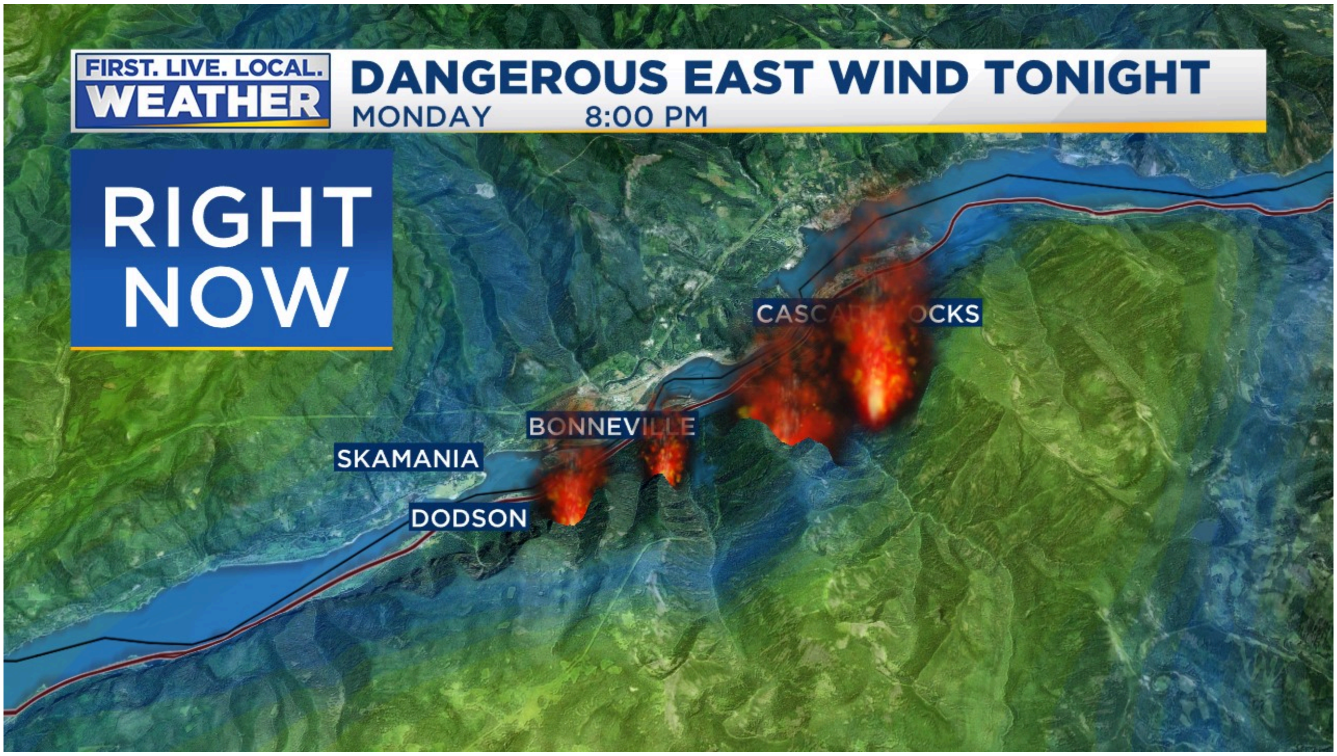

Photo 36: Eagle Creek Fire. Creative Commons.

The big question is what are the likely wind directions during the height of fire season? When the unlikely wind directions are taken out of the equation, then we are left with likely wind directions, the fire season, the most likely topography for carrying fire, and then finally an assessment of the fuel as the third side to the fire behavior triangle.

Fuel

Fuel is the actual agent of how fire moves and spreads. Regardless of how aligned all of the other factors are, fuel continuity ultimately determines the transmission of fire through the landscape. From a design perspective, fuel is the piece of the fire equation where we have the most leverage. Once you have a specific site you're working with, you won't change the fire season, topography, or weather. But you can alter the fuel load relatively easily in many cases. The first step is assessing the existing fuel conditions.

For many people who have studied ecology, the horrendous fuel conditions in areas like the conifer forests of the Western United States are daunting. One-hundred-fifty years of fire suppression combined with overgrazing have created much more dense stands of vegetation then ever existed when there were regular cycles of fire that cleared out underbrush and small trees, leaving stands of large stately trees with clearings and an open understory of diverse low and mid-sized species. The conditions in many areas are now of dense stands of smaller trees, with ladders of vegetation leading from grasses up to shrubs to dead low branches and into the closed dense canopy. This represents a continuity of fuels from the ground level all the way up into the tree canopy, and this is what we are primarily trying to avoid when protecting a site from fire. Once a fire enters the canopy, it can become much larger and harder to put out.

In chaparral regions, many species require fire for their germination, and exist in extremely thick stands with lots of dead wood due to suppression of cyclic fires which keep the fuel load down and space between stands.

In Oak woodlands, it is the same, with thick woody understories and ladder fuels leading from dry grasses up into woody canopies. These are the types of ecosystems that have shifted into very hazardous places to be during fire season in this age of rising temperatures and erratic rainfall patterns.

Many areas in the wet-dry tropics also suffer dangerous fire seasons, and the issues are basically the same in assessing the potential spread of fire through the ecosystem. Especially in tropical climates with warm wet periods, the growth of grasses and leafy material that then dry out become a dense flammable layer.

Human development has also crept farther and farther into the edges of fire prone ecosystems, into an area we call the urban wildlands interface. This only adds fuel, in the form of houses, propane tanks, sheds, fences, firewood, and all the flammable materials we accumulate in our surroundings. It also adds breaks to the spread of fire in the form of roadways, ponds, lawns, orchards and more, and in the section on design, we will look at how to position those elements in relation to the likely direction of wildfire in order to mitigate the risk.

Assessing the fuel load of a site or region can start with looking at a satellite map and examining the density of vegetation in every direction and how directly it leads to your location from outside. This is where the work done of assessing the likely wind directions and slope steepness and solar aspect will guide which slopes to look at.

Is there a continuous band of fuel coming at your site, and where is that band of fuel connected to? Even if the band of fuel is broken, what about flying embers? During the Eagle Creek fire in the Columbia River Gorge in Oregon during the summer of 2018 mentioned previously, embers literally blew across the Columbia River over one mile to start a spot fire on the Washington side of the river. How do you plan for that? So there is a point where it is necessary to really zoom out and take a regional view of the potential spread of fire, ignoring small fire breaks that would normally stop a blaze under less severe conditions.

Assessing the flammability of vegetation takes some knowledge of ecology and natural history that is beyond the scope of this book to cover for every ecosystem. That is not usually something that can be assessed from a satellite image, unless you have really intimate knowledge of regional ecosystem conditions, which many readers will.

Climate Change

Assessing wildfire risk in the age of climate change is a whole other realm. As mentioned in the first part of this book, there are major climatic shifts happening both latitudinally and altitudinally. The temperature shifts towards warmer climate zones are happening and new climate types in the temperate zones can be predicted by looking at latitudes at similar elevation and geography but closer to the equator.

New climatic conditions can be predicted by looking at lower altitudes and seeing ecosystems and vegetation types that are lower down in elevation and hence warmer. This is not only for the temperate climate zone, but anywhere in the world where altitude has a strong influence on climate.

For assessing fire danger, this provides a window into the future in a number of ways, including the fire regimes for different vegetation types that may dominate in the future, and the length of the fire season in warmer regions. Some fire seasons are dominated by a shift in winds, and the length of the fire season may not lengthen in those situations, but only intensify.

Looking at future vegetative types for a region is really taking the long view, because the ecosystem has to shift to that new vegetative type before that information is relevant. In the short term, we are really talking about the agent of the current ecosystem shifting, which is likely to be fire intensification based on higher temperatures and greater dehydration of the landscape.

Shifting ecosystems can be interpreted by looking at the range of dominant tree species and biotic communities. One example in the Western US is the shifting of the Douglas Fir forest northward to higher latitudes and higher elevations.

All of the orange on the map in the below image are places where the current range will no longer be viable by the given time period 2030, 2060, and 2090. Unless there is some human assisted transition of those forest ecosystems, the agent of change will be fire. There are situations like this all over the planet.

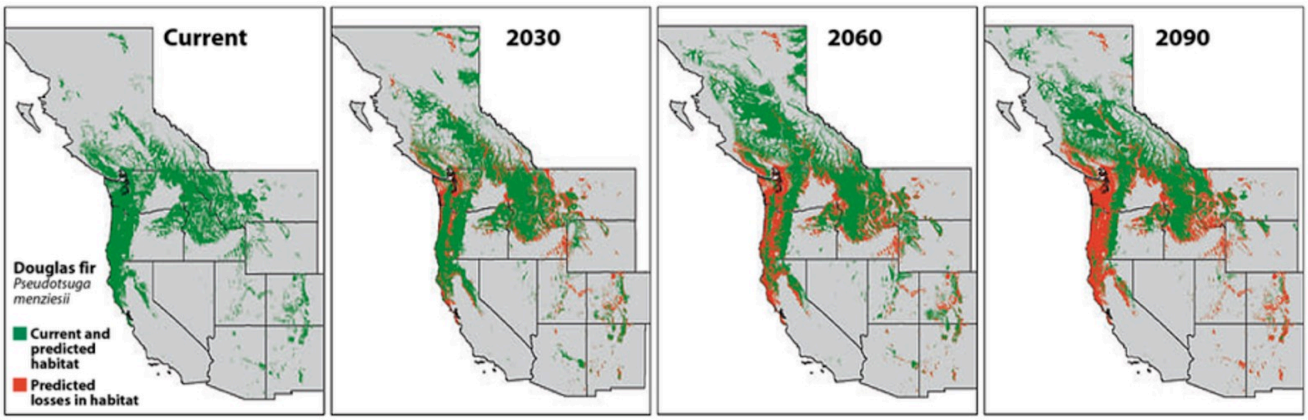

Figure 60: Predicted loss of Douglas fir habitat. Image by US Forest Service.

If not planned for, shifting climate conditions and the subsequent shifts in ecosystems will create massive catastrophic fire potential. Assessing the overall survivability of an area in the coming decades is an important and realistic action to take. If an area appears to be high risk, then design based mitigation is the most productive course of action. The permaculture principle "creatively use and respond to change" is best utilized when change is anticipated in advance. Climate models and forecasts are giving us explanations of the present and glimpses of the future. This next section will look at ways that we can get ahead of wildfires with thoughtful planning.

Firestorm

There are certain magnitudes of fires that are so great that they create their own weather patterns, and as well may reach temperatures so high that everything that might possibly burn is ignited. Unlike a low intensity fire where soil nutrients can actually increase, in a high intensity fire soil nutrients are decreased as they volatilize with extreme temperatures[4]. In the situation that a very intense firestorm moves through a site, recovery can be more difficult due to the amount of material that will burn or melt, as well as detrimental effects on soils.

4. "Fire Effects on Soil Nutrients". Northern Arizona University. Web. Jan.2018 http://www2.nau.edu/~gaud/bio300w/frsl.htm

Site Mitigation Plan

The previous section was all about assessing the threat, with the goal of mapping the most likely direction that a wildfire will come from. At the individual site level, there are many strategies to employ to lessen the destructive force of a wildfire, and maybe even save the critical infrastructure of the site in case of a huge fire.

The first thing to plan for is a fire break between the likely direction of a fire and the important infrastructure of the site. Permaculture designed sites that use the concentric zone model have an advantage because the critical infrastructure is clustered in the inner zones that are the center of human activity. So infrastructure is less likely to be spread all throughout a site, but instead is clustered centrally for efficiency of movement and workflow. Of course each permaculture design site is unique, and will sit in its landscape in its own way, but there will be a tendency for clustering if the permaculture design protocol has been followed.

Fire breaks consist of any design element that will not carry fire through the landscape. Some examples are roads, irrigated gardens, crop fields, irrigated orchards, recreational lawns, concrete slabs, animal grazing areas, ponds, wetlands, greywater systems, and closed canopy hardwood forests comprised of fire resistant species.

The strategy is to nest the clustered critical infrastructure within layers of fire resistant elements to create a multi-layered fire break consisting of many elements to create a wide swath of “defensible space” that is unlikely to carry fire to the nested infrastructure. In permaculture the firebreak and protected area will consist of zones one, two and three.

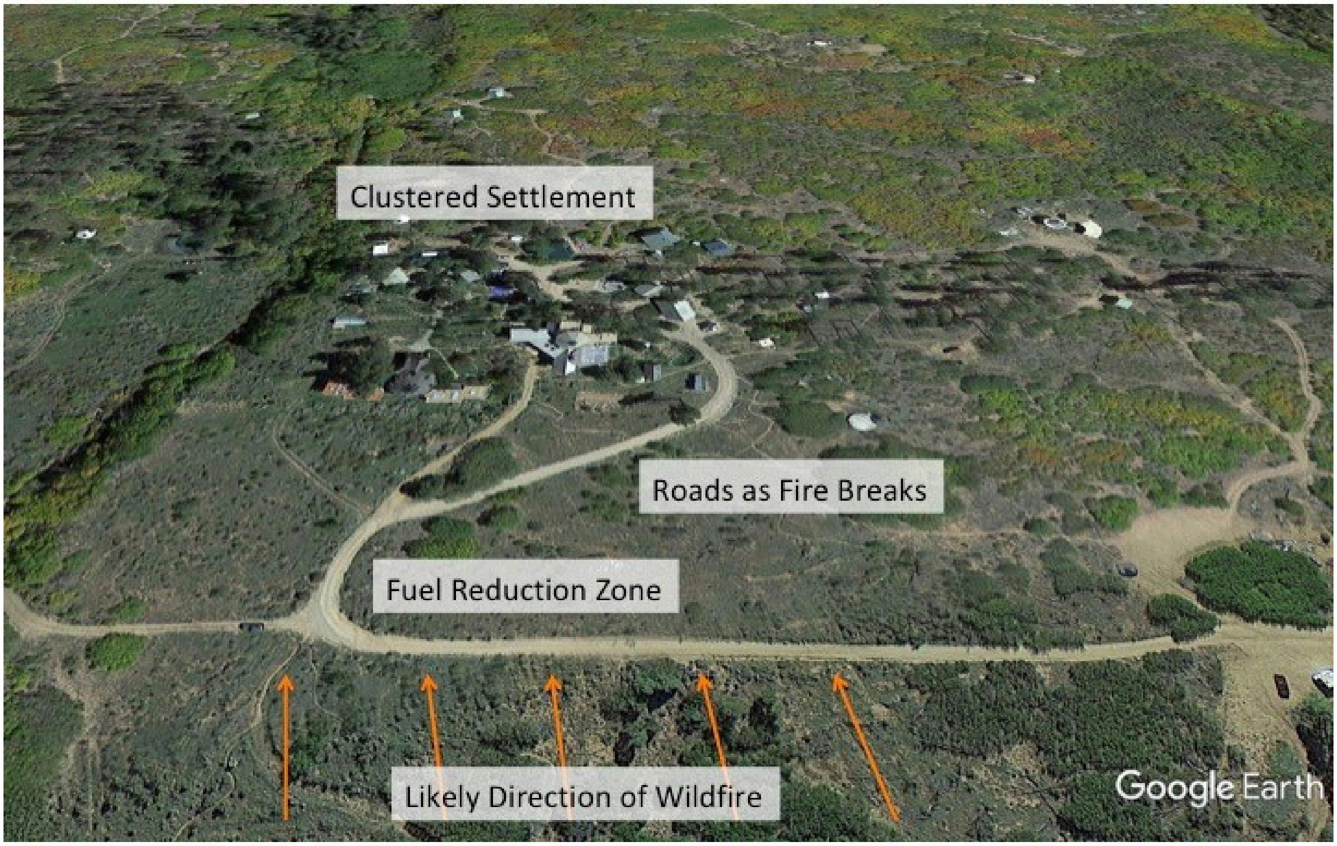

Figure 61: Site Plan Diagram

We are not talking about a particular situation and scale here, but the most fire prone locations are going to be adjacent to unmanaged natural areas or industrial forest areas, and will either be rural, or located on the urban wildlands interface. Once we get deeper into cities, it is less likely for huge fires to sweep through, and the space that any one site controls for mitigation is small. So these suggestions apply primarily to rural areas and the urban fringe.

Beyond the fire break of zones one, two and three is the semi-managed zone four. This is where studying which forest types in a region carry fire and which don't is important. In an interview with Erle Rahaman-Noronha of Wa Samaki Ecosystems, a permaculture farmer on the Caribbean island of Trinidad, I learned a lot about his design for fire mitigation during the dry season. Trinidad is located in the wet-dry tropics, so there is a period of vigorous growth of vegetation, including grasses, and then a long hot dry period where fire is a big risk.

For fire mitigation in his zone four, Erle established a closed canopy Teak plantation. When a fire approaches the Teak trees, it will lay down and burn cool in the understory, leaving the trees overhead to survive and stopping the fast and hot spread of the fire. As a rule of fire mitigation in existing forests, fire ladders are eliminated through pruning that can carry fire from the ground into tree canopies. The idea of closed canopy hardwood forest systems and their ability to "lay down' fire is a concept echoed by permaculture planner Tom Ward. Planned and managed forest systems can function as vegetated fire breaks[5].

Erle also uses donkeys to keep dry grasses down, resulting in "mowed" fire breaks. Using animal grazing and patterning their rotation on a site so it keeps down vegetation in the fire sector is a great integration strategy that is applicable for different climate zones. Where some animals graze grasses like donkeys and sheep, other animals eat woody material, like goats. A herd of goats rotated intentionally through areas where fuels have built up can be very effective in maintaining fire breaks and transmuting woody fuel into milk and meat.

Erle is able to irrigate areas with overhead sprinklers when fire is approaching, and will soak his main cash crop of cut flowers in the event of a fire to use both as a fire break for other critical infrastructure, and to save the crop which is the farm's main economic income. Having the existing irrigation system also doubling as a fire-break soakage system is a great example of stacking functions[6].

This connects to the whole main frame design process of a site in the way that the water use of sprinklers as an irrigation system will affect the water use and need to be planned for in the overall water-use equation. Drip irrigation certainly uses less water, but will not accentuate the firebreak aspect of a green and growing field of annual crops like sprinklers will at the point of crisis. This could bring up interesting choices for some sites: Can you afford to plan for greater water use in a field because it's also a fire break? Does that work with the total water budget for the site? Fire is a yearly occurrence at Erle's Wa Samaki Farm in Trinidad, so the design is built around fire, where there are also numerous storages of water throughout the landscape to serve as reservoirs and fire breaks.

Fire is especially risky in permaculture systems where planting trees, increased biomass, and increased vegetative coverage are goals. Integration of water storage in the landscape becomes an important balancing point to the increase in biomass and fuel load. Also, the planting pattern of agroforestry and perennial systems is important in its consideration of how fire will move through that landscape.

Water Storage

There are a number of important considerations around planning water storage structures built specifically for firefighting, fire breaks, and fire suppression. Planning water storage structures is part of a site planning process that puts the design of water flow as the first major design element on which other design elements are layered, like access, perennial plantings, structures, and fencing.

If a water storage pond is primarily to be used for fire suppression, then it needs to be designed to be full during the dry season. Unless the pond is being replenished by a perennial source throughout the dry season, it cannot also be an irrigation pond that is in use or it will dry up. A fire suppression pond is a great pond for recreation, as it maintains its water level throughout the hottest and driest time of the year.

