Quantifying Changes in Monarch Butterfly Habitat in California

by

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To my family

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List of Abbreviations

ARD	Analysis Ready Data
CDL	Cropland Data Layer
COMTRS	County Meridian Township Range Section
DEM	Digital Elevation Model
DPR	Department of Pesticide Regulation (State of California)
GDD	Growing Degree Days
GIS	Geographic Information Science
GM	Genetically Modified
GLM	Generalized Linear Models
HSM	Habitat Suitability Modeling
ID	Identification
MBBR	Monarch Butterfly Biosphere Reserve
MLMP	Monarch Larva Monitoring Project
MRLCC	Multi-Resolution Land Characteristics Consortium
NCDC	National Climatic Data Center
NDVI	Normalized Difference Vegetation Index
NLCD	National Land Cover Database

PCA	Principal Component Analysis
PLSS	Public Land Survey System
PUR	Pesticide Use Report
UC IPM	University of California Integrated Pest Management
USDA	United States Department of Agriculture
USGS	United States Geological Society
WMTC	Western Monarch Thanksgiving Count

Abstract

Western Monarch butterflies in North America have seen a steep population decline from 1990 to 2019 due to climate change and land cover changes in their overwintering sites as well as the decline of milkweed plants in the breeding grounds due to pesticide glyphosate application. Since 1990, North American monarch populations have declined by 68 percent overall, and western monarchs have seen nearly a 90 percent decline, reducing the population of monarch butterfly from more than one billion count of butterflies to less than two hundred million population size (CBD 2018). This project quantified land use land cover changes from 1990-2015 in Monterey county to identify possible impacts to Monarch butterfly habitat. The land cover and land use change were analyzed using Landsat ARD imagery from 1994, 1998, 2002, 2006, 2014 and 2018, using the NDVI (Normalized Difference Vegetation Index) differencing method. The NDVI images for each year were classified into 5 categories based on the spectral index. The results indicate changes in the land use land cover, however, there was not significant change in any class. Additionally, this project analyzed the application of the herbicide glyphosate and weather changes for 1990 – 2015. The weather data analysis did not show any inclement weather which might be unsuitable for monarch winter survival and the pesticide use report showed that grapes and uncultivated agricultural land used high amount of the herbicide glyphosate each year. The application increased between 1996 and 2000, and again it is increasing from 2004 as some of the crop types are using more herbicide. The crucial outcome of this study indicated that the monarch population count increased when there was reduction in pesticide use the previous year and vise-versa, and increase in moderate and healthy vegetation. This might indicate the milkweed might have been abundant during the spring and

summer migration for the monarchs to thrive. Thus, study indicate use of pesticide glyphosate affects the monarch butterfly population, whereas, the other factors such as land cover change, and weather is not affecting western monarch population.

Chapter 1 Introduction

The North American monarch butterflies are a migratory species which travel between winter sites in Coastal California and forests in Central Mexico every winter. These winter habitats have optimum conditions for the monarchs to survive the cold months, which are warmer and moderate, unlike the weather conditions in the rest of continental US. Monarchs prefer warmer weather conditions as they remain in a diapause state (where their reproduction cycle is in a suspended state) till the end of winter and the start of spring season. Monarchs begin their migration in coastal California and the forests of Central Mexico and travel north to the southern Canadian border during spring and summer (Fig 1). During their spring and summer

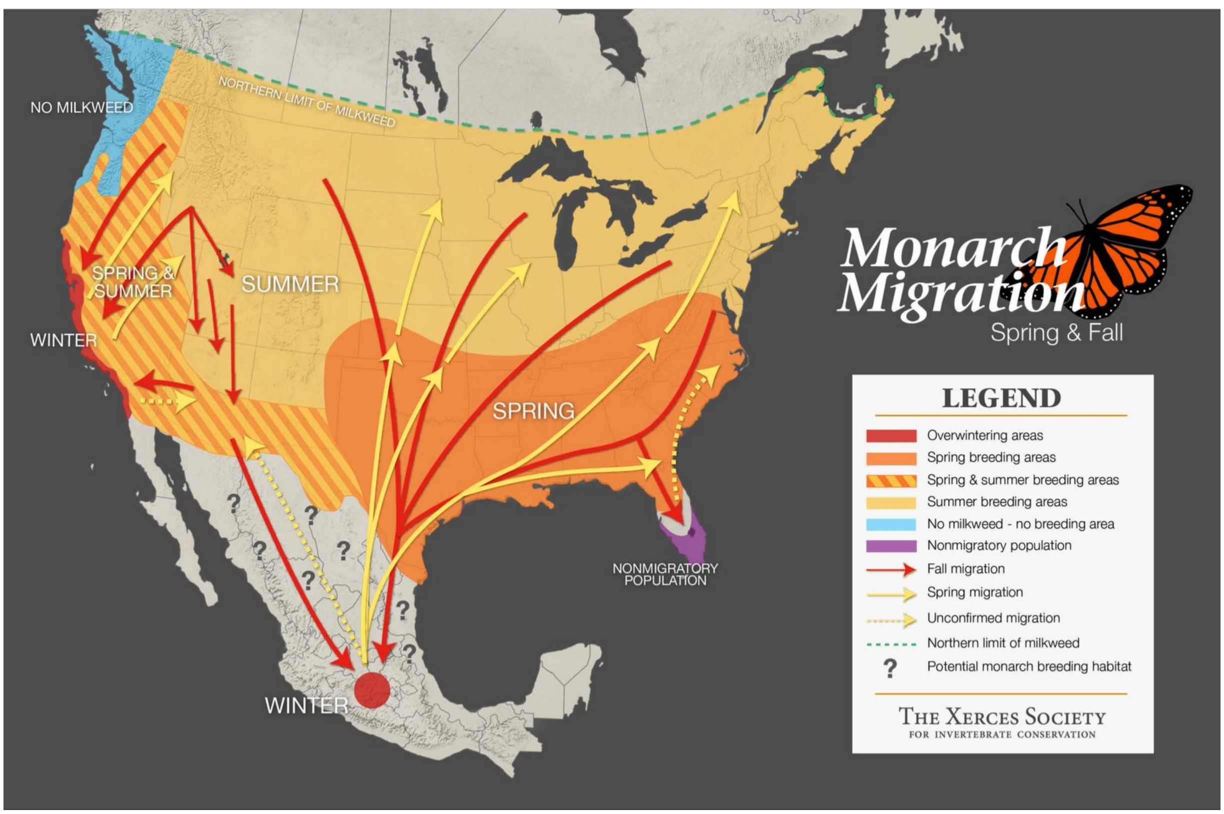


Figure 1: Migration patterns and over wintering sites. *Image source: The Xerces Society*

migration, they come out of the diapause state and start their reproductive cycle. During this time, they use milkweed plants for food and to lay their eggs. For all reproduction stages (egg, larva, pupa, and adult) milkweed is the host plant. Since 1990, the monarch population has declined by more than 80 percent. Habitat degradation and loss in wintering sites, unusual weather changes, and the decline of milkweed plants due to use of herbicide glyphosate in spring-summer habitats have led to the species' decline.

This project aimed to quantify land cover changes in the winter habitat in the Central coast of California from 1990 to 2018, specifically Monterey County. This study site was selected because, the county coastline has significant number of over wintering sites, in open spaces, close to the urban areas, and sites with proximity to agricultural areas. Monterey County alone has 15 active monarch butterflies overwintering approximately (as not all 15 sites see overwintering butterflies each year). The land use land cover changes in and around the winter sites, changes in the weather patterns, and the application of the herbicide glyphosate use from 1990 to 2018 were analyzed using Landsat imagery (ARD 1994, 1998, 2002, 2006, 2010, 2014 and 2018) NDVI image differencing method, weather data, and PUR reports.

1.1 North American Monarch Butterfly

Monarch butterflies (*Danaus plexippus*) migrate to overwintering sites in Central Mexico and coastal California and roost in large clusters on host trees during winter (Griffiths and Villablanca 2015). There are two distinct populations separated by geography. Monarchs west of the Rocky Mountains migrate to the California coast during their fall migration and spend winter months in Monterey pine and Eucalyptus groves. Monarchs east of the Rocky Mountains travel during fall to spend the winter months in the Oyamel fir forests of Central Mexico. This winter sites were discovered by Dr. Fred Urquhart (Urquhart and Urquhart 1976).