Other considerations for pond design includes the ability for the water to be released by gravity and

5. Millison, Andrew S. "Tom Ward Aka Hazel: The Truth About Wildfire." Soundcloud, Earth Repair Radio, 18 Oct. 2017, soundcloud.com/user-193856180/episode-012-tom-ward-aka-hazel-the-truth-about-wildfire
6. Millison, Andrew S. "Erle Rahaman-Noronha: Superstorm Resilience." Soundcloud, Earth Repair Radio, 4 Feb. 2018, https://soundcloud.com/user-193856180/episode-014-erle-rahaman-noronha-superstorm-resilience

wet down areas to prevent the spread of fire or spot fires starting from flying embers. Often times the power grid goes down during a large scale regional wildfire as transmission lines are damaged. If topography allows, it's best to have water storage up above the fire sector with a manual valve to flood areas within the fire break. A gravity fed sprinkler irrigation system can also be used to wet down areas to avoid ignition and spot fires.

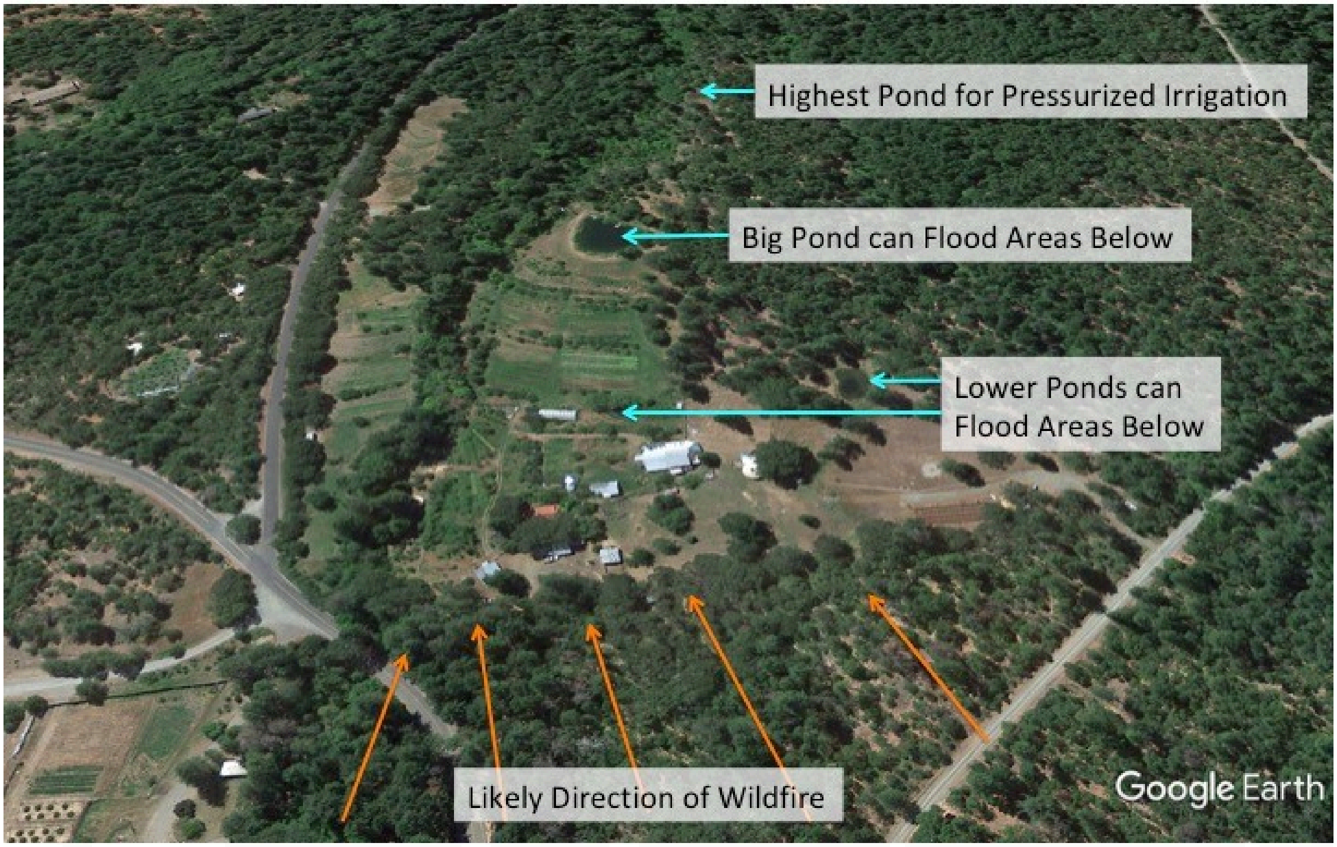

Figure 62: Water Storage Diagram

In this map, we can see the elevational relationship between the main water storage pond, the homestead, and the likely fire sector. Water is pressurized by gravity and can be released to flood lower areas in case of fire.

Access to water storages by fire fighters is another important design consideration. There are two pieces to this. One is access to ponds by fire fighting helicopters. In the United States, helicopters with buckets attached are important fire fighting tools in hard to reach areas. If there is a fire close by and helicopters have easy access to a pond, then their trips back and forth to water are that much shorter and they are that much more likely to get the fire out.

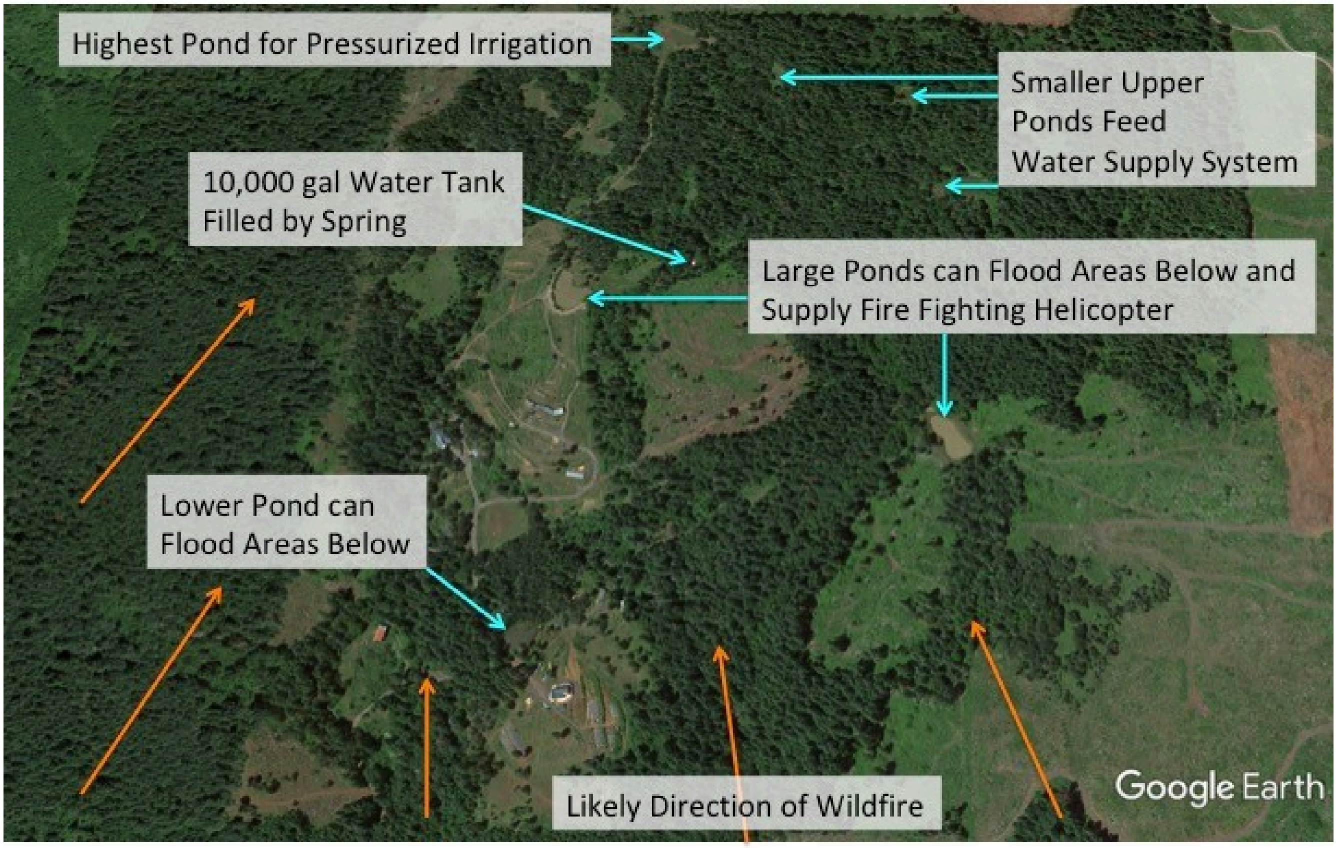

Figure 63: Cougar Mountain Sanctuary Water Storage

This is the case at Cougar Mountain Sanctuary, a permaculture site in the Cascade foothills in Oregon, USA. Their numerous ponds were placed with firefighting helicopter access in mind.

There is also access for fire trucks to account for. This translates to road and turn-around access to critical areas of the site in general, as well as specifically having access to water tanks that have a hook-up that fire hoses can tap into. At the Aprovecho Appropriate Technology Center in Cottage Grove, Oregon they built a 10,000 gallon ferro-cement reservoir that fills from rainwater off of a roof and remains full throughout the growing season. Although the garden is irrigated from this tank, it is continually kept full to a certain level from a well during irrigation season. When the level drops, water is pumped in and the level is replenished, and then it's allowed to empty at the end of the fire season to collect roof runoff. Importantly, it is fitted with hardware that is sized so a firetruck can pump out of it in the event of a fire.

Photo 37: Water Tank. Photo by Andrew Millison

A water tank has no evaporation, but an open source of water like a reservoir will have water evaporate. So if a pond will not be replenished during the fire season and the goal is to maintain water in that pond in case of fire, then evaporation will need to be minimised. Evaporation is accelerated by both wind and sunlight, so sheltering the pond is essential to keeping it as full as possible. Different climate zones have different strategies for reducing evaporation of open water storages, and this text will not go into detail about each one. The image below shows an example of windbreaks integrated with ponds from P.A.Yeomans property “Yobarnie” in Australia:

Figure 64: Wind Breaks in "Yobarnie" Property

Structures

The design of structures to for resistance to flames, extreme heat and flying embers is a topic that could fill an entire book, and the totality of the subject is beyond the scope of this text. However, we will briefly cover the main aspects to consider.

In a major region-wide wildfire, the heat produced can be intense, and even if the flames do not destroy a structure, structures can be damaged simply due to their proximity to a fire. This is where a macro view of the topography, fuel and weather patterns are important to get an honest assessment of the potential in a region and for the design and placement of structures.

The external materials used on a structure are very important because these are the materials that will catch fire or not. The roofing material is obviously very important, especially in the presence of flying embers, which as mentioned before can go very far in a massive fire. Embers can actually blow into a house through vents and gaps, igniting a structure which burns from the inside out during a wildfire. Eaves will trap burning embers with updrafts of wind occuring in front of the fire, and this is an easy way for a roof to catch on fire, as often times a metal roof will still have exposed wooden eaves on the underside. Many people in very fire prone regions will outfit sprinklers to their roofs to wet them down, supplied ideally by a gravity pressurized source.

I parked on a ridge in 2002 overlooking the Indian Fire as it spread through the southern edge of Prescott, Arizona, a landscape that is a mosaic of Ponderosa Pine forest and High Desert Chaparral, watching a man standing on his roof hosing it down continually until he was forced to evacuate. That landscape is the quintessential urban-wildlands interface located in a fire sector with very flammable fuels, seasonally high winds, and steep slopes leading right from vast unmanaged forest areas directly into the city.

A house located in that type of high risk landscape should be fireproof. This may mean that the structure is partly underground, with a living roof, and no exposed flammable materials. Even with the house burning, there should at least be a bunker to retreat to for life saving protection from flames and extreme heat. A quick search on the internet for "wildfire bunker" will yield a number of prefabricated models. In Australia the term is "bushfire shelter", and there's seems to be an established market in that fire-prone continent. Maybe this spends most of its time as a root cellar, but is also designed as a refuge with proper ventilation, stocked with water and a temporary toilet for when it's needed.

Photo 38: A Wildfire Safety Bunker

Other recommendations have to do with outbuildings and wood storage, and making sure that big loads of flammable materials are well away from critical infrastructure. Remember the pattern of nesting critical infrastructure within the band of fire breaks. Flying embers may come into the protected area and should not be able to fall onto a wood pile and start a big fire within the protected zone. Things like wood storage and propane tanks should be located within ember proof structures. The types of critical infrastructure that should be nested within the inner zone is the well, water tanks or other water source, energy generation center, vehicles, animals, other equipment, food and material storages, propane and other gas or liquid fuel storage, and economically important crop areas.

Extreme Event Survival

There are some elements to include on a site in order to survive a wildfire at the point of crisis. Above, the fire bunker was already mentioned, and its potential multiple uses as a root cellar or something else. Another extremely important consideration during the site design phase is evacuation.

Designing multiple ingress and egress points on the property can be a life saving endeavor. Especially in areas where fire can come from multiple directions, having evacuation routes going in different directions are important. This also may be a factor in choosing a site in the first place. When considering a property in a location in a very fire prone area, it is essential to think through a possible wildfire at the outset, and whether or not there is the possibility of being trapped in a dangerous situation, like at the end of a thickly vegetated box canyon with only one way in or out.

On the same note as evacuation is the planning of a meeting place in the event of evacuation. It's important to recall that cellular phone service and the power grid can be taken down in a large regional wildfire, so there may be no means of communication with loved ones. Having a predetermined safe meeting place is prudent planning. It is standard practice in schools to have fire drills. During fire drills, everyone goes out to an open area away from buildings that appears like it would be safe from fire. This is the same concept, but on a larger scale.

Another important thing to consider is being present on site during fire season to be able to respond to a situation immediately. That's what Erle in Trinidad does, where there is always someone on site during fire season, 24 hours per day, to be able to immediately respond to a situation and fight a fire. This could be very important if evacuation is needed and there are animals on site, or if a firebreak can be accentuated by opening up a reservoir and flooding an area.

Regional Mitigation

The scale that needs attention when talking about regional mitigation of wildfires is the bioregion. When we're talking about changing species distribution at the scale of entire ecosystems marching towards the poles, it really needs a macro view to have any meaningful response.

In interviews with permaculture elder and forester Tom Ward, there were a number of recommendations from a permaculture design perspective for wider ecosystem scaled responses to the issue of changing forest types.

To start with, we will return to the concept of slope aspect and recall that in the temperate climate, the fire sector is very dependent on the aspect. Hotter slopes with a sun-facing aspect are south and west in the northern hemisphere, and north and west in the southern hemisphere. Management of different slope aspects should be different, and this can be a patterned management approach at a regional level.

Cooler slopes should be developed as refugia for retreating species, and their coolness and wetness should be enhanced to remain as a viable microclimate for retreating species as the climate warms. Warmer solar exposed slopes that are much more fire prone should be managed for fuel reduction by managed grazing and controlled burning.

The conventional and commercial response to the need for fuel reduction ahead of ecosystem changes would be the logging of endangered slopes. But access to these areas with logging roads and the compaction of heavy equipment will damage the watershed and reduce the capacity of the area to hold water, further accelerating the drying of the land. Logging also leaves a lot of slash on the ground which all becomes dry dead fuel for more fires.

Selective downing of standing trees to thin stands could be really effective if they were left on the ground on contour, with log to soil contact, so they acted as water slowing swales, where snow, water runoff, and detritus would be slowed down and help to build water and soil in the watershed. This would both reduce fuel, as well as build the water holding capacity of the slopes for healthier vegetation and greater resistance to fire with less dead standing fuel.

The above suggestions are an overall strategic perspective with an example of a particular technique, but the techniques will differ from region to region. The main point is that with changing climate and changing species distribution, not all solar aspects and microclimates will have the same effects, and the design for a new ecosystem should account for these differences.

Recovery

Living in the Western United States, I have had a lot of opportunity to watch burned areas recover over time in multiple different forest types and ecosystems. One thing I've witnessed is that there are species who appear to thrive on the renewal caused by fire, and will quickly shoot up to take advantage of the access to sunlight and the nutrients contained in new layers of ash. The pioneer species and fire-dependent species will differ from place to place, but they are present in every natural ecosystem that has regular fires as part of its life cycle.

Immediately after a fire there is the risk of erosion and landslides before any vegetation recovers and heavy rains occur. This is common when the fire season is followed by the rainy season; there is no time for recovery. Landslides can be just as catastrophic as wildfires, so the risk must be assessed and preemptive evacuations made if necessary.

Soil stabilization work must begin right away. It may be that the gardener quickly throws down seed balls or seed bombs, where seeds of desired pioneer species are mixed into a clay and manure ball that protects the seeds until rain melts the ball and germinates the seed. There are many other erosion control structures that are too numerous to mention in this book, that would assist soil stabilization in different types of ecosystems and climate types. But overall the scale is the biggest concern. Major wildfires cover a lot of ground in a short time frame, and can result in an overwhelming area of exposed soil to be created all at once. So it is necessary to have a realistic perspective on how much stabilization work can be done between the time of a fire and that of heavy rains.

Photo 39: Seed Bombs. Photo by Kevan Davis. CC 2.0

What will help is to have a vision of the desired successional model for a recovered agroecosystem. In permaculture it is said that the problem is the solution. One thing that a fire can provide is a total reset for an ecosystem and a point of intervention in the system where a permaculture designer can guide succession towards a productive landscape.

This happened in Northern New Mexico in 1996 to a community called the Lama Foundation, and their recovery from a devastating fire is documented on their website, where their core central node survived the fire, and the rebuilding and new landscape centered at that nucleus, and spread outward to the entire larger site:

> "On May 5, 1996, a massive forest fire turned the once highly forested area into a relative empty expanse. The fire, which consumed about 7,500 acres of national forest, nearly wiped out everything at Lama Foundation. However, the Dome Complex and the kitchen, along with the, as yet incomplete, new kitchen and community center, survived. Twenty-two other buildings were entirely destroyed. The Intensive Studies Center (ISC) was burned to rubble though much of the foundation and the

original adobe walls remained intact. Work immediately began to rebuild Lama Foundation, and enormous outpourings of love, effort, and funds poured in….

Throughout the late 90's and the first decade of the new millennium, Lama Foundation began building with a new vision, adding permaculture to the spiritual and community focus that were always present. Massive efforts were undertaken to protect the unstable soil from eroding and to provide clean drinking water. New buildings were constructed with fallen timbers, straw bales, cob walls, passive and active solar heat, and other natural building techniques. New gardens were developed, and the whole mountain buzzed with activity."[7]

7. "History of Lama Foundation". Lama Foundation. Web. https://www.lamafoundation.org/about-lama-foundation/history-of-lama-foundation/

10. Tropical Cyclone Effects

Threat Summary

Hurricanes, cyclones and typhoons are all words that officially translate to the same thing, a tropical cyclone. Which term is used depends what part of the world the storm is in. A storm is named and becomes a tropical storm at 39 mph or 63 kph. It enters the category of tropical cyclone at 74 mph or 119 kph. There are different categories, and it enters the strongest category 5 at 155 mph or 249 kph. In Australia there is a different categorization. For this chapter we will use the term tropical cyclone to describe the event[1].