The fall migration starts from late September and they reach and roost in the winter sites in coastal California and Central Mexico by November. During fall they enter reproductive diapause state (Anderson and Brower 1996) and remain in this state for six to seven months. For the population to grow, adult butterflies must survive through the winter. Inclement weather conditions during winter can be catastrophic to these insects and have direct impacts on their population size.

The abundance of host trees in coastal California and Central Mexico provide cover to survive the cold of winter. The dense canopy of the host tree clusters in overwintering sites provides protection from temperature fluctuations and rain, and thus, helps to conserve their lipid storage (The fat energy reserve stored in their body from feeding on the nectar during migration), and diapause state (Stenoien et al. 2018). The wet conditions during winter rain can lead to freezing of the monarchs and can cause mortality as the water particles on these insects tend to freeze them at just above freezing winter temperatures and forces the monarchs to burn their energy reserves fast (Calvert et al. 1983; Anderson and Brower 1996). Therefore, dense tree canopy and clusters provide shelter from rain and wind. This in-turn helps to conserve their lipid storage as they rarely fly to find nectars during winters.

Monarch butterflies of both east and west of the Rockies start their migration during spring from their overwintering sites and travel north towards the Southern Canadian border. In spring, they begin their reproduction cycle and lay eggs on milkweed plants. The adult butterflies and larva feed on the nectar and leaves of these plants (Malcolm et al. 1993). The availability of milkweed plants during spring and summer is critical, as monarch butterflies lay eggs and feed only on these plants. Weather changes in the spring and summer breeding grounds can affect the plant phenology and thus change monarch migration patterns.

1.2 Western Monarch butterfly

The California coast hosts approximately 400 wintering sites for the western monarch butterfly. Since 1990, there has been significant land cover changes in the winter sites in California and in the overwintering sites in Mexico (Frey et al. 1992; Anderson and Brower 1996; Brower et al. 2016). The transformations are due to anthropogenic activities, and logging of tree clusters. Land cover changes in winter sites in Mexico have been the subject of many studies over the last 40 years, and it has been observed that the reduction in tree canopy cover and below freezing temperatures, and precipitation can have a catastrophic effect on the monarch survival in Mexico (Calvert et al. 1983). However, the changes in the overwintering habitat in California has not been extensively studied. Since the early 1990's the population of the western monarch have been declining rapidly. Therefore, it is important to analyze changes over the last two decades in the winter habitat of the western monarch butterflies.

The State of California also provides spring summer breeding habitat for the western monarch population. During breeding season, monarchs depend on milkweed plants for survival (Fig 2). The larva feeds on the milkweed leaves and enter pupal state on these plants. Therefore, an abundance of milkweed plant is crucial to the monarch's lifecycle. Milkweed plants are often found in the cropland areas, open areas, and right of ways (Hartzler and Buhler 2000; Hartzler 2010; Wyrill and Burnside 1977; Pleasants and Oberhauser 2013).

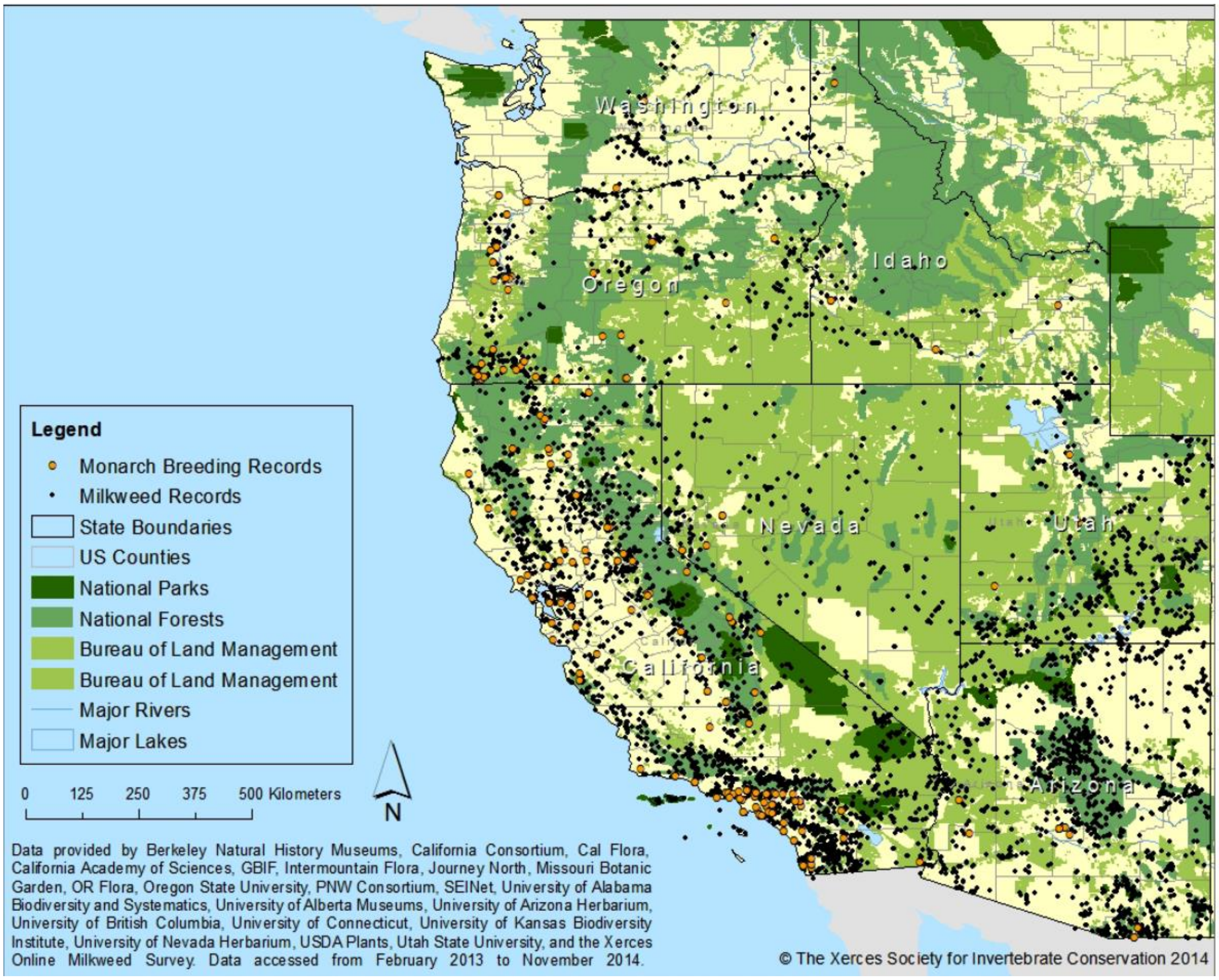


Figure 2: Monarch Breeding and Milkweed Records of the Western Region

Since 1990, increase application of the herbicide glyphosate in the cropland areas have been a major cause of the decline of milkweed plants (Wyrill and Burnside 1977; Pleasants and Oberhauser 2013; Pocius et al. 2017). According to the California Department of Food and Agriculture, one-third of the country’s vegetables and two-thirds of country’s fruit and nut are grown in California (California Agricultural Production Statistics 2018) . Application of certain herbicide glyphosate can kill all vegetation in the applied area, and is used where genetically modified herbicide-resistant crops are cultivated. The herbicide application kills the unwanted plants in the croplands. Pesticide and herbicide application are a common practice on agricultural lands, potentially causing a decline in milkweed and thus affecting monarch survival (Wyrill and Burnside 1977; Pleasants and Oberhauser 2013; Pocius et al. 2017).

1.3 Research Aim

This project aimed to quantify changes in land use and cover in the western monarch butterfly winter habitat. Monterey county (Fig. 3) in California was selected as the study area. Monterey county has 15 active overwintering sites out of the 400 known sites of the western monarch butterflies. The county also has significant agricultural lands where herbicide glyphosate is used on various crops each year. Monarch butterflies depend on the milkweed plant for survival and these plants are known to be in agricultural areas, open areas and right of ways. Increasing use of glyphosate is known to be causing decline in milkweed plants (Pleasants and Oberhauser, 2013).