According to the US government's National Oceanic and Atmospheric Administration (NOAA), they have five major conclusions about tropical cyclones that they are stating which I have paraphrased below:

1. It is inconclusive as to whether or not greenhouse gas emissions have yet had a detectable impact on global tropical cyclone activity. They may have, but there's not enough data to substantiate this.
2. It's likely that anthropogenic warming will raise the wind intensity of tropical cyclones by 2-11% by the end of the 21st century. When that is translated to the actual destructive potential per storm, the percentage becomes higher as particular wind speed thresholds are broken.
3. There are "better than even" odds that tropical cyclone wind intensity will be much higher than the 2-11% increase. This does not increase the number of storms, but their intensity. This is less likely to apply to the Atlantic Basin.
4. Anthropogenic warming is causing greater atmospheric moisture content and this will increase the amount of rainfall from tropical cyclones 10-15% within 100 km or 62 miles from the eye of the storm. There is "medium confidence" that this is already happening.
5. Sea level rise will cause higher storm surges for tropical cyclones when all else is assumed equal.[2]

The magnitude of this new reality was evident in the summer of 2017, when the United States National Weather Service had to add a new color to their maps to express how much rain fell in the Houston, Texas area in the 4 days that the storm lingered there.

1. "Typhoon? Hurricane? Cyclone? Here's the Difference". CBS News. 11 Nov. 2013. Web. Feb.2018 https://www.cbsnews.com/news/typhoon-hurricane-cyclone-heres-the-difference/
2. "Global Warming and Hurricanes: An Overview of Current Research Results". Geophysical Fluid Dynamics Laboratory. 24 Jan. 2018. National Oceanic and Atmospheric Administration. Web. Feb. 2018 https://www.gfdl.noaa.gov/global-warming-and-hurricanes/

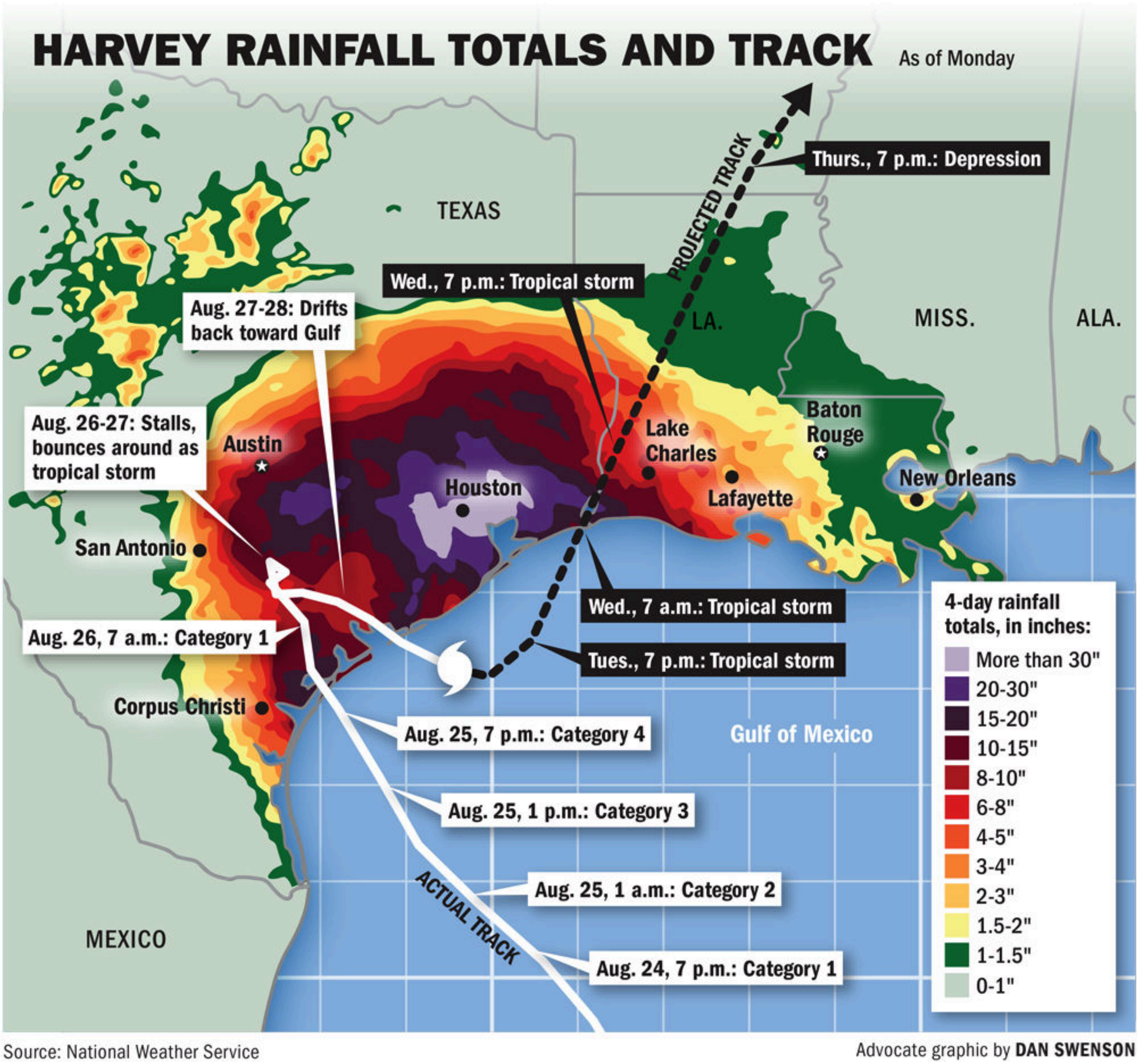

Figure 65: Hurricane Harvey Rainfall Totals. Image by The National Weather Service.

Site Assessment

When assessing the actual danger to a site from the permaculture design perspective with the goal of mitigating that threat, there are several things to look at in relation to wind. The following section in this book will cover sea level rise and storm surge, so those impacts will be examined separately from wind.

The first thing to do is research historic events that have hit areas with a similar geography, like island, delta, barrier island, major coastal city, steep hillside, flood plain, and the many other geographic positions around. What were the maximum wind speeds? What was the total rainfall accumulation? What direction did the winds come from? What was the greatest source of damage? Was there flooding? What were the barriers to recovery? What species survived? Although it was stated above by NOAA that wind intensity and rainfall amounts are forecasted to go up, and may have already, a look into history will reveal what we absolutely do know is possible.

Mapping wind direction and creating a tropical cyclone 'sector' like we like to do in a permaculture site analysis is tricky, because cyclones swirl by their nature. So depending on how a site is oriented within that swirl, intense winds can literally come from any direction. This image of an extratropical cyclone off of the coast of Iceland really illustrates the fact that winds in a cyclonic system can come from every side depending on where a site is in relation to the cyclone pattern:

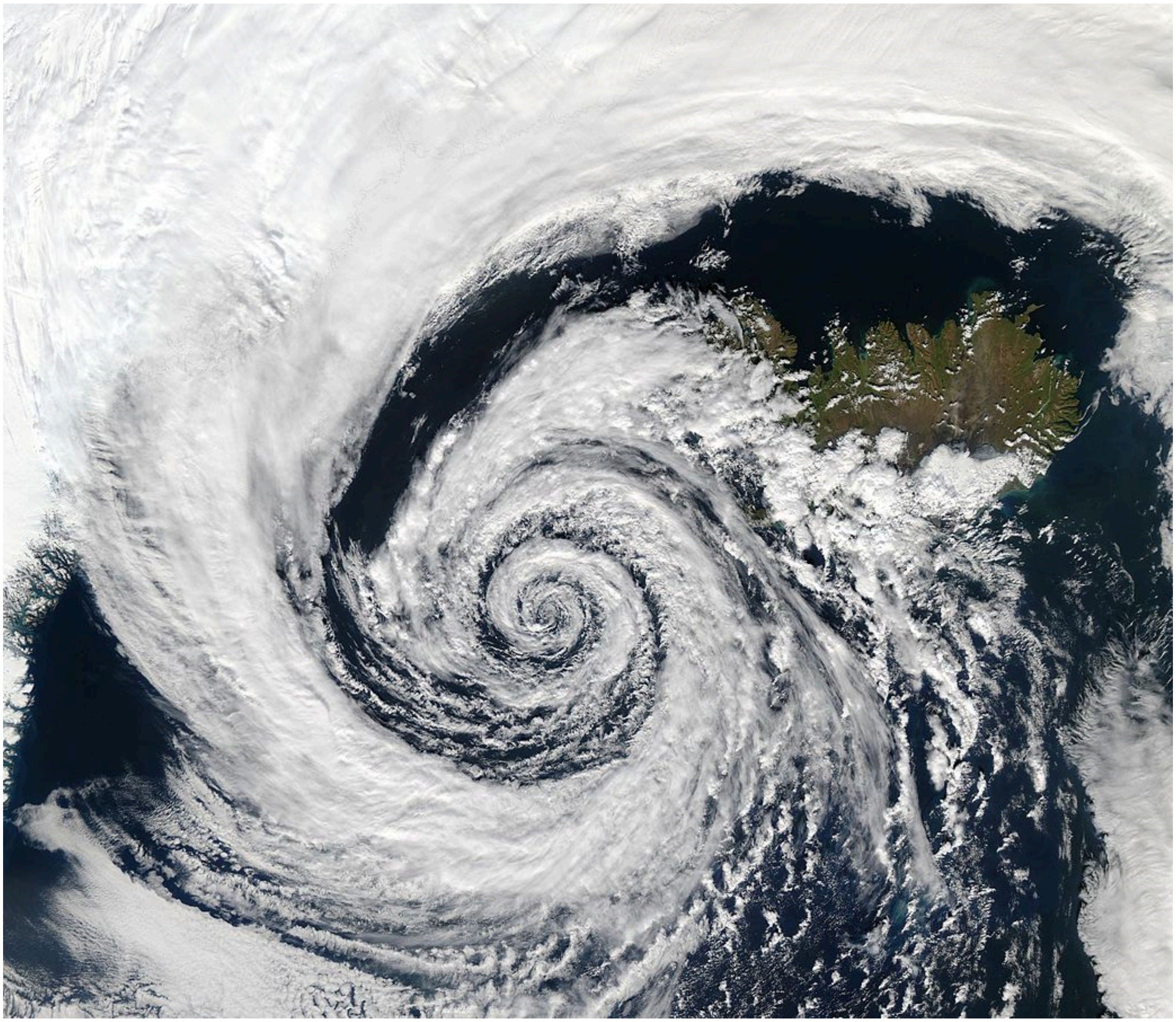

Figure 66: A Cyclone over Iceland. Image by NASA

The same goes for where and how these storms make landfall. They can take erratic twists and turns at the last moments and follow very surprising paths, as we saw with Hurricane Sandy that struck New York City in 2012.

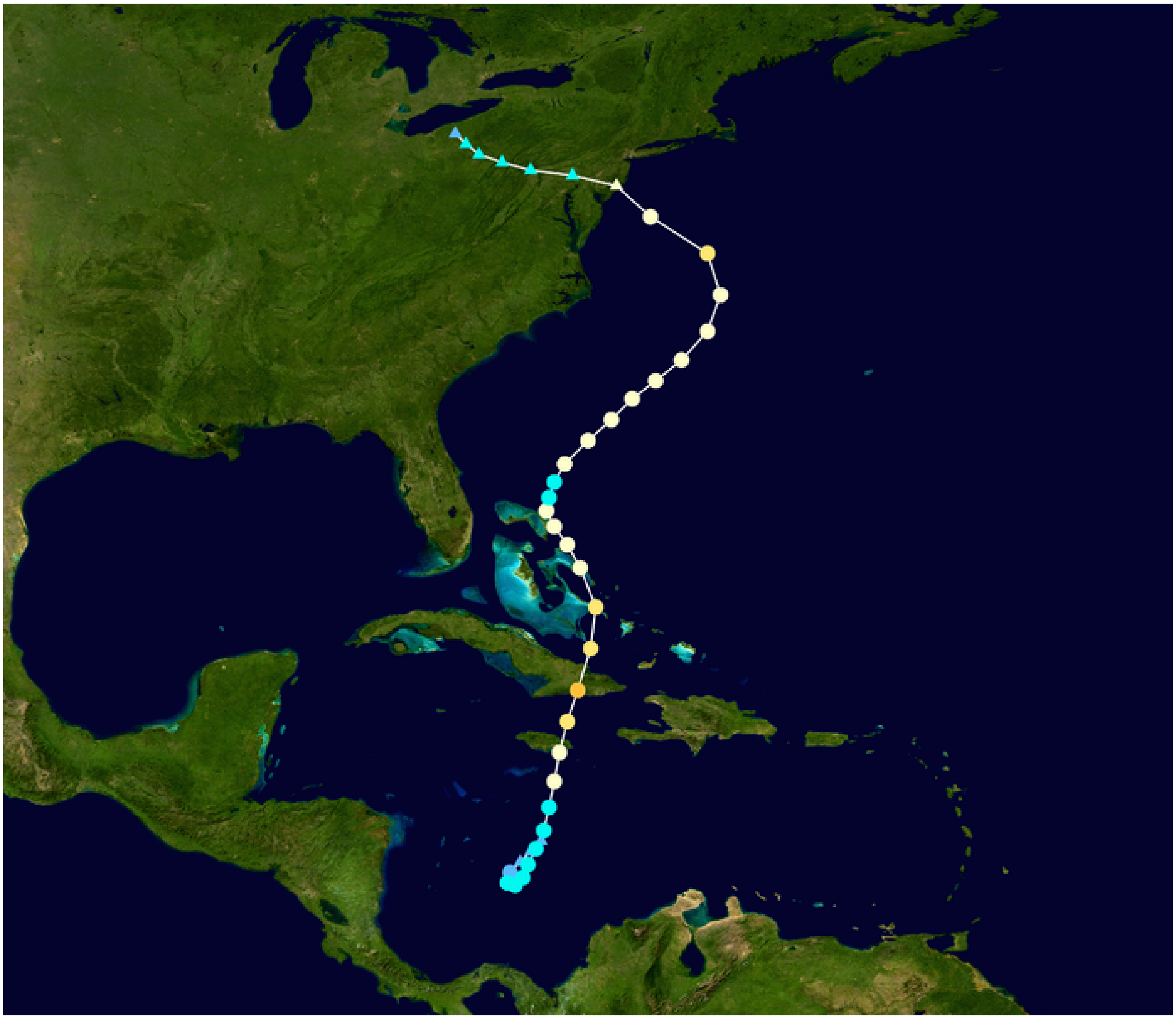

Figure 67: Tracked Hurricane Sandy

We see another example of an erratic pathway in Hurricane Harvey from 2017, whose twists and turns sheds light onto why it was used as an example above of an unprecedented amount of rainfall accumulation:

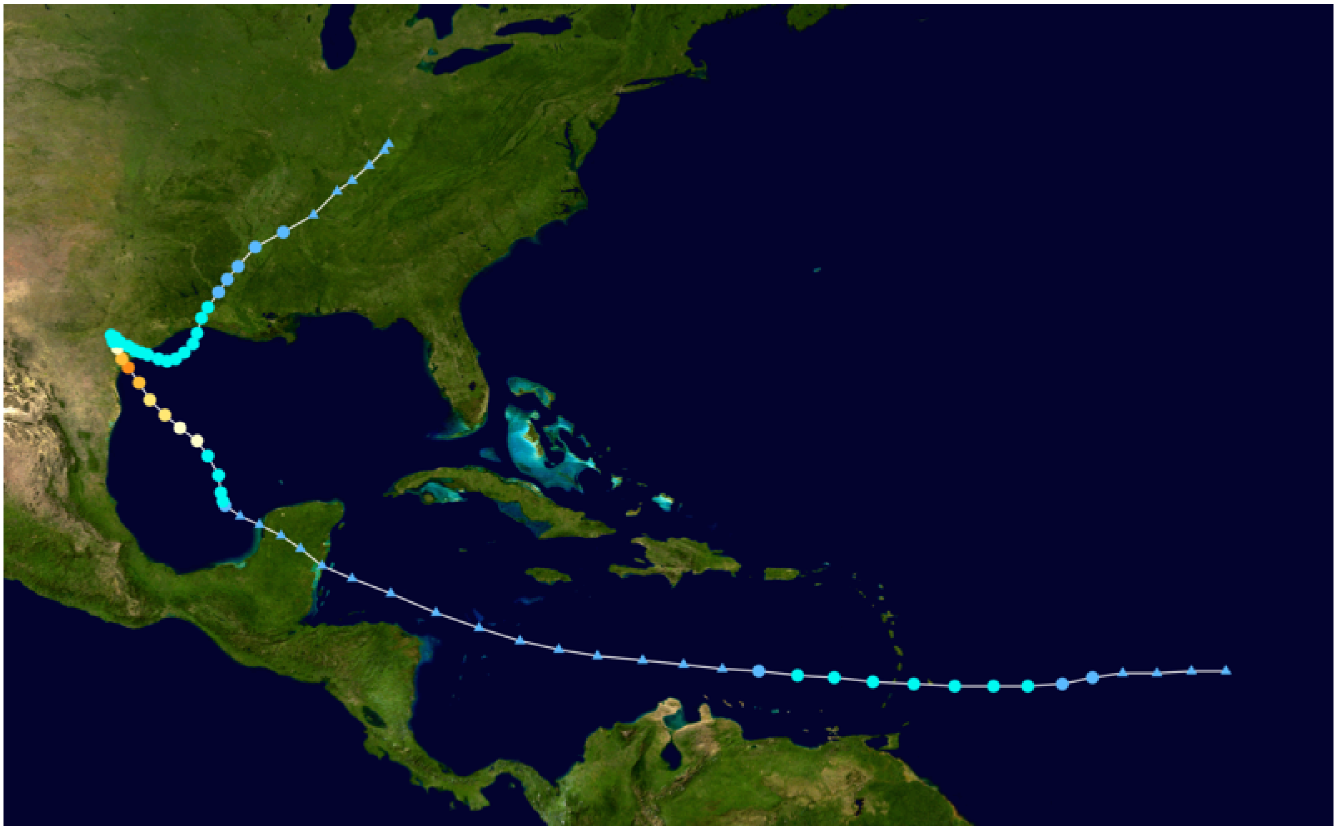

Figure 68: Tracked Hurricane Harvey.

So the point is that you won't be able to create a cyclone sector on a sector compass diagram. That sector comes from everywhere. But there are other sectors related to tropical cyclones that can be mapped. Below are four important elements to map out:

1) Distance to coast

How far from the coast is a site located? Winds dissipate as the storm moves inland

2) Elevation above sea level

This is important for analysis in terms of storm fueled sea level rise.

3) Watershed

What is the potential for flash flooding in a watershed, based on the size of the watershed? What is the health of the watershed and its ability to absorb water, or on the flip side, the amount of non-absorptive water shedding surfaces? Where a site sits within the watershed? Low areas receive inevitable flash flooding that occurs with heavy amounts of rainfall all at once.

4) Geology

Where does the site sit in relation to potential landslides due to extreme rainfall, and how stable is the geology to handle the load? Is there unstable and denuded land at risk of slippage?

Some of the specific damage that comes from tropical cyclone winds is defoliation. During the Atlantic hurricane season of 2017, there were multiple direct hits with category 5 storms on a number of locations, and the impacts were tremendous. Hurricane Maria landed a direct hit on the Caribbean Island of Puerto Rico, and completely denuded the island's prized El Yunque National Forest[3].

After Hurricane Irma went through the Caribbean in September of 2017, NASA released satellite imagery revealed before and after images of the islands of Tortola, St. Johns, St. Thomas, Barbuda, Antigua, and Virgin Gorda, showing them turning from green to brown overnight.

Figure 69: Caribbean Islands Before and After Hurricane Irma. Image by NASA

Just like a major wildfire, a tropical cyclone represents an ecological disturbance at the level of an ecosystem reset. This doesn't just go for the natural environment, but can also destroy buildings, and even flood whole towns and cities. One major difference between the impacts of of a tropical cyclone versus a wildfire is that in a wildfire, the impacted area has a major fuel reduction event, and will not have the same fuel load and potential for many years. But a tropical cyclone can strike the same location more than once in the same

3. Hopewell, John. "Hurricane Maria Decimated the Nation's Only Tropical Rainforest Outside Hawaii". The Washington Post. 29 Sept. 2017. Web. Mar. 2018 https://www.washingtonpost.com/news/capital-weather-gang/wp/2017/09/29/hurricane-maria-decimated-the-nations-only-tropical-rain-forest/?utm_term=.3ae9ef436cd3

season, and certainly the next year or any year after that. So planning really needs to be for repeated events to have long term resilience.

Extreme event survival

There are three aspects to surviving a tropical cyclone that are discussed in this section. They are preparation before the event, survival during the event, and survival during the aftermath of the event. There are many lessons to be learned from history on this, as there have been so many massive tropical cyclones during recent times to study.

Evacuation

Evacuation can be one of the best ways to survive a massive tropical cyclone that is approaching. With modern satellite technology, there is forewarning of approaching tropical cyclones, and forecasts of their potential routes. However the nature of the patterns of movement and intensification of the storms is chaotic. The fact that storms are named is indicative of the fact that they have their own "personality", and can be erratic and unpredictable, at least for now. This statement comes out of recent observations of hurricanes from the summer of 2017.

The below image tracks the Hurricane Maria and its intensification as it approaches the Islands of Dominica and Puerto Rico. You can see that it goes from being a tropical depression (blue triangle) to tropical storm (blue circle) and then from a category 1 hurricane (beige circle) to a category 5 (red circle) in an extremely short distance. This is called rapid intensification and the people on the islands of Dominica and Puerto Rico were caught off guard without a lot of time to prepare for that level of wind intensity.

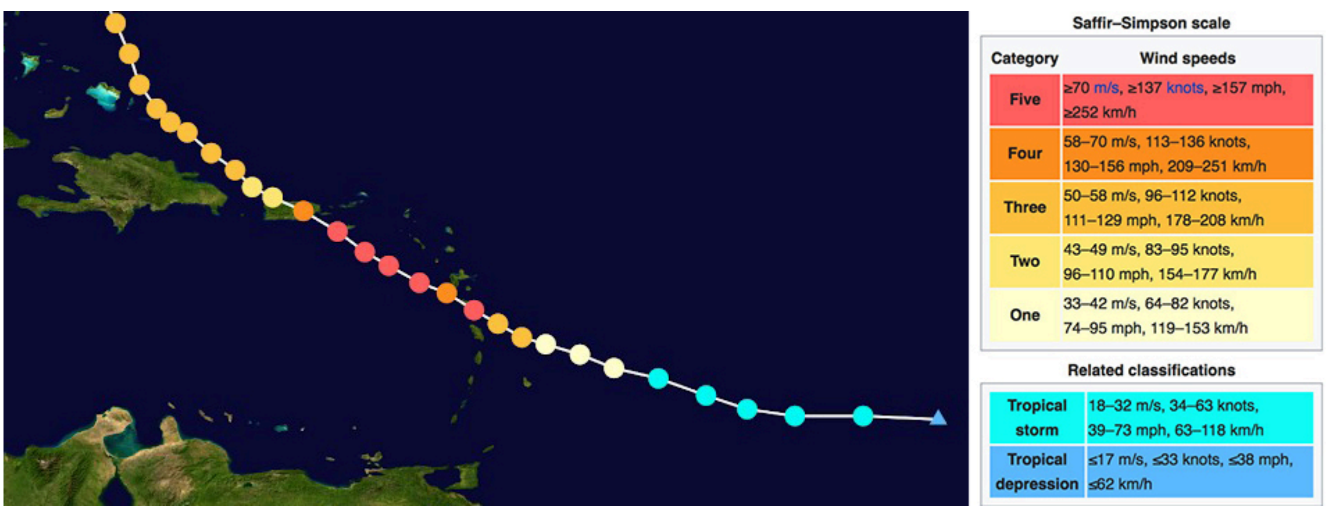

Figure 70: Tracked Map of Hurricane Marie Color Coded by Severity. Adapted from wikimedia image.

The early forecasts had the speed of intensification much lower and most looked a lot more like this:

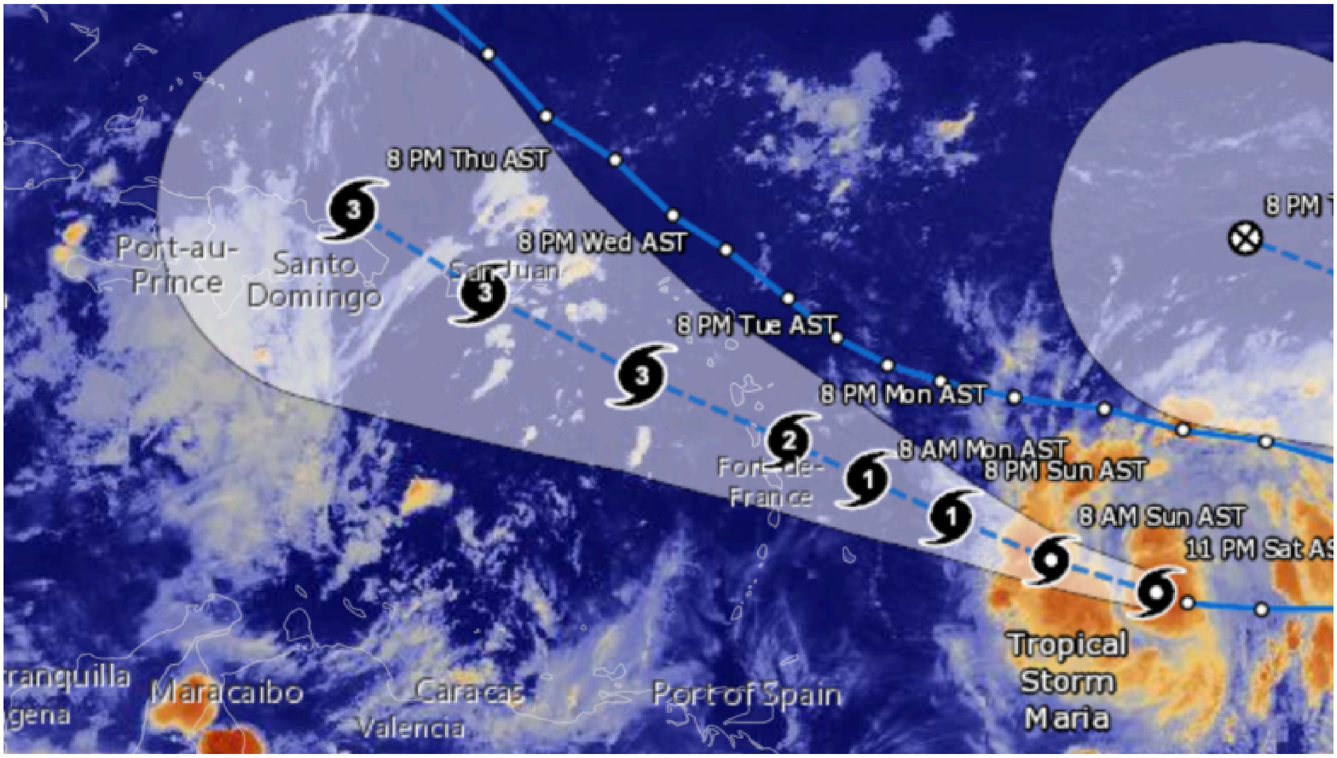

Figure 71: Hurricane Marie Forecast. Image by NOAA

With rapid and unforecasted intensification, evacuation may not be an option. This is especially relevant on an island, where air evacuation is the only way to get off of an island quickly, and is only an option for a limited number of people who have the resources for an impromptu flight.

When a superstorm is approaching land, there is much more potential for evacuation overland. Hurricane Irma approached Florida as a category 5 storm 2 weeks before Maria struck in the summer of 2017. This prompted the largest evacuation in Florida's history of 6.5 million people.

Evacuation also has its hazards, and the 2005 evacuation of 2.5-3.7 million people from the Houston, Texas area as category 5 Hurricane Rita approached is remembered for standstill traffic in 100 degree F (37 degree C) heat, where some people were out on the road for up to 36 hours. The hurricane weakened and changed course, but if it had struck at its full intensity, those who evacuated and were stuck outside could have been at the greatest risk .

From the permaculture perspective, mass evacuation is not the best option. Preparation is. Because mass evacuation depends on a level of industrialization where the highway system, power grid, and fuel distribution systems are able to serve millions of people in an energy intensive and possibly hazardous relocation. Mass evacuation is certainly an option for some nations and some citizens, but is less of an option for those without access to resources.

One glaring exception to the inequity and chaos of mass evacuations is the Island of Cuba. As a socialist republic, the central government controls the lion's share of resources and infrastructure. Cuba sits in the Caribbean Sea in an area that is very prone to tropical cyclones, and has an extremely organized system of mass evacuation into government shelters. During Hurricane Ike in 2008, the Island successfully evacuated a quarter of their entire population, 2.6 million people, without major incident. That level of control and organization is much more difficult to accomplish in capitalist economies, for better or for worse[4].

Establishment of regional shelters and localized evacuation is a much better option from the permaculture perspective then massive evacuation out of a region entirely. It is important for people to assess their particular risk when there is not a tropical cyclone approaching. Site analysis is the first key measure to take, assessing the stability and resilience of structures, elevation above sea level, positioning in relation to a floodplain, stability of nearby slopes, and overall integrity of the watershed. Once a tropical cyclone based site analysis has taken place, then the need to evacuate in the event of a storm may be very clear, and contingency plans can be made well before the event occurs. The information about the potential risk to an area can also be shared with friends and neighbors, so the community as a whole is psychologically and physically prepared for the event.

During the storm

When riding out the storm, survival depends on the site design and preparation discussed in more detail in the "Site Mitigation Plan" section. The quality of housing and presence of a shelter are essential. Flood, salt, and wind resistant plant species, and a knowledge of local edible plants will all aid in survival. Housing for the protection of animals is also essential to keeping an agricultural system intact, as well as stores of food, medicine, and other essentials. Alternative and decentralized water, energy, and waste treatment systems are also described in greater detail below in the "Site Mitigation Plan" section.

Storage methods

In Cuba in 2013 at the International Permaculture Conference, there were multiple talks by Cuban permaculture practitioners discussing their tropical cyclone resilience strategies, some of which are mentioned in the text. One important point they brought up was about storage and planning storage of essential items to withstand wind and water damage. The example given was the storage of seeds. People who stored their seeds in glass jars on the shelf risked the shelf falling over, the jars smashing, and the loss of the seeds then to water damage. People who stored their seeds in plastic containers did not suffer the loss of their seeds when the building containing them was compromised. Those small details can mean a lot during the recovery and replanting period.

4. "Lessons From Ike: Cuba Gets Evacuations Right: Low Death Count Attributed to Island's Efficient Hurricane Response System". Associated Press. 10 Sept. 2008. Web, Mar. 2018 http://www.nbcnews.com/id/26647041/ns/world_news-americas/t/lesson-ike-cuba-gets-evacuations-right/#.WpmOLhPwb8s

Photo 40: Hurricane Damage in Cuba. Image by FEMA

In the event of the situation that was described in Myanmar with Cyclone Nargis, it's hard to say what the population of the entire Irrawaddy Delta should have done when storm surge brought water 25 miles (40 km) inland and 150,000 people died. In an ideal world, there would be local shelters that were raised up above projected storm surge levels and were resistant to cyclone force winds. These shelters would be stocked with supplies and would be plentiful enough to house the population during a storm and dispersed enough that a population on foot could reach them. The shelters could double as community centers, schools, food storage and distribution centers, or serve some other regular infrastructure purpose. In the US, many schools end up serving as shelters during disasters because of their size, construction, location, and distribution. In an impoverished country like Myanmar that hosts the world's longest running civil war[5], an infrastructure building task of that magnitude could prove challenging.

5. "Lessons From Ike: Cuba Gets Evacuations Right: Low Death Count Attributed to Island's Efficient Hurricane Response System". Associated Press. 10 Sept. 2008. Web, Mar. 2018 http://www.nbcnews.com/id/26647041/ns/world_news-americas/t/lesson-ike-cuba-gets-evacuations-right/#.WpmOLhPwb8s

Site mitigation plan

Designing a site to be resilient to tropical cyclones has a few different parts to the whole picture, and on the physical level those are structures, energy, grading and drainage, forest and cropping systems. When talking about the destruction from storms, most people focus on structures, so that's where this section will begin.

Structures

In a major wind event, the interface between walls and roof is a point of failure, and roofs will be peeled back and blown off of a structure in the worst case scenario. So one major architectural strategy is to either reinforce the interface between the walls and roof and strengthen the roof's connection with the ground, or avoid having a roof that is separate from the structure at all. Domed structures do not catch the wind like a more conventional roof with eaves. This is why domes are so resilient to strong winds, as we see in these images of Earthship cyclone shelters on the island of Vanuatu in the Pacific Ocean

Photo 41: Dome house survived hurricane: Pennsicola, Florida. Creative Commons.

Photo 42: Monument Valley Housing. Photo by Dsdugan CC BY-SA 4.0

There also a lot to learn from the design of the traditional Native American Navajo Hogan located on the Colorado Plateau in the USA, where very strong winds blow.

Shelters without sharp angles to catch the wind will in general be more resistant. In the images above, we can see there is no point where the roof juts out. It is contiguous with the ground. Another strategy is to have a roof extend all the way to the ground, and be tied to the ground for greater support. This is a strategy used in the tropical cyclone prone island of Cuba. On permaculture sites, with a tight central cluster of buildings, they will tie all of the buildings and other associated structures for animals and storage and processing together so they form an interconnected building web, which is more strongly rooted than single isolated individual buildings.

Photo 43: Traditional cyclone resistant Nakamal structure on Vanuatu. Photo by Andrew Grey. Creative Commons

Retractable Infrastructure

Structures and systems that are built to be taken down without a lot of notice and stored safely during storms is another effective resilience strategy. This could include solar energy and solar hot water systems, wind turbines, greenhouses and hoop houses, trellising, portable fencing, and portable animal structures like chicken tractors.

In this day and age of satellite technology, there is advanced warning of approaching storms. Even though storms can take surprising turns, there are still warning systems in place.

Decentralized Energy, Water, and Waste Systems

Power grid failure is a reality in the aftermath of major storm events, and power can take days or weeks or months to be restored. Three months after Hurricane Maria devastated the Caribbean Island of Puerto Rico, power was only back on for half of the population[6]. Decentralized power systems like solar, wind, micro hydro, and biomass energy generation can turn a long term power grid failure into uninterrrupted or briefly interrupted power supply.

Water sources and supply systems have the same parameters. If water is provided by a central grid that involves the power grid for treatment and distribution, then that can fail long term as well. Permaculture urges to have multiple sources of essential elements. So backup water supply could be rainwater harvesting

6. Robles, Francis, and Jess Bidgood. "Three Months After Maria, Roughly Half of Puerto Ricans Without Power". The New York Times. 29 Dec. 2017. Web. Mar. 2018 https://www.nytimes.com/2017/12/29/us/puerto-rico-power-outage.html

tanks, a well to access stored groundwater, development of a spring, or home-scale treatment of wastewater. The backup water system could be integrated with an alternative energy system.

Many flush toilets are also connected ultimately to the power grid for pumping and treating water at a municipal scale. Composting toilets, constructed wetland treatment, greywater systems, and a number of other localized waste treatment systems are all encouraged with permaculture design. The number and types of systems and their appropriateness to particular situations is too big of a topic to cover in detail in this book. There are numerous resources to study for more information.

Forests and cropping systems

There are a couple different aspects to planting systems that will be discussed. One aspect is the stability of the landscape from heavy inundation by major rainfall. The other aspect is having food to eat in the aftermath of a major tropical cyclone.

Watershed stability

Permaculture is known for its design of earthworks, which are excavation and sculpting of soils in connection with water management. Earthworks are often done as part of water harvesting and soil stabilization systems. It is always advised to size the capacity and overflow of water management earthworks to handle historic level flood events. But in some instances, that may not be practical, given the magnitude of rainfall that is being dropped by some of these storms. Designing earthworks systems to handle the 40 inches or 1000 mm of rainfall that fell in 48 hours during the US Gulf Coasts' Hurricane Harvey in 2017[7] may just not be feasible for some sites given the amount of space and existing infrastructure, or size and condition of the watershed upstream of the site.

When it comes to the watershed during a massive rainfall event, big risks are soil erosion and landslides. In the event that earthworks are overwhelmed or fail, tree cover on steep slopes and tree belts interspersed throughout the landscape are essential. The more tree cover, with deep intertwined roots, the more stable soils and slopes will be, and will provide security in the event that other water management structures are overwhelmed.

Another aspect to this strategy falls within the general permaculture pattern of breaking the landscape up into smaller field components. This is accomplished with hedgerows and agroforestry belts that are integrated into open field areas. So the end result is that there are fewer large open expanses, where forces like wind and water can concentrate. The landscape is a tighter mosaic of field and hedgerow, where belts of trees and shrubs with deep perennial roots are more dispersed throughout the land, keeping soils stable.

7. "Major Hurricane Harvey". National Weather Service. 25-29 Aug. 2017. National Oceanic and Atmospheric Administration. Web. Feb. 2018 https://www.weather.gov/crp/hurricane_harvey

Figure 72: India's cyclone prone southern state of Kerala shows small fields bordered by trees.

This Google Earth image from India's cyclone prone southern state of Kerala shows small fields bordered by trees.

Species selection

As far as species selection, there are a number of species that are known in the tropics for their soil stabilization qualities. These are Vetiver Grass (*Chrysopogon zizanioides*), Napier Grass (*Pennisetum purpureum*), and different species of bamboo, to name a few examples. It's necessary to avoid introducing a potentially undesirable rampant species, so this needs to be considered with any tough species brought into an area.

It is also necessary to consider the potential fire danger of planting lots of grasses and bamboos, as many areas located in the wet-dry tropics that are prone to tropical cyclones are also prone to wildfires during the dry season. The placement of any fire prone species needs to be considered with proximity to major infrastructure, and it requires an advanced level of design to plan for both tropical cyclone and fire resilience in the same landscape.

Selecting tree species that can withstand tropical cyclone force winds and have a measure of salt tolerance is wise. A quick internet search reveals resources available for tree and shrub selection from the University of Florida and James Cook University in Australia for sources in English.

Resilient perennials

In a previous section, the risk of complete defoliation from strong winds was explained and demonstrated with satellite images. The planting plan needs to account for this possibility. In permaculture, zones one and two are considered the inner zones that are clustered around the house or central area of human activity. This is where the diverse home garden and orchard, compost, and small animals are often located.

Annual and perennial root crops are potentially ready for immediate foraging after a tropical cyclone, even if the above ground portion of the plant is defoliated. So having a diversity of root crops in the ground provides some level of food security. Additionally, wild leafy greens that are perennial may come back rapidly after a big disturbance. The typical permaculture homestead model of a diverse polyculture garden immediately around the house full of perennial edible and medicinal plants is a great pattern for providing forage after the storm, and plant selections can be made to maximise disturbance resistant species.

Regional Scale Mitigation

At the regional level, there are some major strategies that could go a long way to mitigate the impacts of tropical cyclones. Actions on this scale predominantly need to be undertaken at the level of zoning ordinances and planning departments, and have to do with appropriate land use related to slope stability, flooding, and coastal stability.