This project addressed the following spatial and temporal questions:

- What are the changes in land use in the habitat area? Can this change be correlated with the change in monarch count?
- Which sections of the county are using glyphosate and how much is the pesticide use? What is the trend at the county and section? (The county is subdivided and are categorized into Meridian, Township, Range, and Section (MTRS). Section being the small geographical area level)
- Are the locations of glyphosate application correlated spatially with the winter count of monarchs

1.4 Study Area

Monarch butterflies arrive at overwintering sites in early November. The Monterey pine, Eucalyptus, and Monterey cypress trees remain their home for the duration of winter. These groves are located along the coast and at low elevation (Fig 3). Densely clustered trees provide protection from wind, temperature fluctuations, precipitation, and direct sunlight. Throughout the winter they move amongst trees within the cluster to find cover from wind and direct sunlight. These sites act as micro-habitats. Due to their proximity to the ocean, these groves are susceptible to change in wind direction and temperature change.

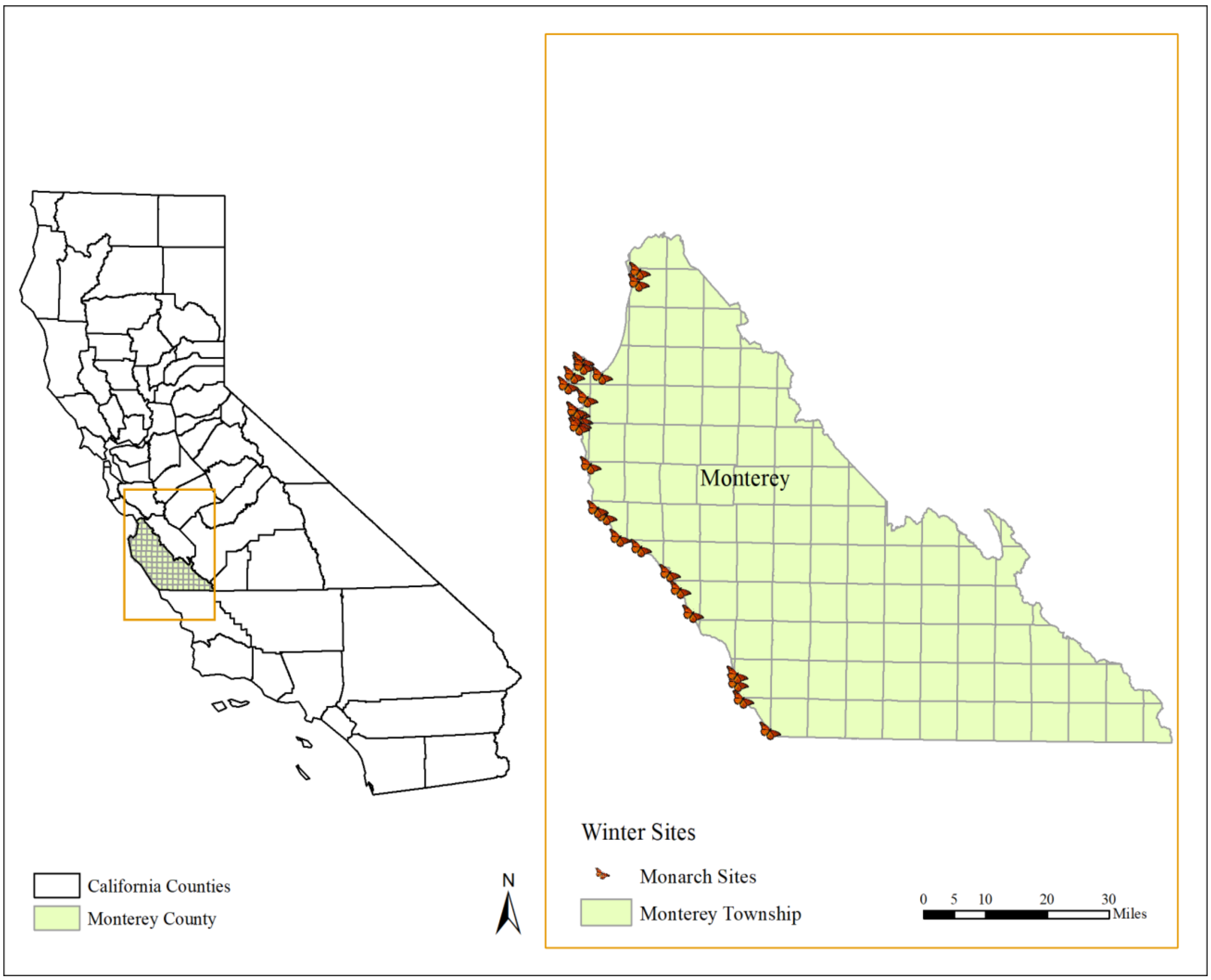


Figure 3: Study area Monterey County at township level and Monarch winter sites

California has a spring and summer migration path as well as breeding grounds. During the start of spring migration, monarchs search for milkweed plants to feed on the leaves and nectar. The state of California has the highest agricultural production in the US and depends heavily on the use of herbicides and pesticides. Milkweed in the agricultural areas is declining due to herbicide use (Stenoien, et al. 2018). Application of herbicide in cropland areas is attributed to a major decline in the monarch butterfly population (Thogmartin 2017; Zipkin et al. 2012). For this project, application of herbicide glyphosate in the Monterey county from 1991 to 2015 showed, an average of 98,696 pounds of glyphosate usage with a minimum amount of 53,121 pounds used in 1995 and maximum of 161,587 pounds used in 2000. There has been a steady increase in herbicide usage from 2003. Grapes (for wine and fruit consumption), and uncultivated agricultural lands in the county used high amount of glyphosate every year.

Another factor affecting monarch populations are changes in the land use (Thogmartin et al. 2017). California, and Monterey County in particular, is witnessing land cover changes due to urbanization and wildfires. The land cover land change analyses in this project used NDVI differencing method to quantify the land use change. The changes due to wildfire has not been included in this study.

Extensive studies have been conducted on the eastern monarch population and their migration. Their winter, spring, and summer migration habitat have been studied through statistical and spatiotemporal analyses. Research and volunteer projects such as. Journey North and Monarch Joint Venture are some the ongoing citizen participation projects. Through this project citizen volunteers register their monarch sighting with spatiotemporal data. They tag the butterflies to track the migratory path of eastern monarch butterflies.

In the west, Xerces Society conducts annual count of overwintering butterflies along the California coast during Thanksgiving. From the literature review and search for related journal shows, there are limited spatial analysis studies on the western monarchs and its habitat changes. This is the biggest motivation for this project.

1.5 Previous Studies and Gaps

Western Monarch butterflies in California have been subject to few studies, insofar as there has been little study of landcover cover change in the western monarch habitat. Some of the gaps are listed in a report to the Commission for Environmental Cooperation 2009 (Davis et al. 2009). Per the report, there has been extensive loss of winter habitats in California with a decline from 1990 to 1998. The habitat loss is due to tree loss, due to senescence or diseases, and urban infrastructure development and other related human interference (Meade 1999, Leong et al. 2004) The eastern monarch population is monitored during winter, spring migration and breeding season via citizen science project. Annual fourth of July count are conducted in the monitoring sites, where volunteers gather egg, larva, pupal, and adult butterfly count. In addition, land use land cover change, pesticide application affects have been studied as well (Zipkin et al. 2012; Pleasants and Oberhauser 2013; Batalden, Oberhauser, and Peterson 2007; Vidal, López-García, and Rendón-Salinas 2014). Whereas, the western monarch population during spring and migration is not monitored.

The first sighting of western monarch butterflies during the spring season is an indication of their migration towards the Rocky Mountains. This journey is usually not well documented, during spring and summer, and the population is not counted or surveyed, creating a void in the migration data.

Much of the study of eastern monarch migration tags the butterfly, which documents the location where the individual was found, indicating their migration path and route. Similar documentation of the western monarch spring migration has not been conducted. Thanksgiving count every year of the overwintering butterflies during the week of Thanksgiving is the only record which provides information about the western population. This creates a huge gap in the data. Spring, summer and fall migration data collection and documentation would help understand the impact of land use and climatic changes on monarch populations and habitat.

Since spring and summer migration and population data is not readily available, changes in monarch breeding habitat cannot be considered for this project. Therefore, the primary aim of this project is to quantify changes in the winter habitats. Temperature datasets, herbicide application timeline for overwinter sites, and breeding time were used as major data sets. The data sets for this project were identified and collected based on studies conducted on eastern and western monarch habitats. The next chapter on related work explains the studies and observations made in the monarch winter and summer habitat, weather changes and, herbicide application trend in both eastern and western monarch habitats

Chapter 2 Related Work

North American butterfly is known for its annual migration. During fall, they travel from South of Canadian border to coast of California and forests in Central Mexico to the overwinter sites, where they spend the winter months in the dense tree clusters (Brower et al. 2017; Brower et al. 2002; Oberhauser et al. 2017). They start their migration up north every spring and start their reproduction cycle by laying eggs on the milkweed plant. These host plants are crucial as monarchs feed and lay eggs only on native milkweeds. Monarch life span during spring and summer is around 2-6 weeks. It is the third or fourth generation which reach the south of Canadian border by the end of spring summer migration. The generation of monarchs which travel to over wintering sites in California and Mexico may survive up-to 6-9months (Oberhauser 2004).

The multi-generation migration during spring-summer, and single generation fall migration and overwintering survival is affected by its surrounding environmental changes in terms of land use and weather changes (Brower et al. 2002; Pelton and Jepsen 2019; Espeset et al. 2016).

The decline in the western monarch butterfly population is alarming (Dingle et al. 2005; Pelton and Jepsen 2019). In 2018, only 28,429 butterflies were counted from 213 active sites along the California Coast, (Xerces Society 2018). That is 85.2 % decline from the previous year 2017 and a 99.4 % decline since the 1980. Similar trend in monarch population has been observed in the Monterey county, only 4000 butterflies were reported in 2018 in comparison with the 2017 count of 35000 (Fig 4). The US Fish and Wildlife service states that the decline in monarch population is due to loss of habitat for breeding, migration, and overwintering.

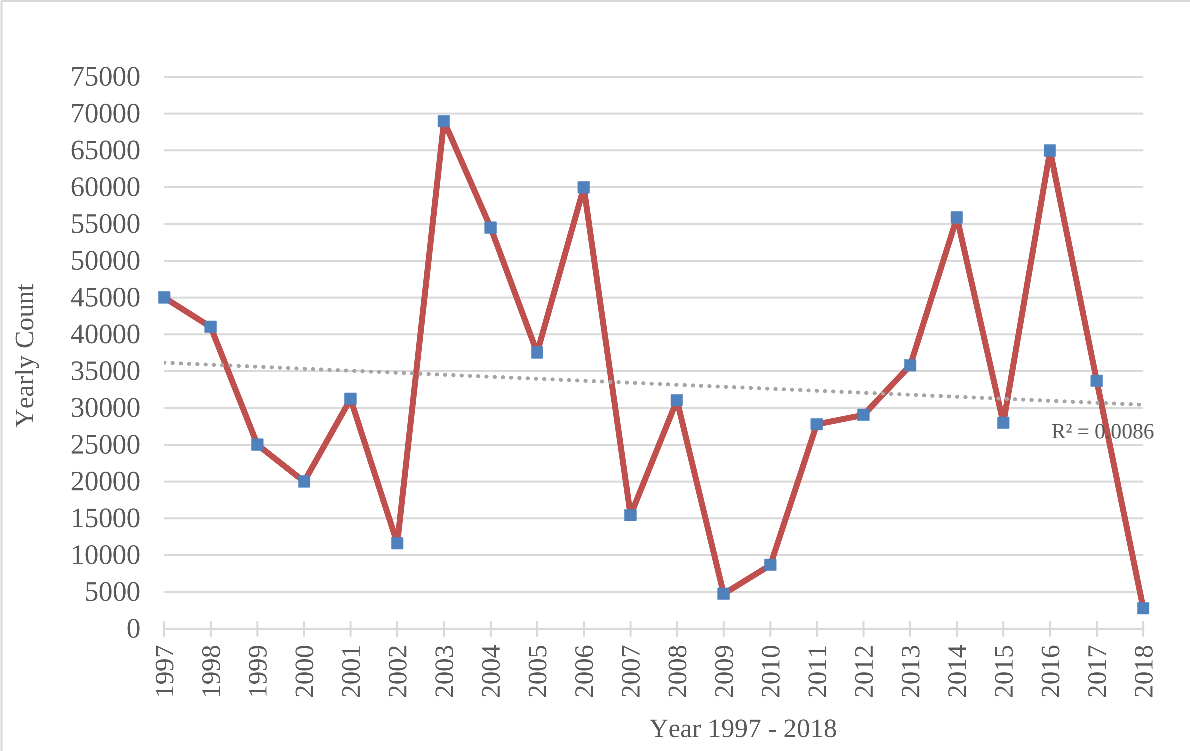


Figure 4: Monarch Yearly Count, Monterey County. *Source: Thanksgiving Count Xerces Society*

Monarchs are sensitive species, they need ambient weather conditions throughout winter to survive. Changes in the habitat can affect the micro climate of the winter sites and can have a direct effect on their winter survival. Thinning of tree clusters, can expose them to wind and direct sunlight in winter. The inclement weather with precipitation and below freezing temperature in winter habitat in Mexico in 2002 killed close to half a billion of monarchs (Brower et.al 2002).

The decline in milkweed plants in spring summer habitat can affect their breeding cycle and survival. Various study of the eastern monarch has observed and identified the changes in winter and summer habitat and leading causes for such changes. In this chapter, all the previous change observation of eastern monarch habitat has been extracted and the methodologies have been documented.

2.1 Land use land cover changes

2.1.1. Overwintering sites

Eastern monarch butterfly roost on Oyamel fir trees in the forests of Central Mexico. Oyamel fir forests create a microclimate suitable for monarchs to survive the winter. The thick tree canopy protects monarchs from extreme winter temperature and precipitation, acting as a blanket (Anderson and Brower 1996). The Oyamel trunks help regulate the temperature of the monarchs when they are roosting on the trees. Degradation of these forests makes the monarchs vulnerable to change in weather conditions and can lead to mass mortality during a winter storm or due to temperature change (Brower 2002).

All overwintering sites in central Mexico were declared protected areas by the Mexican federal government in 1980 (DOF 1980), established as a special conservation zones in 1986 (DOF 1986), and the government further expanded the protected area in 2000 (DOF 2000) (Stenoien et al. 2018). Though these overwintering sites were declared protected areas, deforestation and illegal logging have been reported and land cover changes have occurred (Brower et al. 2002). In this analysis, stereo imagery of 42,020 ha area taken in 1971, 9184, 1999 were analyzed using GRASS and GIS. Based on the imagery, forest cover was qualified into 3 categories: conserved, semi-altered, and altered. From 1971to 1999, 44% of the forest area was estimated to be degraded and fragmented, and the largest patch of the high-quality forest was reduced from 27,115 ha to 527 ha, that means the high-quality forest cover is reduced to 21%. From 1984 to 1999, some of the protected forest areas were degraded and fragmented at an annual rate of 3% or more, in comparison to 1% from 1971 to 1984, indicating 31% reduction in high quality forest in central Mexico. In this study, a subset area of 6596 ha inside the area decreed as protected in 1986 was also conducted and showed 38% degradation. The study indicates at this rate less than 10,000 ha of high-quality forest will remain in 20 years. Thick forest covers and tree canopy provides shelter from rain and freezing temperature. As the winter progresses, the monarchs shift to downward slope, therefore any fragmentation of forests makes the monarchs vulnerable to survive.

Between 2001 and 2012, Vidal et al. (2013) conducted a GIS analysis examine trends in deforestation and forest degradation of Monarch biosphere in Mexico using aerial and satellite imagery and field surveys. They conducted a biennial analysis of aerial and satellite imagery to determine changes in land cover due to large-scale illegal logging. To determine small-scale logging and changes, 2001 image was compared with 2012 imagery. The 2007 SPOT multispectral and panchromatic imagery were compared with 2005 and 2009 images. In addition to satellite imagery, every year aerial imagery was acquired to determine the changes in land cover. Results show 2179 ha forest in core zones were affected between 2001 to 2012. 1254 ha were deforested, and 925 ha were degraded. Illegal logging persisted even after these forest areas were declared as protected area. The study indicates though Monarch Butterfly Biosphere Reserve was a protected area and there has been a decrease in large scale illegal logging since 2012, small scale logging has been clearing patches of crucial land and canopy inside the Reserve could affect the future monarch population. Such GIS analysis is essential to monitor the deforestation trend and visual maps aid the authorities in decision making.

Spatial modeling using GIS have been used to analyze the distribution pattern of overwintering monarch butterflies. The area covering the maximum overwintering habitat was delineated by Bojorquez et al. (2003). In this analysis, digital map layers, 149 overwintering colonies, boundaries of 12 sanctuaries, DEM, landform, vegetation, and land use layers were used to create a database. The Landsat TM was used to quantify land cover and vegetation data.