The first thing is for a watershed perspective to be adopted by municipalities and communities so assessment and planning can happen on the scale that it needs to. In an interview with Erle Rahaman-Noronha of Trinidad, it was pointed out that the watersheds of the Caribbean Islands are small, which makes flash flooding more of a threat than widespread flooding at the bottom of large watersheds. This is not the case for all tropical cyclone prone regions by any means, but it is typical of the geography of Islands.

Tropical cyclone Nargis that hit Myanmar in 2008 is considered the worst natural disaster to strike that country in recorded history. There was catastrophic flooding caused by a storm surge that sent water 25 miles (40 km) inland through the densely populated Irrawaddy Delta, killing nearly 150,000 people. There was also large amounts of rain that fell in the large watershed, so rainfall flowed down into the same delta that the storm surge flowed up into. This was in addition to category 4 winds of 130 mph (215 kph).

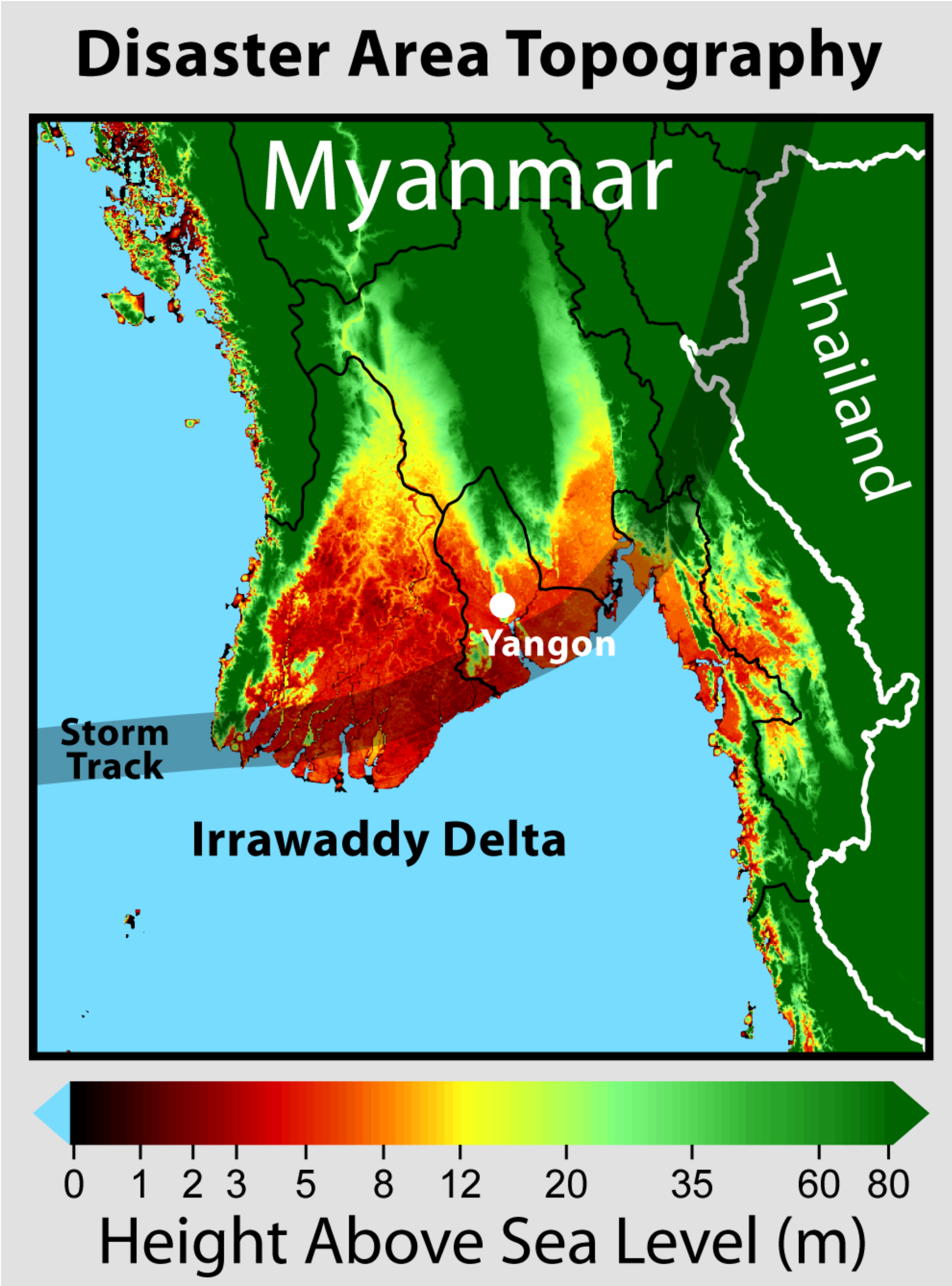
Disaster Area Topography
Myanmar
Thailand
Yangon
Storm Track
Irrawaddy Delta
0
1
2
3
5
8
12
20
35
60
80
Height Above Sea Level (m)

Figure 73: Myanmar Disaster Area Topography. Image by Robert A. Rohde. GNUFDL 1.2

So the scale of potential damage and mitigation has a lot to do with the scale of the watershed and the amount of low lying area that is at risk of widespread flooding and the amount of slopes that are at risk of landslides.

Mitigating the risks in uplands are the same strategies that we see for slopes and watersheds in general in permaculture design. Some of the typical strategies employed are listed below and some are the same strategies employed by government soil conservation services:

- Planting areas steeper than 30% slopes in permanent forest cover
- Interspersing trees and hedgerows throughout gentler slopes
- Breaking up large areas of open lands into smaller segments divided by perennial hedgerows
- Covering soil for greater water absorption and percolation
- Aligning roads and crop rows so water is maintained and soaked into the landscape instead of shed into drainage systems

The lowlands will benefit from water moving down more slowly from high ground, but coastlines are a different story. In a natural system, coastal vegetation can reduce storm surge. This could be coastal forests like Mangrove, coastal marshes and vegetated dunes. Depending on the type of storm, it's wind speed, duration, and intensity, coastal vegetation may or may not actually reduce the overall storm surge. It's a complicated formula. But it certainly can help in many cases, and will undoubtedly slow the velocity of moving water during a storm surge event[8].

In a conversation with permaculture elder Rosemary Morrow, she related some advice that she had given to coastal farmers in the Tanh Hoa province of Vietnam, which was to plant a dense belt of vegetation 50 meters (164 ft) wide between the coast and their farms. Closest to the coast they will need to consist of salt tolerant species, and beyond they should consist of as much bamboo as possible. There should be no straight lines or pathways directly from the beach inland. All pathways should be angled or zigzagged so there is not a direct route for water to penetrate inland without seeping its way through the dense plantings. It was interesting to look at some of the patterning of coast, forest, estuary, and farm fields that can be viewed on Google Earth of the Tanh Hoa Province:

8. Masters, Jeffrey. "Storm Surge Reduction by Wetlands". Weather Underground. Web. Mar. 2018 https://www.wunderground.com/hurricane/surge_wetlands.asp

Figure 74: Patterning at Coast of Tanh Hoa province of Vietnam.

Plant research and propagation

There are resources from universities detailing species resistant to wind and salt known as tropical cyclone resistant species. This is certainly an endeavor that could be further organized and undertaken at the government, university and municipal level. It would be easy to identify resistant species because after tropical cyclones strike an area, observations can be made about what survived and what regrew within a certain time period.

Once resilient species are identified and a database produced, those species can be promoted through education and their propagation encouraged. This is an action that would make good use of the climate analogue tool. Where on the world's tropical cyclone prone coastlines are there species that have endured storms over time and have served to stabilize coastlines and protect settlements and villages from storm surge in some cases? Where in the tropics are the best examples of slope stabilising plants that have endured the highest winds and rainfall amounts? What species are suited to extreme winds, salt spray, and are fire resistant for the wet-dry tropics? These questions and more are all those that can be researched and answered with the help and resources of large organizations.

Recovery

From an ecology perspective, a strong tropical cyclone or any major damaging windstorm is a disturbance event that moves an ecosystem to an earlier stage of succession. Large and weak trees are taken down, limbs broken off, and canopies opened up to allow new species to fill the niches. Plants are defoliated and need to use the energy stored in their roots to regrow on stripped branches or from the ground. Soils are washed away and deposited elsewhere. Humans clear out fallen trees and debris near their roads and habitations. Understories become the new overstories with rapid growth from increased light. New spaces are opened up for life to fill.

As a permaculturist, the view is that the ecological succession that will occur can be guided by human hands to serve our needs for food, medicine, fiber, shelter, energy, and water, while at the same time benefiting the natural environment. In gardens and landscapes, this guiding hand can take the form of selecting what species will be allowed to grow and where, what species will be planted and encouraged to grow, and which will be removed and discouraged from growing.

In permaculture it is said that the problem is the solution, and the perspective on a damaging tropical cyclone would be to look at the opportunity that it presents. A vision of what the new productive tropical cyclone resistant landscape will look like will guide choices at the point of the successional reset, which is really a leverage point in time where new species compositions can be implemented.

The permaculture principle that asks us to value the marginal has already positioned permaculture projects in disturbed locations, and many well known techniques practiced by permaculturists have been developed for disturbed and degraded landscapes. Examples are the use of pioneer species like nitrogen fixing ground covers and herbaceous perennials to rapidly cover exposed soil and create the conditions for further successional species. Pigeon Pea (Cajanus cajan) is one example of a tropical nitrogen fixing plant that grows rapidly while producing an edible seed. The plant can be perennial and last for up to five years, setting the stage for the next species to be planted in an intentional succession. Pioneer species like Pigeon Pea can be planted swiftly, and then occupy the accessible light and root zone so other undesirable plants don’t become established during recovery while resources are being gathered for longer term plantings.

Photo 44: Pigeon Pea Cajanus cajan. Creative Commons.

As was mentioned before, root crops by nature have their energy stored in roots. The fact that root crops are edible is even better. Some can be easily divided and spread in the aftermath of a cyclone disturbance event. Erle Rahaman-Noronha of Trinidad related this about root crops in tropical cyclone recovery scenario: “Cassava will work well as it can plant almost any time of the year as long as there is a little moisture, and will be harvestable in 9-12 months. The young leaves can also be cooked and eaten. Sweet Potato slips will produce tubers the quickest, in 4 months and are fairly easy to propagate. Other root crops like Taro and Tania are also easy to propagate but they tend to grow best during the rainy season and go into hibernation during the dry season. So depending on when the hurricane hits, production may not be as good.”

The diverse permaculture landscape should already contain much of the plant material for the next stage of succession to be sourced from. Rooted cuttings, root division, air layering, stool beds, grafting, and other plant propagation methods can be used to multiply existing resources.

Seed banks are also essential. The truth is that recovery from a disaster needs to be a community undertaking, and cooperation is a key ingredient for preparation, survival, and recovery. Community scale seed banks are the best option, as everyone is simultaneously recovering from a big storm, and it’s a perfect time for good ideas and beneficial plants to spread within a community.

11. Sea Level Rise and Flooding

Threat Summary

Sea level rise

According to the Intergovernmental Panel on Climate Change, sea level is currently rising at an average of 3.2 mm per year, and this is projected to go up in the future. Seas are not rising uniformly, and there is variation based on global location[1]. Over the past century, the Global Mean Sea Level has risen by 4-8 inches or 10-20 cm. Sea level rise is caused by the thermal expansion of water as it expands with heat, the melting of glaciers and polar ice caps, and ice loss from Greenland and West Antarctica[2]. Where this puts us by the end of the century is only speculation, and projections vary widely based on emissions scenarios and potential environmental feedback loops that set temperature rise in motion at a greater speed than the current trajectory. Regardless of the speed of sea level rise, the fact is that CO2 emissions are at their highest level in 66 million years [3] , and this leads us to expect more warming, melting of ice, and expansion of water. So we'd better be ready.

1. "Is Sea Level Rising?". IPCC Fourth Assessment Report: Climate Change 2007. Intergovernmental panel on Climate Change. Web. Mar. 2018 https://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-5-1.html
2. "Sea Level Rise". National Geographic. Web. Mar. 2018 https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/
3. Doyle, Alister. "Carbon Emissions Highest They Have Been in 66 Million Years". Scientific American. Web. Mar. 2018 https://www.scientificamerican.com/article/carbon-emissions-highest-they-have-been-in-66-million-years/

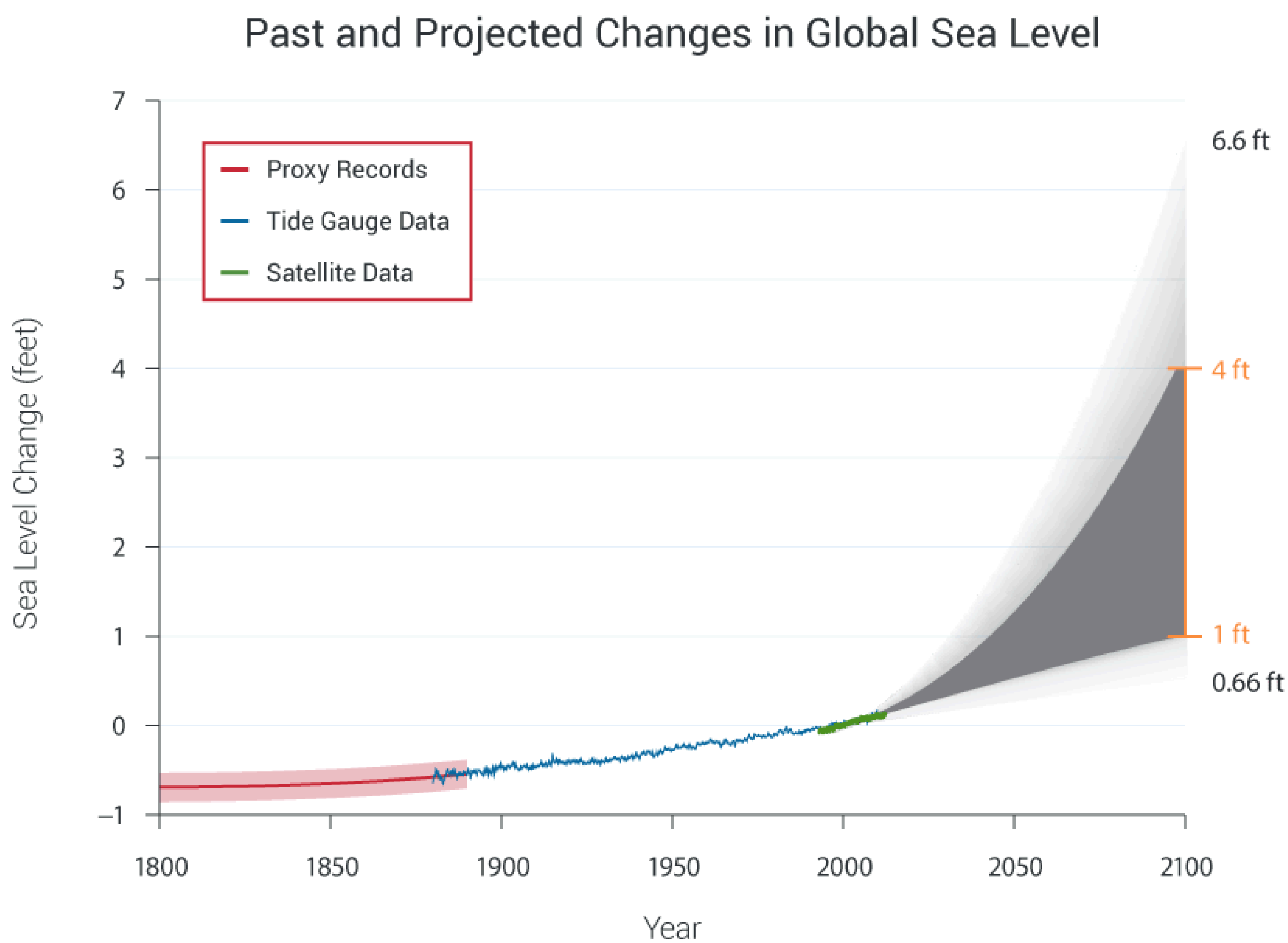

Figure 75: Past and Projected Changes in Global Sea Level Rise. By the National Climate Assessment

Figure 75 shows the projected average sea level rise of 4 feet or 1.2 meters by the end of the century, but that number is misleading for a number of reasons. Firstly, it is an average, which means it will be higher in some areas and lower in others. Second, this doesn't account for the natural fluctuation of tides and the effects of the moon. So what happens when there's a simultaneous high tide, full moon, and storm surge? That could be a number significantly greater than 4 feet for particular locations at particular times.

Regarding coastal flooding, many of the issues are the same as they are for storm surge that was discussed earlier in this text. The fact is that oftentimes major cities and prime agricultural areas have been developed around deltas and on floodplains because of the soil fertility, plentiful water, and ease of transport. So there are many agriculturally, economically, and ecologically important areas that are vulnerable.

Even though seas have risen modestly up to this point, to a marginal farmer in Bangladesh growing rice in a delta at the edge where freshwater meets salt water, 8 inches is a considerable amount. The problem is not just the fact of high tide waves overtopping levees and flooding rice paddies. It is the infiltration of salt water subsurface into the root zones of plants located on those edges[4].

4. Cornwall, Warren. "As sea levels rise, Bangladeshi islanders must decide between keeping the water

When we examine the maps that show both population density as well as elevation above sea level, the issue is clearly a global one, where there is overlap between high population density and low elevations. These are the areas of greatest impact and vulnerability to sea level rise.