Weather and meteorological datasets were used to ascertain precipitation, the sun's relative position to analyze potential solar irradiation. Using GRASS, two spatial analysis approaches were used to map potential overwintering habitat, which were: habitat suitability evaluation, and logistic model using georeferenced records of overwintering colonies and GIS database. The analysis results were used by 20 experts to generate potential overwintering habitat maps for monarch butterfly biosphere reserve based on biological requirements of the butterfly. The georeferenced records of the colonies revealed majority of the sites were at higher elevation (2890 m and 91% sites), with low aridity, also with south -southwest aspect, with short distance from streams, and on moderately steep slope. Multicriteria potential habitat analysis and experts' opinion were thus combined to identify potential habitat areas to refine Monarch Butterfly Biosphere Reserve

Landcover change from illegal logging and deforestation have been observed in the overwintering sites in Mexico since 1977. However, the rapid decline in monarch population has happened since 1990 (Stenoien et al. 2018). Land cover changes due to wildfires near the monarch overwintering habitats have been observed (Vidal and Salinas 2014; Brower et al. 2017). Persistent drought conditions, low humidity, and high temperatures have resulted in wildfires close to the overwintering sites in coastal California. Landcover change and quantification for the western monarch butterfly habitat has not been analyzed. In this thesis project land cover change due to drought could be seen in NDVI image difference analysis results.

Quantifying the forest cover loss and land cover changes has been subjected to many studies. Research indicates that there is ongoing illegal logging in the monarch winter habitat in Mexico. The historical data from 1977 indicates that monarch form colonies at Sierra Chincua arroyos in November and move to downslope areas by March as the winter progresses. The downslope areas are where the logging have taken place. Scientists believe logging affect the monarch remigration pattern with an assumption that monarchs might start their migration early. Satellite imagery of Sierra Chincua before logging activity in 2013 was compared with 2015 imagery after logging. Recent study shows illegal logging of approximately 10 ha of forest in Monarch butterfly biosphere reserve in 2015 (Brower et al. 2016). The satellite imagery of Sierra Chincua before logging activity in 2013 were compared with 2015 imagery after logging. The historical data from 1977 indicate that monarch form colonies at Sierra Chincua arroyos in November and move to downslope areas by March as the winter progresses. The downslope areas are where the logging have taken place. Scientists believe logging affect the monarch remigration pattern with an assumption that monarchs might start their migration early.

In addition to habitat change analysis, monarch abundance has been measured in Mexico since the 1994-1995 overwintering season and has been ongoing each year (World Wildlife Fund). Areas occupied by the monarchs are combined and measured yearly. Western monarch abundance in overwintering sites in California are measured through volunteer participation annually during Thanksgiving under the supervision of Xerces Society. Since monarch roost in small groves at each location, the actual count of monarch butterflies is recorded. The average area occupied by monarchs until 2011 were 7.24 ha (average), with maximum of 20.97 ha during 1996-1997 and a low of 1.92 ha during 2009-2010 (Brower et al. 2012). Western monarch abundance in the overwintering sites in California are measured through Volunteer participation during Thanksgiving every year under the supervision of Xerces Society.

Deforestation due illegal logging is limited in the country and there are no reports of illegal logging in the western monarch overwintering habitat. Deforestation leads to habitat degradation and loss. However, other changes in land cover and land use can also lead to habitat loss and degradation. Urban development, alterations of host tree cluster, tree trimming etc., have all been observed near many of the winter sites in California (Pelton and Jespen 2019). Some of the changes observed by Xerces Society were tree trimming, changes in tree cluster due to fallen trees from disease and improper logging. Such change in the winter habitat is considered as land cover change, as most of the winter sites are cluster of trees of the size 10 m^2 (approximately).

2.1.2. Spring and summer migration habitat

Land use land cover changes during the spring and summer migration of eastern monarchs have been analyzed at multiple geographical regions and multi-temporal scales. Studies of eastern monarch spring and summer migration habitat in the mid-west indicate the loss of milkweed due to climate change, and due to use of glyphosate herbicide in agricultural and open-lands (Pleasants and Oberhauser 2012; Pleasants 2015). Changing weather conditions and frequent droughts, and their impact on have been affecting spring migrant butterfly breeding cycle and reduce nectar availability for fall migrant butterfly (Pleasants and Oberhauser 2012; Brower et al. 2006).

The stable hydrogen and carbon isotope ratios from 597 wintering monarchs from 13 wintering sites in Mexico were compared with the isotropic patterns measured from butterflies at breeding sites over a migration cycle (Wassenaar and Hobson 1998). The study indicated that monarchs at the over wintering sites in Mexico originated from the Midwest, in the United States. 50% of the monarchs studied in the winter sites indicated that their origin was from the breeding areas of Kansas, Nebraska, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and

Ohio. These are the geographical areas where corn and soybean are produced extensively, and the possibility of milkweed abundance in these areas.

Milkweed habitat is primarily found in the agricultural areas, roadsides and in the open areas. Milkweeds are also found in the urban landscape. Studies indicate loss of milkweed between 1999 and 2009, which corresponds to the time period when use of herbicide glyphosate increased and increase in herbicide resistant corn and soybean production (Hartzler and Buhler 2000; Hartzler 2010; Oberhauser et al. 2001; Oberhauser et al. 2012). Oberhauser et al. (2012) observed that monarchs foraged on milkweed found in corn and soybean fields. Land use changes in agricultural areas is due to the use of herbicide-resistant corn and soybean crops. The agricultural and nonagricultural area were mapped through citizen-science project and milkweed data collected over a period of few years were analyzed to estimate the habitat loss. This study was conducted from 1999 to 2010 and subsequent results showed an 81% decline in agricultural milkweeds due to increased use of herbicide-resistant corn and soybean and glyphosate herbicide application, and a 31% decline in nonagricultural milkweeds.

California has the highest agricultural production in terms of food related crops, accounting to 13 percent of the nation’s total agricultural value (California Agriculture Statistics Review, 2018). The leading commodities include livestock (dairy), grapes, almonds, berries, and other nuts and vegetables. Production of corn and soybean grown in California is very low in comparison with Iowa and other Mid-western States. Grapes and uncultivated agricultural areas were found to use high amount of glyphosate in California, and particularly in Monterey county, study area for this project. The use of herbicide glyphosate is increasing steadily since 1996, in the Monterey county. However, there is no data to understand the changes in milkweed abundance due to increase in glyphosate use.

Land use and land cover change due to development, wildfires, and drought are other contributing factors responsible for western monarch decline. Recent data on western monarchs indicate that after breaking up from the overwintering sites in spring, the monarchs travel only shorter distance (According to USDA and Monarch Joint Venture 30-100 miles in a day). There is no determined direction or path monarchs fly through. Once on their migration path, the monarch butterflies lay their eggs on emerging milkweed. In a study conducted by Dingle et al. (2005) used monarch data collections from museums and databases which stored monarch's sighting site's geography and topology. DEMs, temperature, and a GIS layer of river locations were used to analyze the spatial movement of the western monarch. The results indicate an eastward and northward migration pattern, and monthly plots of data collection also show monarch sightings in central and inland California from April to October, which indicates the study area of Monterey county is also in spring-summer migration path of the monarchs travelling from southern California coast and Mexico The study indicated that milkweed plants are abundant in central and inland areas and analysis of land use and land cover change in these areas are crucial for the conservation of host plant species.

2.2 Weather changes

Monarch butterflies are sensitive to weather and climatic changes. Above normal temperature in winter can affect their lipid storage and diapause state which are crucial for winter survival (Stenoien et al. 2018). Monarchs have a narrow micro-climate range to survive in the winter. Freezing temperatures and precipitation can lead to mass mortality (Calvert et al. 1983). Similarly, temperature fluctuations and weather change during spring and summer migration have an effect on monarch and milkweed plants. Cooler temperatures and increased precipitation can lead to longer developmental phase, above normal temperature, and drought-like conditions, which reduce the lifespan of adults and larvae (Zalucki 1981 & 1982).

Studies have been conducted to understand the impact of climatic changes on the eastern monarch butterfly overwintering habitat in Mexico (Oberhauser and Peterson 2003). Weather data such as temperature, precipitation, and vapor pressure, and topographic data such as elevation, slope and aspect were used with AVHRR NDVI at 1 km spatial resolution. These data sets were used to analyze the climatic changes and develop a prediction model to forecast the future of this overwintering habitat. Similar studies have been conducted in the southern California overwintering habitats (Giffiths and Villablanca 2015).