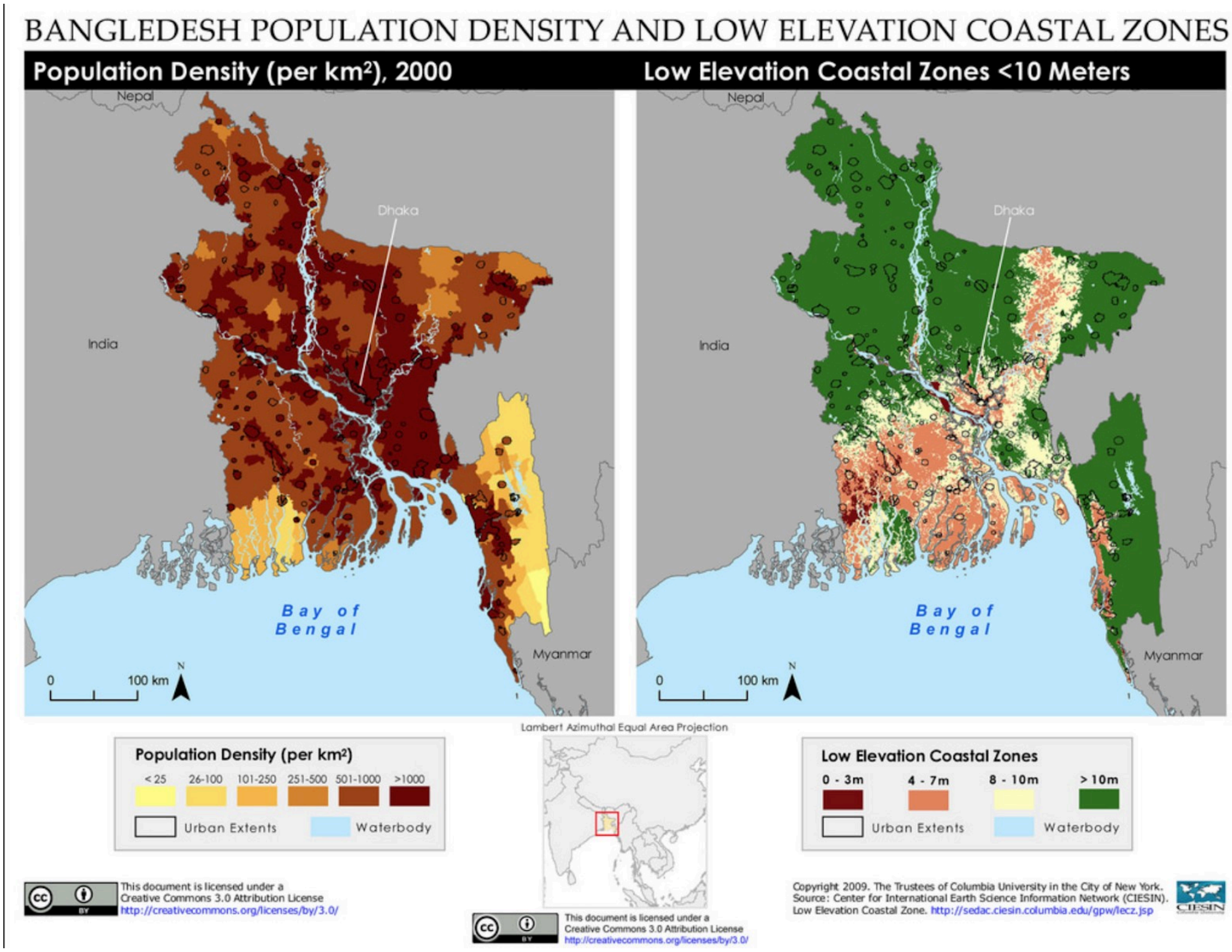

Figure 76: Bangledesh Population Density and Low Elevation Coastal Zones. Image by Center for International Earth Science Information Network.

out—or letting it in". Science. 1 Mar. 2018. Web. http://www.sciencemag.org/news/2018/03/sea-levels-rise-bangladeshi-islanders-must-decide-between-keeping-water-out-or-letting

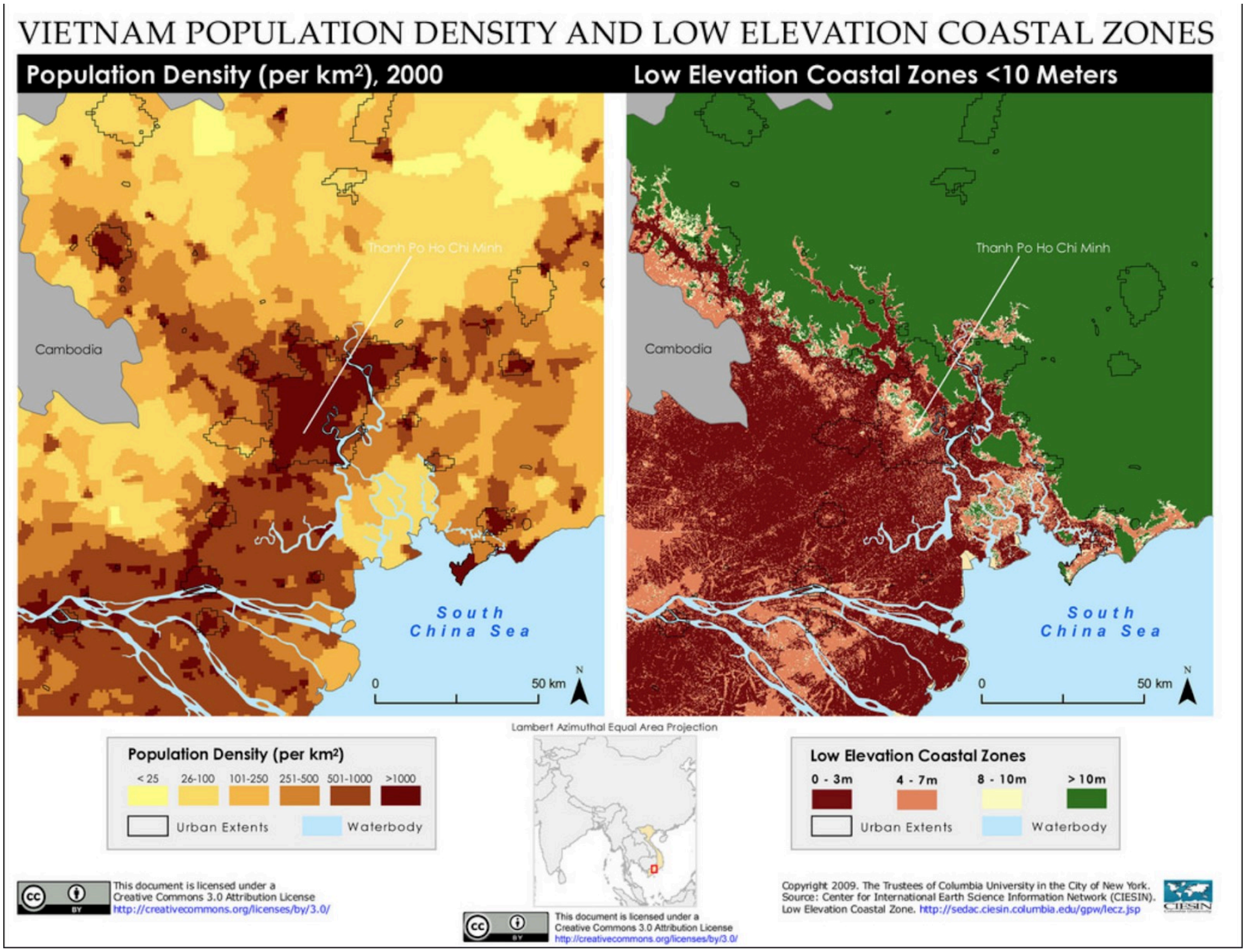

Figure 77: Vietnam Population Density and Low Elevation Coastal Zones. Image by Center for International Earth Science Information Network.

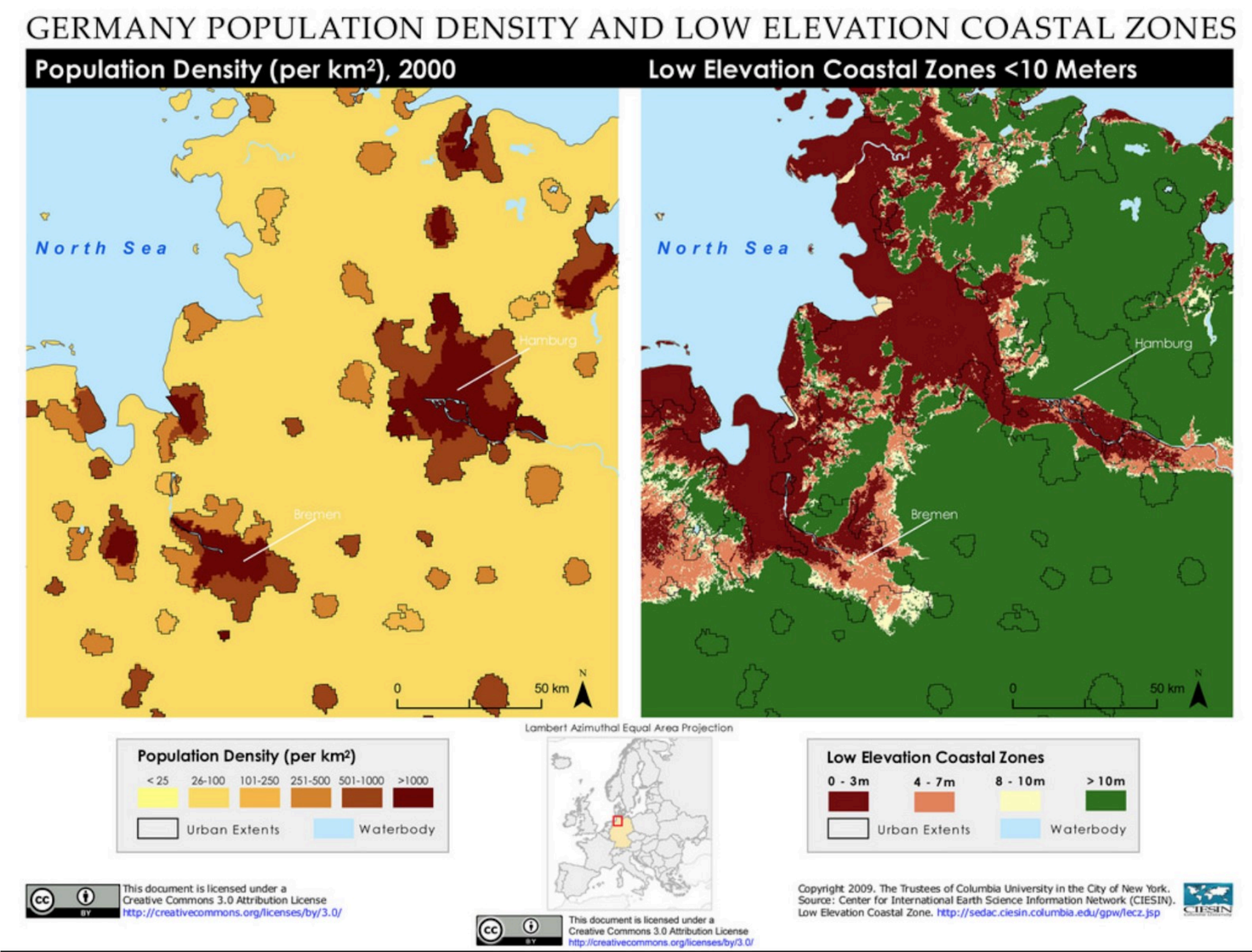

Figure 78: Germany Population Density and Low Elevation Coastal Zones. Image by Center for International Earth Science Information Network.

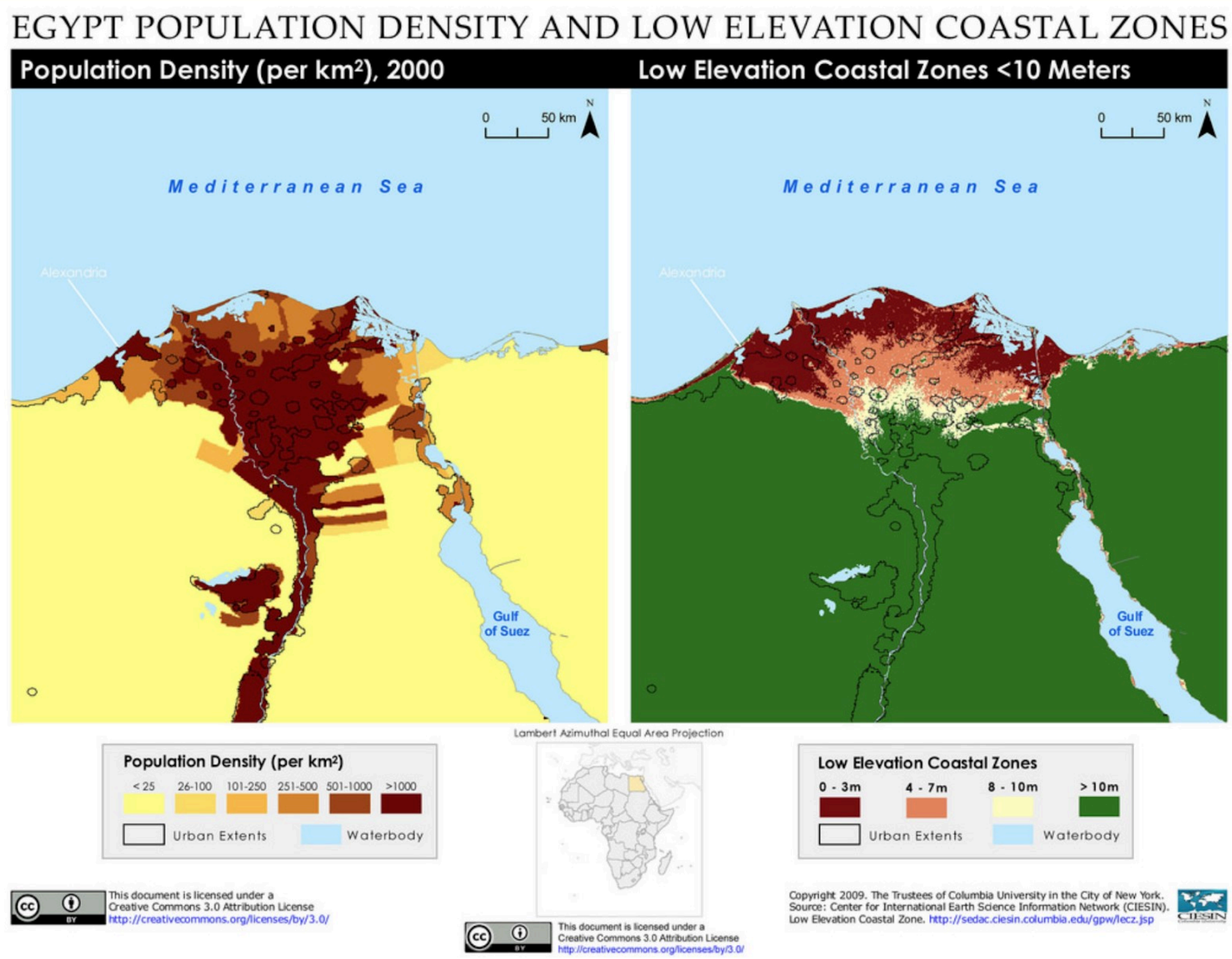

Figure 79: Egypt Population Density and Low Elevation Coastal Zones. Image by Center for International Earth Science Information Network.

Aside from the impacts on agriculture and housing, there are critical infrastructure elements often located at the water's edge. Wastewater treatment facilities are naturally located at the bottoms of watersheds where water can be collected by gravity, treated, and then discharged into a body of water. This makes these systems particularly vulnerable to sea level rise, as intrusion of saltwater into the biologically active treatment medium can undermine its functionality.

Figure 80: San Mateo wastewater treatment plant, San Francisco Bay, California, USA

Figure 81: San Francisco and Mel Leong wastewater treatment plants, San Francisco Bay, California, USA

Flooding

Previously in this text, we examined the effects of flooding around erratic rainfall events in dry climates and flood events caused by tropical cyclones. Heavy precipitation is increasing, and this increase is leading to greater and more frequent flood events than throughout previous history.

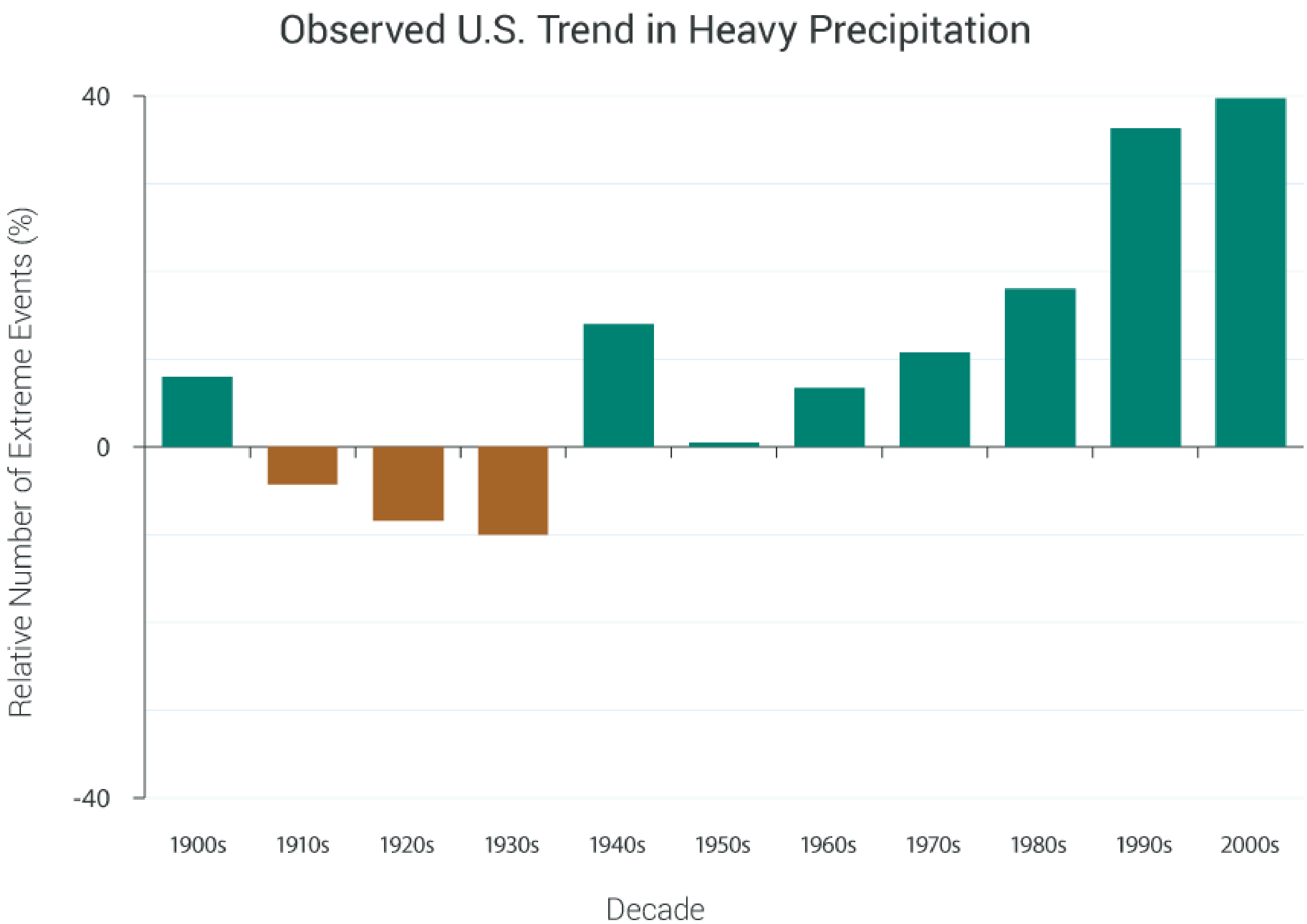

Figure 82: US Trend in Heavy Precipitation Graph. By National Climate Assessment

Flooding has the most profound effects on lowlands as the water moves down and concentrates in floodplains, so assessing the location of a site within 100 and 500 year floodplain maps will help to reveal the magnitude of the danger. When heavy rains fall on unstable slopes, landslides are also a risk. Talking to local elders about their recollection of historic flood events can also provide a vision of what to be prepared for.

Site Mitigation Plan

In this next section, the topics of the site mitigation plan, extreme event survival, and recovery are all wrapped into one. This is because sea level rise is less of a singular disaster event like a cyclone or wildfire to recover from. It is more of a permanently changing condition that can be temporarily designed for as sea levels rise to a particular elevation range. Adaptations may get successively swamped over time, leaving a permanent state of retreat and redesign in low lying coastal regions.

As a steward of land that is currently or will be affected by sea level rise or increased flooding, there are a number of coping strategies that can be employed to keep areas productive in the near term. As was stated previously, the seas will continue to rise and migration will be the eventual destiny of many people in low lying areas. But for now, adaptations to the gradual rise of waters can be made.

For some endeavors, simple adaptations can be made to vulnerable structures like these beehives on risers in Key West, Florida, USA built by Keez Beez, where high water can just pass right under the hives without incident.

Photo 45: Bee Hives on risers. By Keez Beez

Structures

In places throughout the world, the architecture is already suited to fluctuating water levels, and there are many examples of stilt houses that can be found in wet ecosystems throughout the planet. Often times it is poorer people who are forced to inhabit the tenuous margins.