Weather change and its implications during summer migration of the eastern monarch population have been studied using ecological niche modeling by Batalden et al. (2007). In this study, the geo-locations of the monarch eggs collected through the Monarch Larva Monitoring Project (MLMP) were used. Descriptive stations of temperature datasets (max, min, mean monthly, monthly solar radiation and monthly precipitation) and topography (elevation, slope, aspect and tendency to pool water) were used for ecological assessments. Ecological Niche Modeling has been used to identify areas adequate for overwintering for current and future climate scenarios for the eastern monarch and the overwintering sites in Mexico (Oberhauser and Peterson 2003). The study suggested that during breeding season, monarchs need to have an optimum temperature and precipitation tracking northward with seasonal changes.

Study of climate change and its implications on monarchs and milkweed plants is limited. Data on the summer breeding activity and location of the western monarchs are scarce as well. Potential natal grounds of the western monarch have been analyzed based on milkweed availability during summer and regional climatic conditions using “bottom-up” regression models by Stevens and Frey. (2010). The study analyzed the relationship between moisture variations at natal habitat and inter-annual monarch abundance variation at overwintering sites between 1998 and 2007. Milkweed data at the county level, weather datasets, and monarch abundance datasets were used for this study. Historical temperature data from the National climatic Data Center (NCDC) was used to identify the regions in west that had degree days, which could support late summer monarch recruitment. Presence and absence of milkweed available for late monarchs was created as well. Natal ground maps for migrant generation of monarchs was delineated as NCDC climatic divisions. The NCDC maps of western state climatic divisions with super-imposed county-level boundaries were used to transform county wide milkweed pattern to 54 climate divisions. For each of the 54 divisions degree-days available for egg-to-egg monarch development were developed considering the temperature regimes averaged across 30-year period from 1970–2000. In phase II of the study, NCDC data from 1998-2007 were used to estimate the amount of moisture available to regional flora each month. Monthly Palmer Drought Severity Index values across the years 1998 to 2007 from NCDC climate archives to estimate inter-annual variation of western moisture conditions in 54 divisions. Using series of linear regression 29 divisions out of 54 divisions yielded favorable conditions for monarch lifecycle development.

Various predictive models and strategies have been developed to identify 'bioclimate envelop' of the species using climate variables (Pearson and Dawson 2003). According to Pearson and Dawson, Bioclimatic envelopes are defined as the climatic component of the fundamental ecological niche. Identifying the bioclimate envelop using correlation between species distribution and climate variables could help in predicting the impact of climate change on the species physiology. The bioclimatic modeling is based similar to ecological niche theory;

however, it uses only climatic variables and does not include environmental factors (Pearson and Dawson 2003). A simple bioclimate model can provide a useful starting point when applied to a suitable species at appropriate spatial scale. They can be used to identify the future changes to the species and habitat distribution and assess the risk from climate change.

The changing climatic conditions can alter wind direction, and wind currents might increase an insect's energy demands and spatial disorientation (Liechti 2006). Migratory behavior depends on the climatic variations as the timely arrival to the breeding grounds is essential for the successful reproduction of the species. The growth and abundance of milkweed plants and the onset of breeding of monarchs must align temporally for the species' survival. The temperature cues used by these insects may vary in comparison to the temperature cues used by milkweed plants, and this mismatch and could potentially affect the breeding success of the dependent species (Visser and Both 2005). Analyzing the trends in temperature changes along the overwintering sites and spring-summer habitat could indicate if there is a mismatch in milkweed growth period and monarch arrival during to the breeding grounds.

California hosts a good number of monarchs every year in its winter and breeding grounds, nevertheless, assessment of western monarch habitat has been limited as monarchs of the west are little less known (Stevens and Frey 2004). The literature in this chapter provided inputs about techniques to assess the changes in habitat, data types, data sources and the outcome. Comparing the studies conducted in winter habitat in Mexico to western monarch winter habitat, this project identified that: quantification of land use land cover changes in the western monarch winter and breeding habitat; trend in herbicide glyphosate application in breeding habitat such as amount used, type of crops, and application year or time; and identifying inclement weather pattern during over wintering season, are some of the gaps which are taken up as topics of research interest in this project. In the next chapter, data types and their sources, methodologies followed for analyses and the technical challenges faced in this project are discussed extensively.

Chapter 3 Data and Methods

This project involved quantifying the land use land cover changes of the Monterey county from 1994 to 2018 at four-year interval, trend analysis of herbicide glyphosate use at section level (using yearly data from 1990-2015), identifying inclement weather conditions using daily weather data, and consolidating monarch yearly count data at each sites using WMTC data from 1997-2015.NDVI differencing method was used to quantify the land use land cover changes using Landsat ARD datasets; herbicide database was created and queried to analyze the trend in glyphosate application and similarly, daily weather data was queried to identify inclement weather during overwintering.

3.1 Data and Methods Overview

This project used spatial and non-spatial data sets to examine land use land cover change analysis. The methodology was based on that established by Lo and Shipman (1990) wherein aerial photography, and topographical and geological datasets were used to quantify the land use changes. There were five stages for quantifying land use, which were data extraction, data capture, data integration, data analysis, and output of results.

As a preliminary step, data sets required for this project were identified (see Table 1). This table lists all the data sources and type as used in this project. Some of the data listed in the Table 1 were analyzed and were found to be less useful (marked in red) due to lower resolution of the Landsat ARD imagery (30 meters resolution) in comparison with the size of the monarch winter sites (few m^2 in area), therefore, were not used further. Though the DEM was identified as a data source to quantify the winter sites terrain and the changes in the southward slope, where monarchs roost during winter. However, western monarch butterfly winter sites are small clusters of Monterey pine and eucalyptus trees (Espeset et al. 2016; Xerces Society Western Monarch Overwintering Sites Database, 2017).

Table 1: Data, Type and Source

Data	Data type	Data source	Data format	Temporal resolution	Spatial scale
Monarch winter sites	Spatial	Xerces Society	Shapefile	Single year dataset, updated 2018	Monterey County
County boundary	Spatial	California Department of Pesticide Regulation	Shapefile	Single year dataset	Monterey County
Weather data	Non-Spatial	University of California Integrated Pest Management	Tab delimited file	1990 - 2018	Monterey County
Landsat ARD imagery	Spatial	USGS	Raster	1994, 1998, 2002, 2006, 2010, 2014, and 2018	Clipped to Monterey county
Monarch winter count	Non-Spatial	Xerces Society Thanksgiving count	Tab delimited text file	1997 to 2018 Yearly count	Monterey County
County Township and Section	Spatial	California Department of Pesticide Regulation	Shapefile	Single year dataset 2018	Monterey County
Pesticide Use Report	Non-Spatial	California Department of Pesticide Regulation at Section level	Tab delimited text file	1990 to 2015 (98578 records)	Monterey County

3.2 Research Design

This project aimed to understand the usefulness of remote sensing and GIS in quantifying changes in the monarch overwintering and breeding habitat. Creating a geodatabase, building land use classes through Landsat imagery NDVI, creating spatial layer using the Pesticide Use Reports (PUR), extracting the monarch sites in the study area, and spatial joining the weather data from the nearest weather station to the were the first few steps of the analyses.

The research followed the Lo and Shipman (1990) land use change methodologies following the five-step process of: data extraction, data capture, data integration, data analysis, and output results and maps, for this project, as the project involved multiple data types and different methodologies. The steps are explained in the following sections.

The Monterey county was selected as the study area for two reasons: (a) the county has 15 active over wintering sites, and (b) the county also has significant agricultural areas, making the pesticide application analysis meaningful. All the analyses were carried out within the whole county.

3.3 Data Description and Methods

This project aimed to understand the environmental and anthropogenic factors that has been affecting the monarch butterfly population based on the various studies and observations (Pleasants and Oberhauser 2013; Pocius et al. 2017; Oberhauser et al. 2001; Brower et al. 2012). These studies indicate that changes in environment due to human activity around monarch winter sites have affected the quality of monarch habitat. The changes in monarch butterfly overwintering habitat has been analyzed through spatiotemporal analysis using spatial and nonspatial data sets (Section 3.1, Table 1). Different methodologies were followed based on the dataset selected for this project and were divided into land use land cover change analyses, Pesticide use trend analyses, identifying weather conditions during overwintering and analyzing the pattern of monarch count each year. The following sub sections explains the datasets, data preparation and analyses methods followed.