Photo 46: Stilt house in Bangladesh. Image by Development Planning Unit University London CC BY 2.0

Photo 47: Stilt houses in Myanmar. Image by Justin Blethrow GNUFDL 1.2

Photo 48: Still houses in Switzerland.

Floating houses are also popular throughout the planet as well on the edges of water and land. The systems on a houseboat can be degenerative or regenerative, depending on the design. A former permaculture student of mine created an off the grid houseboat that he floated in the highly polluted Gowanus Canal in Brooklyn, New York, where he harvested rainwater, produced electricity, composted humanure and other wastes, and treated his wastewater on site using an miniature wetland system. He grew food on the decks and heated in winter with scrap wood collected in the city.

Photo 49: Floating houses on the Amazon River. Photo by Bruno Girin CC BY-SA 2.0

Photo 50: Houseboat in Southern India.

Photo 51: House boat in Victoria, British Columbia, Canada. Photo by Ian D. Keating CC BY 2.0

Agriculture

With saltwater intrusion into low lying agricultural fields, there are a couple of directions that are being worked on to maintain production in spite of brackish waters. One of the solutions put forth is to transition farmers from soil-based systems to aquaculture systems. This is happening in Asia, where many rice farmers are turning to shrimp production as salinity increases[5]. This has not necessarily been an ecologically beneficial endeavor, but with the application of permaculture design principles to the already transitioning populations from rice farming to brackish water aquaculture farming, there could be some creative solutions that are simultaneously beneficial ecologically, agriculturally, and economically for regions where traditional crops like rice are now becoming unfeasible.

Another potential is the development of salt-adapted varieties of crops, as well as breeding current saltwater plants to be more useful for humans. This work is happening, with one example currently going on in the Southern Indian state of Tamil Nadu at the M.S. Swaminathan Research Foundation. They currently have 350 halophytes (salt adapted species) that are candidates to be bred into crops in the future[6].

5. Nair, A. "Brackish Potential for a Shrimp Farming Surge in India". The Fish Site. 22 October 2017. Web. Mar. 2018 https://thefishsite.com/articles/untapped-brackish-water-sites-may-provoke-a-shrimp-farming-surge-in-india
6. Daigle, Katy. "Salt-tolerant Plants Eyed As Crops of the Future as Sea Level Rises." The Associated Press. 17 Aug. 2015. Canadian Broadcasting Corporation. Web. Mar. 2018 http://www.cbc.ca/news/technology/saltwater-plants-1.3193535

This brings up interesting questions about the potential of genetically modified crops to play a role. Normally from the permaculture perspective, genetically modified organisms are considered harmful to life. There are a lot of reasons for this belief, but one of the main ones is that the science is just not being used responsibly by corporations and is primarily a tool for greater profits. This has lead to some very unsavory GMO developments like terminator seeds that deny farmers the ability to save their own seeds, or species bred to use with a specific herbicide brand so the crop's planting is integrated with chemical use by its very nature.

But in a world where the development of salt resistant food crops using genetic modification could happen at the hands of non-profit entities who are pledged to work for the common good, then the development of food staples that can be grown in saltwater could enable people to stay on their lands instead of migrating away as fields become saline. Perhaps this can also be accomplished by conventional non-GMO breeding methods in the given time frame. As it stands now, seas are rising and a lot of people's livelihoods are becoming more and more marginal on the edge of fresh and saltwater. It's an important question to ponder.

In other flooding situations that don't include brackish water or just have seasonal intrusion of brackish water, there are other solutions. Changing elevations is a common practice in many permaculture designed systems, and there are many examples where wetland ecosystems have been made agriculturally productive, like the well known chinampa systems of Southern Mexico. Soil from the bottoms of marshes was piled onto floating rafts that were eventually rooted into placed and became a network of islands and peninsulas interspersed with canals. These systems have been in place in Mexico for nearly a millennium and have proven their ability to turn wetlands into productive agricultural areas.

Photo 52: Chinampa outside of Mexico City. Photo by Jflo23 GNUFDL 1.2

This same strategy can be applied in a less intensive way by small farmers seeking to get a head start in getting plants established in seasonally inundated fields. The pictures below show the adaptation strategies documented by the Development Research Services and Communication Centre in West Bengal, India. Plants are begun in bags, planted out on mounds, and then the bags can be breached to allow roots to enter the soil as the water level drops.

Photo 53: Photo by Ardhendusekhar Chatterjee

Photo 54 and 55: By Ardhendusekhar Chatterjee

Water supply

Groundwater salinity is another ill effect of rising seas and the infiltration of brackish water further inland. People who rely on wells, especially shallow wells, for their primary water supply may find that the aquifer has become polluted by salt water. This is an irreversible decline in water quality for people in coastal locations and other permanent sources need to be developed.

Rainwater collection and storage is the best solution in salt water environments, in order to intercept water before it makes contact with the salty ground level. Rainwater catchment systems take many forms, and many innovations have and are continually being made by people practicing permaculture and others.

In-ground storages are only feasible on high ground which is not subject to saltwater infiltration, so in most situations on wet lowlands, containerized water storage is necessary. In areas with high rainfall, a simple structure can provide water for domestic use as is seen below in this picture provided by the Development Research Services and Communication Centre in West Bengal, India.

Photo 56: Photo by Ardhendusekhar Chatterjee

It is beyond the scope of this book to outline the entire teachings on permaculture water systems, but there are many other design features that are commonly used in permaculture systems that can assist in making the most out of fresh water before it is mixed with brackish water. These include greywater systems, constructed wetlands, and clay pot irrigation to name a few.

Regional Scale Mitigation

This issue is too big to go through completely within the scope of this text, as there will need to be a restructuring of coastal-based civilization around the planet as waters rise through this century and beyond. About 1/10 of humanity lives in low lying coastal regions[7], so the scale of the restructuring as waters rise is overwhelming.

Some areas will be able to erect mega dikes and seawalls like was undertaken in Holland beginning in the 1300's. But those areas will be wealthier nations that can afford to undertake massive infrastructure projects. The energy intensity of projects of this scale makes them unaligned with the permaculture principle of "Use Small and Slow Solutions", but there may in the future be projects at scales like this that do utilize permaculture design methodologies.

7. Greenfieldboyce, Nell. "Study: 634 Million People at Risk from Rising Seas". National Public Radio. 28 Mar. 2007. Web. Mar. 2018 https://www.npr.org/templates/story/story.php?storyId=9162438

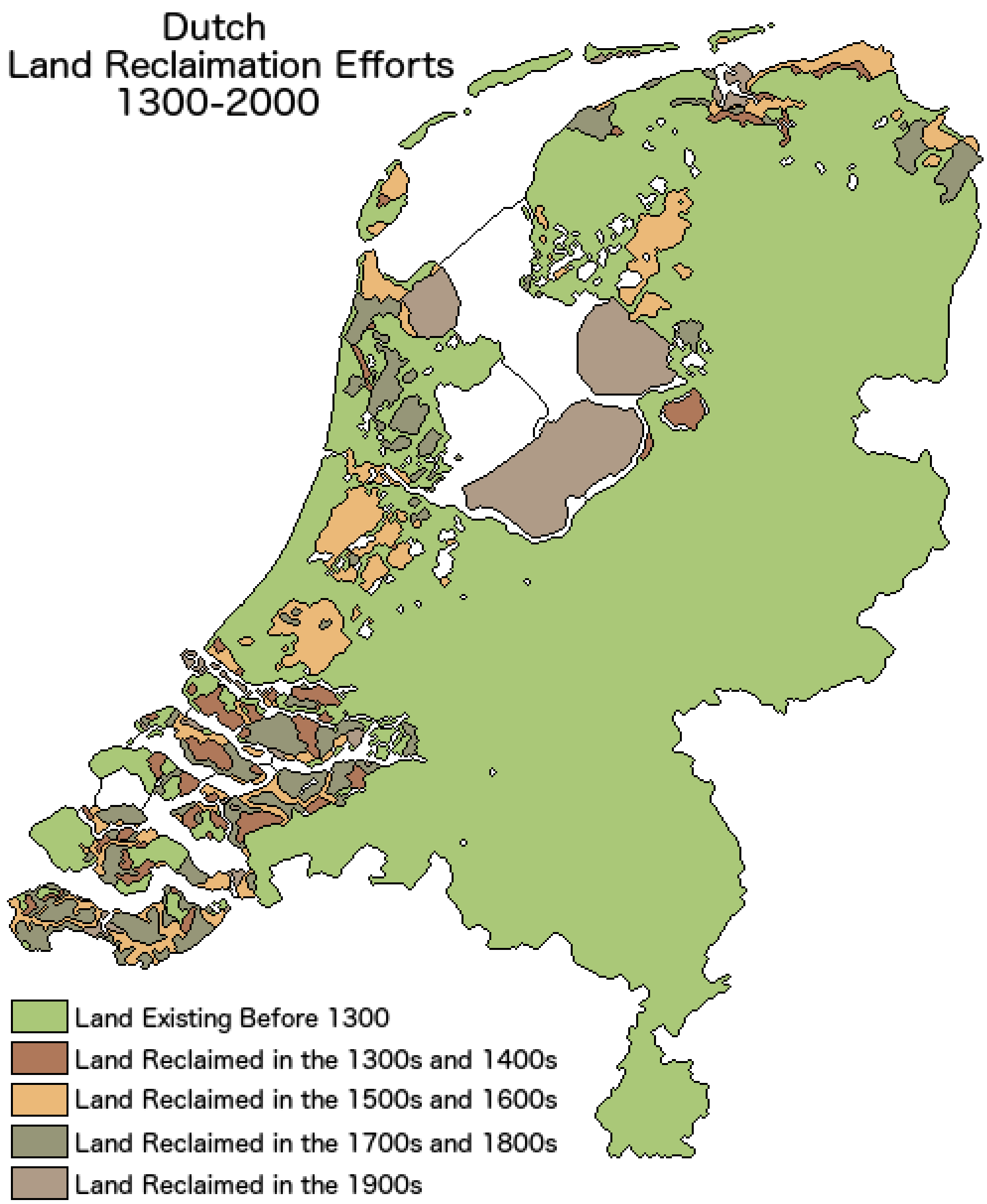

Figure 83: Land Reclamation Efforts in the Netherlands. Image by Theman77777

Aside from large scale infrastructure projects and mass relocation of populations, there are many small scale changes that can mitigate the issue in at risk regions. For example, if people are processing their wastewater in localized small scale systems, then that lessens the impact on centralized wastewater treatment plants located at shorelines. Many of the common permaculture practices already have positive downstream impacts because an aim in permaculture is to create site based systems and rely less on centralized power and water grids.

The most effective undertakings at the regional level at this point are planning and zoning regulations that take into account the inevitable sea level rise and increase in flood events. If governments could take this threat seriously and realize that sea level rise does not stop at the end of this century but keeps on rising throughout the remainder of the foreseeable human experience, then wise choices could be made about placement of elements within the landscape. This requires a full societal reckoning with the situation, and an intentional migration of infrastructure to higher elevation, with rules, regulations, and enforcement that reflect that.

Vision of future coastlines

It could be that all new strategies and patterns for human sustenance can be developed as the oceans rise and population pressure forces people to innovate in these environments. With a mixture of large scale infrastructure projects, stilted homes, raised islands, aquaculture, salt adapted crops, and the breeding of saltwater species into usable crops, people can continue to make use of the coastlines as they creep steadily higher up onto land.

This is not a bright future, as coastal populations all over the planet cope with their particular dynamics and ecosystems change and impact countless species, but there will be room for innovation and creative adaptation within it all, and that's the aspect where the permaculture design system places its focus. Climate resilience means seeing the changes coming, and planning resilient systems that can cope and even thrive within the changes.

Appendix A: Climate Analogue Report

Please place photo and reference links in the text of responses. Erase highlighted text once you have filled out document

1) Info

Name:

Current Site Location:

2) Koppen-Geiger Climate Classification

What is the 3 letter Koppen-Geiger code and what do the letters represent?

Current Site:

3) Latitude

What is the latitude, either North or South, of your design site?

Current Site:

4) Potential Climate Analogue:

List general region, and then 3+ potential analogue locations and their latitudes

General Region:

3 Potential Towns or Cities: We choose towns because there is climate data

5) Koppen-Trewartha Climate Classification:

What is the 2 letter Koppen-Trewartha code and what do the letters represent? Cross-reference the Koppen-Trewartha classification map to see if there is any difference between your site and its potential analogues.

6) Analogue Site for more research:

7) Proximity to Coast or Large Water Body

How far, in miles or kilometers, is your site to the nearest ocean, sea, or large inland lake? Which direction is the body of water, North, South, East or West?

Current Site:

Analogue Site:

8) Elevation

What is the elevation, in feet or meters, of your design site and potential analogue site? Please place any photo or reference links in the text of your responses.

Current Site:

Analogue Site:

9) Precipitation Quantity

What is the average annual precipitation, in inches or millimeters?

Current Site:

Analogue Site:

10) Precipitation Seasonality

When during the seasons of the year does precipitation typically arrive?

Current Site:

Analogue Site:

11) Thornthwaite Climate Classification

What is the Thornthwaite climate classification, which is based on precipitation and evaporation rates?

Current Site:

Analogue Site:

12) Global Air Circulation and Storm Tracks

Are there particular air circulation patterns that affect the timing and qualities of precipitation, winds and storm events? (i.e. monsoon, seasonal hurricanes, oceanic jet stream etc.)

Current Site:

Analogue Site:

13) Ocean Currents

Are there particular ocean currents that affect temperature and seasonal weather events? (i.e. North Atlantic Gulf Stream bringing warm water North or California Current bringing cold water South etc.)

Current Site:

Analogue Site:

14) Topographic Features

Are there mountain ranges in the vicinity of the area? What are they called and what are their elevations in feet or meters?

Current Site:

Analogue Site:

15) Landscape Positioning

If there are topographic features present, what is the proximity of the site and directional relationship to them (North, South, East or West)?

Current Site:

Analogue Site:

16) Temperature

What is the yearly average temperature of the site in degrees Celsius or Fahrenheit? What is the average temperature during the hottest and coldest months?

Current Site:

Analogue Site:

17) Plant Hardiness Zone

What is the plant hardiness zone of the site in degrees Celsius or Fahrenheit? This has to do with the average yearly extreme low temperature.

Current Site:

Analogue Site:

18) Soil Types

Do the sites have the same global soil region? If not, what are the regions found for both sites?

Current Site:

Analogue Site:

19) Crops

What are the main crops grown in the region?

Current Site:

Analogue Site:

20) Building Materials and Methods

Current Site:

Analogue Site:

21) Narrative Summary

In your words, what are the main similarities and differences between the two analog climates, and any other observations you want to make about your findings? Please place any photo or reference links in the text of your responses.

Similarities:

Differences:

Further observations:

Areas for further research:

Appendix B: Climate Change Analogue Report

Please paste photo and reference links in the text of your responses.

1) Info

Name:

Current Site Location:

2) Koppen-Geiger Climate Forecast

3 letter code and classification name

Current Day:

Projected climate 2076-2100:

3) Regional Climate Forecasts

with information sourced:

3+ region-specific climate change forecasts:

4) Assess climate data for classification position

Increase or decrease in temperature and precipitation that's needed to shift region to a different climate classification based on regional forecasts:

5) New climate classification

Choose a climate change analogue classification based on climate change forecasts and climate data assessment. It may be that there is not a different climate class to choose from if you are already located in the hottest climate type Bwh (Hot desert) for example. In that case, provide projected temperature and precipitation changes within that climate type.

Projected climate classification for region by the last quarter of this century:

6) Finding the analogue location

Would searching a different latitude be appropriate and why or why not?

Would searching a different elevation be appropriate and why or why not?

Would searching for an area that has the same landscape positioning be appropriate and why or why not?

7) Potential analogue locations

Find at least 3 potential climate change analogue locations, and provide their NAME, ELEVATION, ANNUAL RAINFALL, & AVERAGE ANNUAL TEMPERATURE

Site 1

Site 2

Site 3

8) Climate change analogue site

You will now choose a likely site to examine further

Climate change analogue site location:

Thornthwaite climate classification comparison:

Proximity to water; ocean or continental comparison:

Precipitation seasonality comparison:

Global air circulation and storm track comparison:

Nearby ocean currents comparison (if applicable):

Topographic features and landscape positioning comparison:

Plant hardiness zones comparison:

Global soil regions comparison:

9) Narrative summary

Most positive aspects of analogue choice:

Most questionable elements of analogue choice:

Lessons learned from analogue:

Areas of further research:

Appendix C: Koppen Geiger Classification Descriptions

Group A: Tropical (megathermal) climates [1]

This type of climate has an average temperature of 18 °C (64.4 °F) or higher every month of the year, with significant precipitation.

- Af = Tropical rainforest climate; average precipitation of at least 60 mm (2.4 in) in every month.
- Am = Tropical monsoon climate; driest month (which nearly always occurs at or soon after the "winter" solstice for that side of the equator) with precipitation less than 60 mm (2.4 in), but more than 4% the total annual precipitation.
- Aw or As = Tropical wet and dry or savanna climate; with the driest month having precipitation less than 60 mm (2.4 in) and less than 4% of the total annual precipitation.

Group B: Dry (arid and semiarid) climates

This type of climate is defined by little precipitation.

Multiply the average annual temperature in Celsius by 20, then add

(a) 280 if 70% or more of the total precipitation is in the spring and summer months (April–September in the Northern Hemisphere, or October–March in the Southern), or

(b) 140 if 30%–70% of the total precipitation is received during the spring and summer, or

(c) 0 if less than 30% of the total precipitation is received during the spring and summer.

If the annual precipitation (in millimeters) is less than 50% of this threshold, the classification is BW (arid: desert climate); if it is in the range of 50%–100% of the threshold, the classification is BS (semi-arid: steppe climate).

A third letter can be included to indicate temperature. Originally, h signified low-latitude climate (average annual temperature above 18 °C (64.4 °F)) while k signified middle-latitude climate (average annual temperature below 18 °C), but the more common practice today, especially in the United States, is to use h to mean the coldest month has an average temperature above 0 °C (32 °F), with k denoting that at least one month's averages below 0 °C.

- BWh = Hot desert climate
- BWk = Cold desert climate

1. https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification

- BWn = Mild desert climate
- BSh = Hot semi-arid climate
- BSk = Cold semi-arid climate
- BSn = Mild semi-arid climate

Group C: Temperate (mesothermal) climates

This type of climate has the coldest month averaging between 0 °C (32 °F) and 18 °C (64.4 °F) and at least one month averaging above 10 °C (50 °F).

- Cfa = Humid subtropical climate; coldest month averaging above 0 °C (32 °F) and at least one month's average temperature above 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons . No dry months in the summer (neither abovementioned set of conditions fulfilled).
- Cfb = Temperate oceanic climate; coldest month averaging above 0 °C (32 °F), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).
- Cfc = Subpolar oceanic climate; coldest month averaging above 0 °C (32 °F) and 1–3 months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).
- Cwa = Monsoon-influenced humid subtropical climate; coldest month averaging above 0 °C (32 °F) and at least one month's average temperature above 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation is received in the warmest six months).
- Cwb = Subtropical highland climate or temperate oceanic climate with dry winters; coldest month averaging above 0 °C (32 °F), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation received in the warmest six months).
- Cwc = Cold subtropical highland climate or subpolar oceanic climate with dry winters; coldest month averaging above 0 °C (32 °F) and 1–3 months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation is received in the warmest six months).
- Csa = Hot-summer Mediterranean climate; coldest month averaging above 0 °C (32 °F) and at least one month's average temperature above 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).
- Csb = Warm-summer Mediterranean climate; coldest month averaging above 0 °C (32 °F), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F).