3.3.1. Land use land cover changes

Application of remote sensing using satellite imagery is best suited for long-term habitat change analysis, as in-situ monitoring of the host plant species and habitat is challenging as the host plants and the insects are dispersed through the landscape.

Land use land cover change is one of the major causes of habitat loss. It leads to change in biodiversity and sometimes pushes the sensitive flora and fauna towards extinction (Pelton et al. 2019, Schultz et al., 2017). Land cover and land use changes are due to natural alterations and human interventions. Human interactions with nature and introduction of chemicals are one of the primary causes of habitat change and habitat loss (Falcucci et al. 2007). The habitat loss leads to biodiversity hotspots, which needs to be identified and addressed in a timely fashion to stop the species from extinction. Understanding past and current changes of land use helps analyze the effect on ecology land degradation over time. Since monarch butterflies are migratory species and travel long distances through different geographical regions and seasons, monitoring changes via field observations may lead to inconsistencies and gap in the data. Satellite and aerial imagery, on the other hand, is very useful in multi temporal analysis (Mouat et al. 1993).

Selecting satellite imagery depends on the size of the study area and its temporal coverage. Initially, Landsat ARD (Analysis Ready Data) images of each year from 1991 to 2018 was considered for land use land cover change analyses. Four ARD tiles (Fig 5) covered the Monterey county, and to maintain the temporal consistency ARD images between November 1st – December 31st of each year were included as search criteria. Due to unknown reasons all four tiles for one single date were not available for some years, for example: one (or two) tiles out of four was missing in the data, or, there was more than 10% cloud cover, or, there were Landsat scan line error in the tiles. Since 2003, some of the images have been affected by scan line error, thereby causing data gaps. Data rectification of scan line error using algorithms is a time-consuming process. data was carefully selected, without any cloud cover or scan line error images have been avoided, except 2010 image where H01V10 image tile has scan line error. Landsat ARD (Analysis Ready Data) images of the Monterey county of the year1994, 1998, 2002, 2006, 2010, 2014 and 2018 were selected for quantifying the land use land cover change.

Landsat ARD products are processed from Landsat Collection 1 Level 1 scenes and are ready to use for monitoring or assessing land use change. The Landsat ARD consists of top of atmosphere reflectance, top of atmosphere brightness temperature, surface reflectance, surface temperature, and quality assessment data along with metadata file. These ARD products are available for conterminous US, Alaska and Hawaii through the following Collection 1 Level 1 products:

- Landsat 8 Operational Land Imager (OLI)/ Thermal Infrared Sensor (TIRS) Tier 1, Tier 2
- Landsat 7 Enhanced Thematic Mapper Plus (ETM+) Tier 1
- Landsat 4-5 Thematic Mapper (TM) Tier 1

The Landsat ARD products follows Tile-Grid system, where, each image is available in 5000 x 5000 30m pixel tile (Figure 5). The tiles are the part of the grid system which covers the conterminous US, Alaska, and Hawaii separately. The dimensions of Landsat ARD tile pixels are smaller than Landsat 4-7 (approx. 6,166 x 5,666 pixels), and Landsat 8 (approx. 6300 x 6000 pixels) and are identified with horizontal (H) and vertical (V) tile numbers. The highlighted area, H01V09, H02V09, H01V10, and H02V10 in Figure 5 shows the tile coverage for the study area.

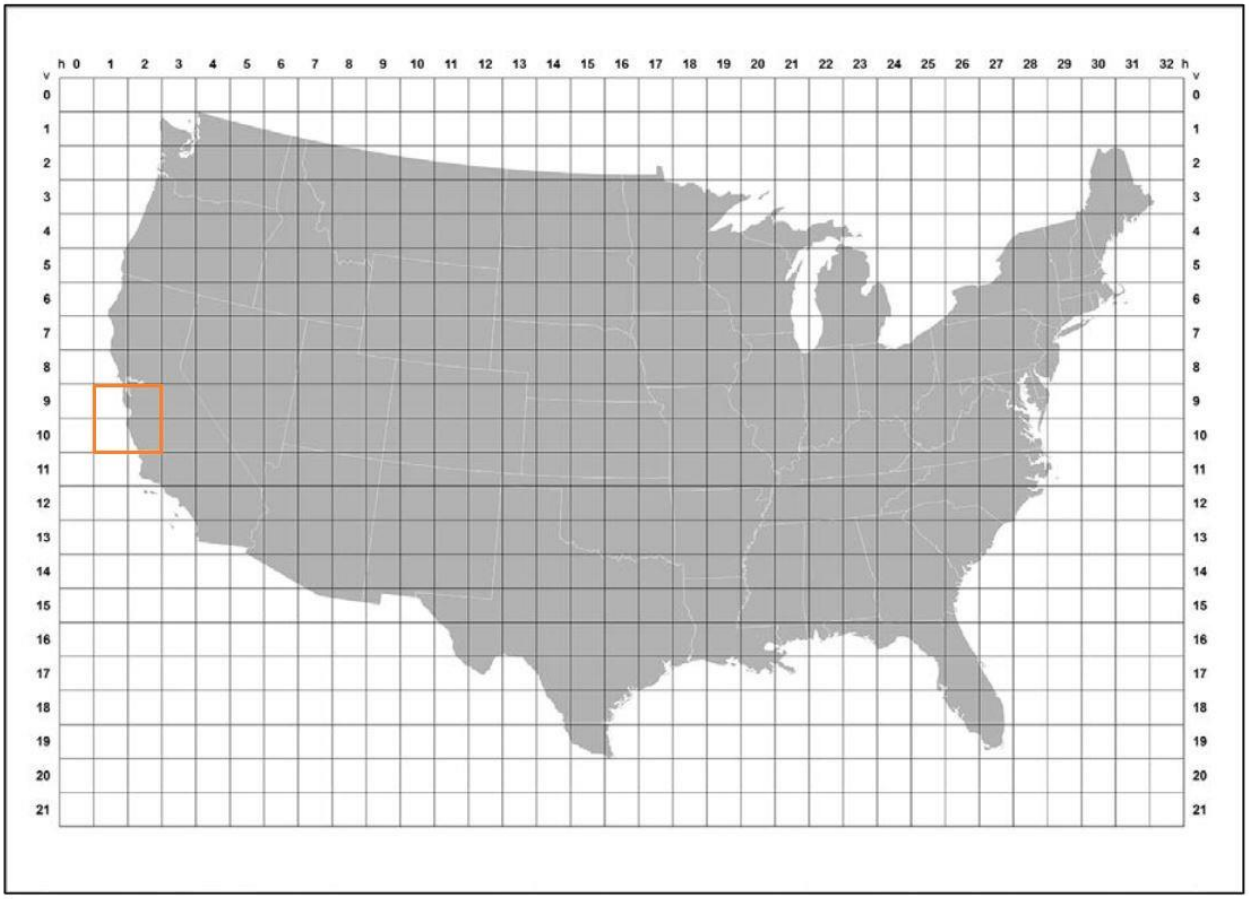


Figure 5: Landsat ARD Tile and Grid format. Source: USGS Landsat ARD

The Landsat ARD Surface Reflectance (Near Infra-Red (NIR) and Red bands) are used calculate NDVI. In this project the land use change was analyzed by calculating the NDVI and quantifying the difference in NDVI between the two temporal images. Surface reflectance band specification is as mentioned in Fig 6 and 7. The surface reflectance bands 4 (Near Infra-Red) and 3 (Infra-Red) of Landsat 4, 5 and 7, and band 5 (Near Infra-Red) and 4 (Infra-Red) of the Landsat 8 were used to calculate NDVI.