At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).

- Csc = Cool-summer Mediterranean climate; coldest month averaging above 0 °C (32 °F) and 1–3 months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).

Group D: Continental (microthermal) climates

This type of climate has at least one month averaging below 0 °C (32 °F) and at least one month averaging above 10 °C (50 °F).

- Dfa = Hot-summer humid continental climate; coldest month averaging below 0 °C (32 °F) and at least one month's average temperature above 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).
- Dfb = Warm-summer humid continental climate; coldest month averaging below 0 °C (32 °F), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).
- Dfc = Subarctic climate; coldest month averaging below 0 °C (32 °F) and 1–3 months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).
- Dfd = Extremely cold subarctic climate; coldest month averaging below −38 °C (−36.4 °F) and 1–3 months averaging above 10 °C (50 °F). No significant precipitation difference between seasons (neither abovementioned set of conditions fulfilled).
- Dwa = Monsoon-influenced hot-summer humid continental climate; coldest month averaging below 0 °C (32 °F) and at least one month's average temperature above 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation is received in the warmest six months).
- Dwb = Monsoon-influenced warm-summer humid continental climate; coldest month averaging below 0 °C (32 °F), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation is received in the warmest six months).
- Dwc = Monsoon-influenced subarctic climate; coldest month averaging below 0 °C (32 °F) and 1–3 months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation is received in the warmest six months).
- Dwd = Monsoon-influenced extremely cold subarctic climate; coldest month averaging below −38 °C

(−36.4 °F) and 1–3 months averaging above 10 °C (50 °F). At least ten times as much rain in the wettest month of summer as in the driest month of winter (an alternative definition is 70% or more of average annual precipitation is received in the warmest six months).

- Dsa = Hot, dry-summer continental climate; coldest month averaging below 0 °C (32 °F) and at least one month's average temperature above 22 °C (71.6 °F) and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).
- Dsb = Warm, dry-summer continental climate; coldest month averaging below 0 °C (32 °F), all months with average temperatures below 22 °C (71.6 °F), and at least four months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).
- Dsc = dry-summer subarctic climate; coldest month averaging below 0 °C (32 °F) and 1–3 months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).
- Dsd = Extremely cold, dry-summer subarctic climate; coldest month averaging below −38 °C (−36.4 °F) and 1–3 months averaging above 10 °C (50 °F). At least three times as much precipitation in the wettest month of winter as in the driest month of summer, and driest month of summer receives less than 30 mm (1.2 in).

Group E: Polar and alpine (montane) climates

This type of climate has every month of the year with an average temperature below 10 °C (50 °F).

- ET = Mild tundra climate; all 12 months of the year with average temperatures between 0 °C (32 °F) and 10 °C (50 °F).
- ETf = Cold tundra climate; at least one month with an average temperature below 0 °C (32 °F).
- EF = Ice cap climate; eternal winter, with all 12 months of the year with average temperatures below 0 °C (32 °F).

Appendix D: Koppen-Trewartha Climate Classification Descriptions

Group A: Tropical climates[edit]

This the tropical climate realm, defined the same as in Köppen's scheme (i.e., all 12 months average 18 °C, 64 °F, or above). The "A" climates are the realm of the winterless frost-free zone.

Climates with no more than two dry months (defined as having less than 60 mm, 2.4 inches, average precipitation, same as per Köppen) are classified Ar, while others are classified Aw if the dry season is at the time of low sun/short days or As if the dry season is at the time of high sun/long days. There was no specific monsoon climate identifier in the original scheme, but Am was added later, with the same parameters as Köppen's (except that at least three months, rather than one, must have less than 60 mm average precipitation).

Group B: Dry (arid and semi-arid) climates[edit]

BW and BS mean the same as in the Köppen scheme, with the Köppen BWn climate sometimes being designated BM (the M standing for "marine"). However, a different formula is used to quantify the aridity threshold: 10(T − 10) + 3P, with T equaling the mean annual temperature in degrees Celsius and P denoting the percentage of total precipitation (in millimeters) received in the six high-sun months (April through September in the Northern Hemisphere and October through March in the Southern).[5]

If the precipitation for a given location is less than the above formula, its climate is said to be that of a desert (BW); if it is equal to or greater than the above formula but less than twice that amount, the climate is classified as steppe (BS); and if the precipitation is more than double the value of the formula the climate is not in Group B. Unlike in Köppen's scheme, no thermal subsets exist within this group in Trewartha's, unless the Universal Thermal Scale (see below) is used.

Group C: Subtropical climates[edit]

In the Trewartha scheme the "C" climate group encompasses Subtropical climates that have 8 or more months with a mean temperature of 10 °C (50 °F) or higher.

There are only two types within the "C" or subtropical climate group: Cs which is a dry -summer or Mediterranean climate, and a Cf or humid Subtropical climate. Cw types occur within the Cf group and mean subtropical Monsoon climates (like much of east Asia).

For Subtropical climates, a third letter is often used (a or b) to denote a hot or cool summer. "Cfa" is where the warmest month has a mean temperature of 22.2 °C (72.0 °F) or higher, and “Cfb” is used where the warmest month of summer is below 22.2 °C.

Group D: Temperate and continental climates[edit]

In the Trewartha scheme the “D” climate group encompasses Temperate climates that have 4 to 7 months with a mean temperature of 10 °C (50 °F) or higher.

“D” climate groups have two types – a Oceanic type (Do), where the coldest month has a mean temperature 0 °C (32 °F) or higher, and a Continental type (Dc), where the coldest monthly mean temperature reaches below 0 °C in some interior landmasses like North America and Asia.

For the continental climates (Dc), sometimes the third letter (a or b) is used to denote a hot or cold summer. “Dca” is where the warmest month has a mean temperature of 22.2 °C (72.0 °F) or higher, and “Dcb” is used for cool summer temperate climates, where the warmest month has a mean temperature below 22.2 °C.

Group E: Boreal climates[edit]

This represents subarctic and subpolar oceanic climate realms, defined the same as in Köppen’s scheme, where 1 to 3 months have an average temperature of 10 °C (50 °F) or above. In this climate zone there is only a short period (normally 50 to 90 days) that is frost free. In the original scheme, this group was not further divided; later, the designations Eo and Ec were created, with Eo (maritime subarctic) signifying that the coldest month averages above −10 °C (14 °F), while Ec (continental subarctic or “boreal”) means that at least one month has an average temperature of −10 °C or below. As in Group D, a third letter can be added to indicate seasonality of precipitation. There is no separate counterpart to the Köppen Dfd and Dwd climate types in Trewartha’s scheme, but a letter can optionally be added to the end of the symbol to indicate the temperature of the coldest month (see below).

Group F: Polar climates[edit]

This is the polar climate group, where all months must have a monthly mean air temperature of below 10°C/50 F. Polar climates have two subtypes Ft (tundra) and Fi (ice cap):

In the “Ft” climate type, at least one month has an average temperature above 0 °C or 32 °F (but not above 10 °C), so that there is a brief time when the surface might be free of snow or ice and a scrub or Tundra vegetation cover is possible.

In the “Fi” climate type, all months have an average temperature below 0 °C, this is the region of the vast deserts of perpetually frozen Ocean in the North Pole and the permanent ice plateaus of Antarctica and Greenland.

Group H: Highland climates[edit]

Highland climates are those in which altitude plays a role in determining climate classification.[6] Specifically, this would apply if correcting the average temperature of each month to a sea-level value using the formula of adding 5.6 °C (10.1 °F) for each 1,000 meters (3,300 ft) of elevation would result in the climate fitting into a different thermal group than that into which the actual monthly temperatures place it.

Sometimes G is used instead of H if the above is true and the altitude is between 500 and 2,500 meters (1,600 and 8,200 ft), but the G or H is placed in front of the applicable thermal letter rather than replacing it. The second letter used reflects the corrected monthly temperatures, not the actual monthly temperatures. G stands for glacier for instances.

Appendix E: Koppen-Geiger Climate Shift Maps

Citation found here: http://koeppen-geiger.vu-wien.ac.at/pdf/Paper_2010.pdf

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F. Rubel & M. Kottek: Observed and projected climate shifts 1901–2100

Meteorol. Z., 19, 2010

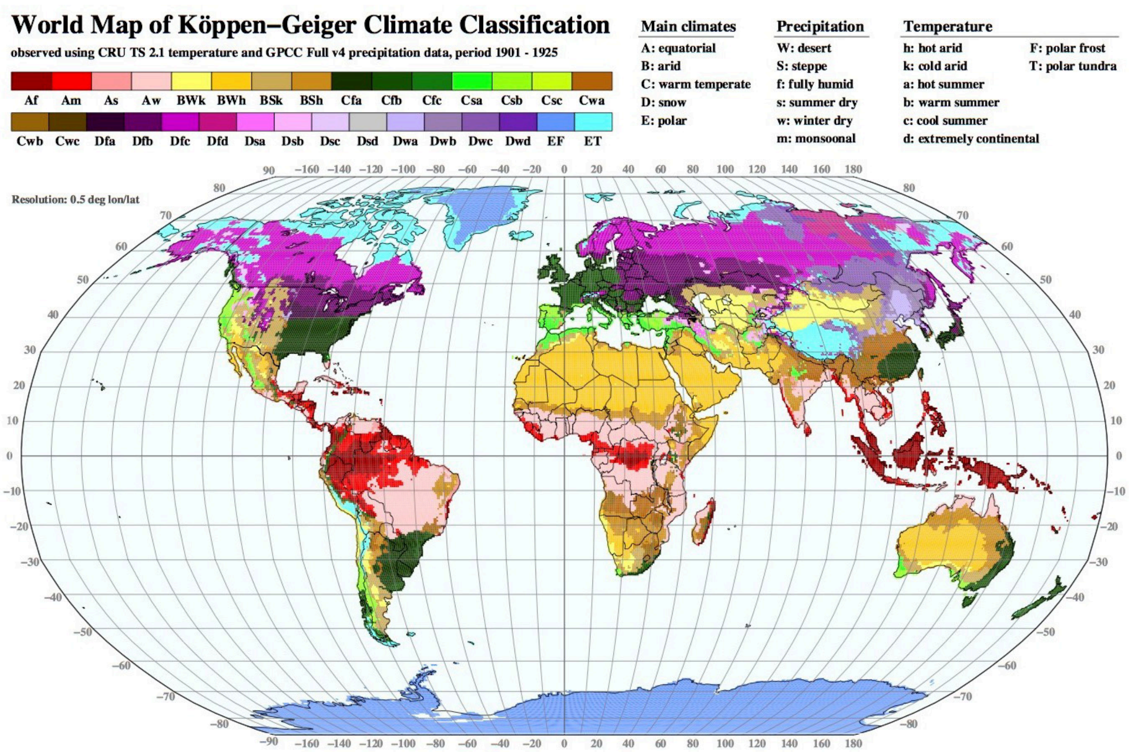

Figure 1: World Map of Köppen-Geiger climate classification calculated from observed temperature and precipitation data for the period 1901–1925 on a regular 0.5 degree latitude/longitude grid.

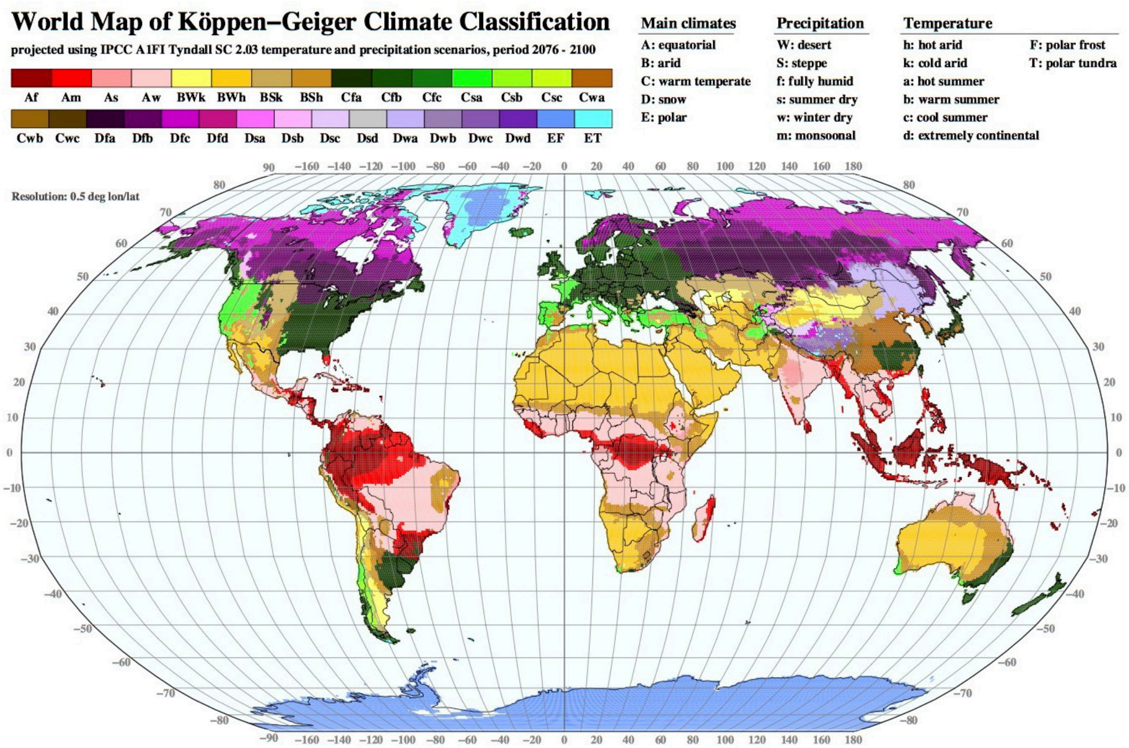

Figure 2: World Map of Köppen-Geiger climate classification projected with Tyndall temperature and precipitation data for the period 2076–2100, A1FI emission scenario, on a regular 0.5 degree latitude/longitude grid.

Appendix F: Resources for predictions and climate models

Koppen climate shift maps:
http://koeppen-geiger.vu-wien.ac.at/pdf/Paper_2010.pdf
The Intergovernmental panel on climate change information at the global to regional scale:
www.ipcc.ch/report/ar5/
The Northwest Climate Toolbox provides very accessible climate data for our region:
climatetoolbox.org/
An example of the work OCCRI does:
climatecirculatororg.wordpress.com/2016/04...roject/ (inactive link as of 05/12/2021)
National Climate Assessment:
nca2014.globalchange.gov/highlights/o...iew/overview (inactive link as of 05/17/2021)
China Trewartha Climate Change Projections:
https://www.researchgate.net/publication/225999545_Use_of_the_Koppen-Trewartha_climate_classification_to_evaluate_climatic_refugia_in_statistically_derived_ecoregions_for_the_People%27s_Republic_of_China/figures?lo=1
Differences Between Plant Hardiness Map from 1990-2015:
https://www.arborday.org/media/map_change.cfm
Global Climate Change Impacts in the United States:
https://nca2009.globalchange.gov/index.html
Animation of USDA Hardiness Zone Changes:
https://www.arborday.org/media/mapchanges.cfm
Animated Map of Future Migrations with Climate Change:
https://www.seeker.com/animated-map-shows-future-migrations-as-earth-warms-1993517197.html?utm_content=Animated+Map+Shows+Future+Migrations+as+Earth+Warms&utm_source=facebook&utm_medium=social-media
Animated Map of What Earth Would Look Like if the Ice Melted:
http://www.businessinsider.com/what-earth-would-look-like-if-ice-melted-world-map-animation-2017-4
What the World will Look like 4 degrees C Hotter:
http://bigthink.com/strange-maps/what-the-world-will-look-like-4degc-warmer
Climate Change and the Path Ahead Podcast:
http://www.thepermaculturepodcast.com/2017/1716/
Australia Climate Change Analog Explorer:
https://ccafs.cgiar.org/tool-climate-analogue-tool#.WXrUXBPyv6d
Climate Change Analogs – Finding Tomorrow's Agriculture Today:
http://www.riesgoycambioclimatico.org/biblioteca/archivos/DC1144.pdf (inactive link as of 05/12/2021)
Using Climate Analogs for Assessing Economic Impacts in Urban Areas:
http://www2.centre-cired.fr/IMG/pdf/PSICC_Partner19_qua.pdf

European Climate Change Prediction:

http://prudence.dmi.dk/

IPCC Climate Change Predictions:

https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html (inactive link as of 05/12/2021)

Climate Wizard Climate Change Prediction Interactive Map:

http://www.climatewizard.org/ (inactive link as of 05/12/2021)

Climate Change Analog Slide Show:

https://www.slideshare.net/cgiarclimate/climate-analogues-introduction

Interactive Map: Koppen Geiger Observed and Predicted Climate Shifts:

https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=7a53584fa55643df969f93cec83788e1

Climate Analogs for Agricultural Impact Projection and Adaptation:

http://journal.frontiersin.org/article/10.3389/fenvs.2015.00065/full

World Agroforestry Center Climate Change Analogs:

http://www.worldagroforestry.org/icraf-subject/climate-analogues

Mapping the Potential Economic Effects of Climate Change:

http://www.npr.org/sections/thetwo-way/2017/06/29/534896130/mapping-the-potential-economic-effects-of-climate-change

Climate Change Impacts on the Pacific Northwest, USA:

http://cliffmass.blogspot.com/2017/07/monday-july-10-2017-new-study-suggests.html

Third Oregon Climate Assessment Report:

http://www.occri.net/publications-and-reports/third-oregon-climate-assessment-report-2017/

Exploring The Impact of Climate Change on the Outbreak of Early 21st Century Violence in the Middle East and North Africa and the Potential of Permaculture as an Effective Adaptation: http://journals.ametsoc.org/doi/abs/10.1175/WCAS-D-16-0130.1

Climate Change in India: Environmental Analysis:

http://blogs.nelson.wisc.edu/es112-311-3/2014/04/29/climate-change/

Climate Change and India:

https://www.slideshare.net/wgpkumar/climate-change-and-india

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- (Full last name, first initial of first name). (Date of publication). Title of source. Title of container (larger whole that the source is in, i.e. a chapter in a book), volume number, page numbers.

Examples

If retrieving from a webpage:

- *Berndt, T. J. (2002). Friendship quality and social development.* Retrieved from insert link.

If retrieving from a book:

- Berndt, T. J. (2002). Friendship quality and social development. *Current Directions in Psychological Science*, 11, 7-10.

MLA outline:
Author (last, first name). Title of source. Title of container (larger whole that the source is in, i.e. a chapter in a book), Other contributors, Version, Number, Publisher, Publication Date, Location (page numbers).

Examples

- Bagchi, Alaknanda. "Conflicting Nationalisms: The Voice of the Subaltern in Mahasweta Devi's Bashai Tudu." *Tulsa Studies in Women's Literature*, vol. 15, no. 1, 1996, pp. 41-50.
- Said, Edward W. *Culture and Imperialism.* Knopf, 1994.

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- Lastname, Firstname. “Title of Web Page.” Name of Website. Publishing organization, publication or revision date if available. Access date if no other date is available. URL .

Source from print:

- Last name, First name. *Title of Book*. Place of publication: Publisher, Year of publication.

Examples

- Davidson, Donald, *Essays on Actions and Events.* Oxford: Clarendon, 2001. https://bibliotecamathom.files.wordpress.com/2012/10/essays-on-actions-and-events.pdf.
- Kerouac, Jack. *The Dharma Bums.* New York: Viking Press, 1958.

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0.1	MM/DD/YYYY		
0.11	08/24/2020	Links to external sources updated	All
0.12	05/17/2021	Links to external sources updated	All