Level 2 Band Designation	ARD Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
sr band1	SRB1	Band 1	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr band2	SRB2	Band 2	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr band3	SRB3	Band 3	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr band4	SRB4	Band 4	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr band5	SRB5	Band 5	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr band7	SRB7	Band 7	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr = surface reflectance, INT16 = 16-bit signed integer, Refl = reflectance									

Figure 6: Landsat 4-7 Surface Reflectance Specifications. *Source: USGS Landsat.*

Level 2 Band Designation	ARD Band Designation	Band Name	Data Type	Units	Range	Valid Range	Fill Value	Saturate Value	Scale Factor
sr_band1	SRB1	Band 1 Surface Reflectance	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr_band2	SRB2	Band 2 Surface Reflectance	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr_band3	SRB3	Band 3 Surface Reflectance	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr_band4	SRB4	Band 4 Surface Reflectance	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr_band5	SRB5	Band 5 Surface Reflectance	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr_band6	SRB6	Band 6 Surface Reflectance	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr_band7	SRB7	Band 7 Surface Reflectance	INT16	Refl	-2000 – 16000	0 – 10000	-9999	20000	0.0001
sr = surface reflectance, SRB = surface reflectance band INT16 = 16-bit signed integer, Refl = reflectance									

Figure 6: Landsat 8 Surface Reflectance Specifications. *Source: USGS Landsat*

Initially, the NLCD (National Land Cover Data) of the study area was considered as the primary data for the land use land cover change. The incompatibility of NLCD 1992 data and the suitability issues of the Retrofit Land Cover data at the local level considered, however, Landsat ARD was selected because of temporal resolution. Also, the NLCD1992 dataset has 21 land use types, whereas NLCD from 2001, 2006, and 2011 have 16 land use types (classifications). This difference in land use classes could lead to conflicts during land use change analyses. The NLCD website warns about the difference in classes for land cover change analysis studies. Due to the difference in the classification types of NLCD 1992 (21 classes) and NLCD 2001, 2004, 2011 (16 classes), NLCD dataset was not included in this project for land use change analysis as the effects of different classes were unknown. Instead, calculating NDVI of the Landsat ARD and creating land use classes based on the NDVI value was considered straightforward and the land use change analysis was executed.

Landsat ARD data was downloaded from USGS Earth Explorer website and four grid tiles covered the Monterey county (Fig 5). Initially, composite band image was created for each tile using the surface reflectance bands. Composite Bands tool in Raster Processing ArcToolbox creates a single raster dataset from multiple bands. This process was followed for all the four tiles of Landsat ARD imagery for each year to create composite band imagery for each tile (0109, 0110, 0209, and 0210). Then the four tiles of each year were mosaiced to form a single image with composite bands (Fig 8). Mosaic to New Raster tool was used to create a new raster dataset. A single image with composite bands was created for each year. The raster datasets were then projected using Raster Project tool in ArcToolbox. This process was followed for each year of the data selected and clipped to the county boundary.

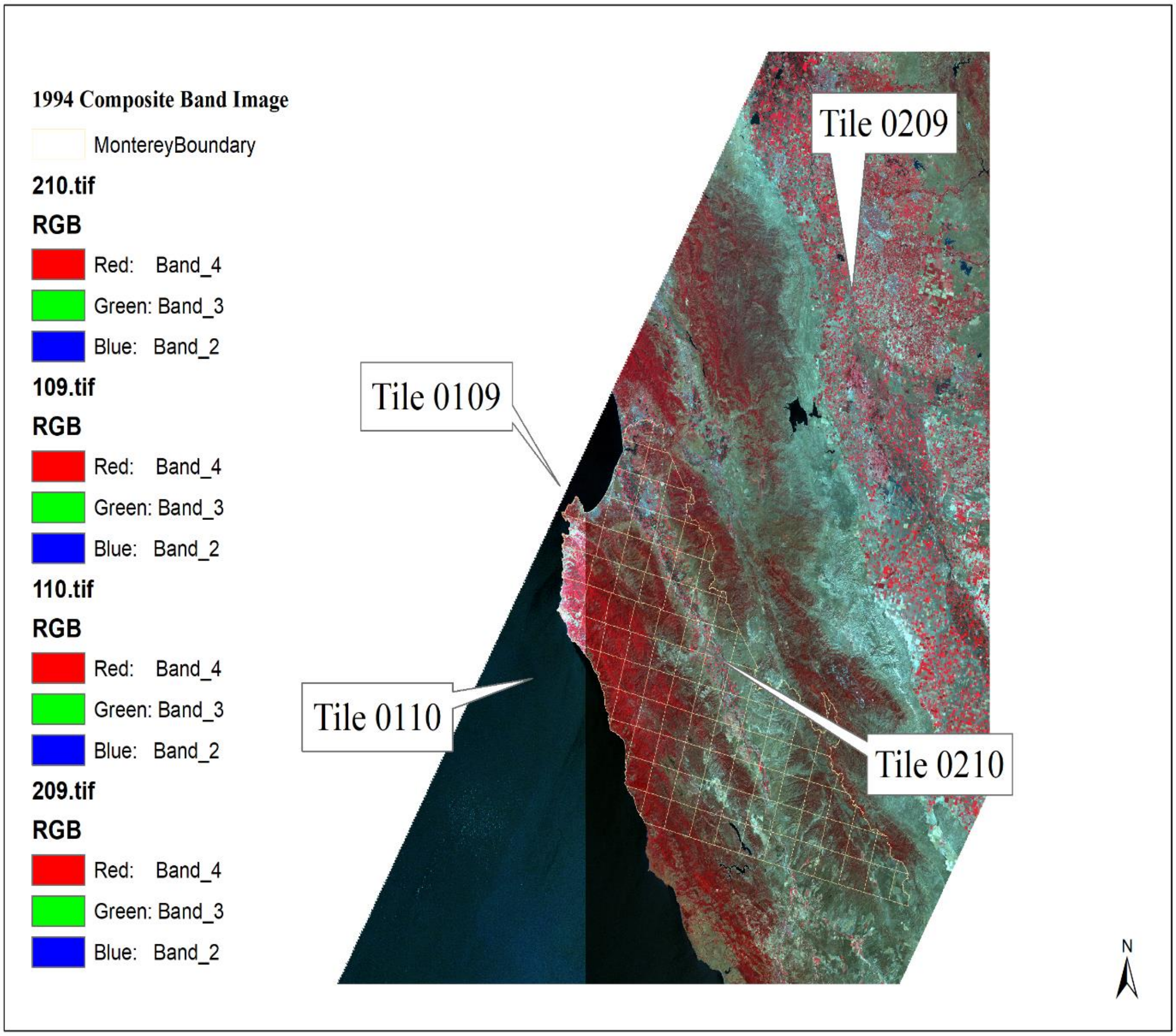


Figure 7: Composite band image of Landsat ARD 1994

NDVI Image Differencing

NDVI differencing method was selected for quantifying land use land cover change. NDVI indicates greenness in vegetation and is useful in assessing plant health (Forkel et al. 2013). There are many suitable methods for assessing and modelling land use change such as image differencing, image regression, and change vector analysis. Sometimes, a combination of methods is used. In this project NDVI differencing and post classification using indices value has been used to quantify the land use land cover change. Near Infra-Red (NIR) and Red (R) bands of the image are used to calculate NDVI as shown in the below (Equation. 1)

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

Equation 1: NDVI, Where NIR is the Near Infra-Red and R is the Red band of the Landsat Imagery

The NDVI values range between −1 and +1(negative 1 to positive 1).The negative value of the index approaching −1 indicate water, values close to −0.1 to 0.1 corresponds to barren areas of rock, sand and built-up areas, values between 0.2 to 0.4 indicate moderate vegetation and shrubs, and values above 0.5 to 1 indicate healthy vegetation and forest areas. A healthy crop land also has higher NDVI values.

Table 2:NDVI Pixel Range and Categories

NDVI Range	**Category**	**Map visualization colors**
-1 to 0.1	Built up area and water body	
0.1 - 0.2	Built-up and Open Area	
0.2 – 0.35	Poor Vegetation	
0.35- 0.628	Moderate Vegetation	
0.628- 1.0	Healthy Vegetation	

The Image Analysis and Raster Calculator tool in Arc GIS were used to generate the NDVI images of 1994, 1998, 2001, 2006, 2010, 2014 and 2018. The Image Analysis tool uses composite band image, and Infra-red and Red band must be manually selected prior to analysis. Raster Calculator in Spatial Analyst can be used to perform NDVI using NIR and IR bands by following Equation 1.

The NDVI value range from the analysis were divided into 5 categories based on the index range. Every image of NDVI followed the same range and category for visualization and further for NDVI image differencing. Reclassification tool was used to create land use categories.

Discrepancies in NDVI pixel values were observed in 1998, 2006, 2010 and 2014 images. The NDVI value in some pixels were out of range (-1 to 1) with values ranging from −1.1 to −10 on the negative side and values from 1.1 to 20 on the positive side as shown in Figure 9. The images in the left are the NDVI maps with values ranging from -1 to +1, and the images on the right indicate the pixels in the image which have out of range NDVI values, with negative values in the range of -1.1 to -10 and positive values from 1.1 to 20. In the maps on the right side, to identify the pixels having out of range NDVI value, they are represented in color (blue, purple and pink), whereas, pixels within NDVI values of -1 to 1 are represented as ‘no

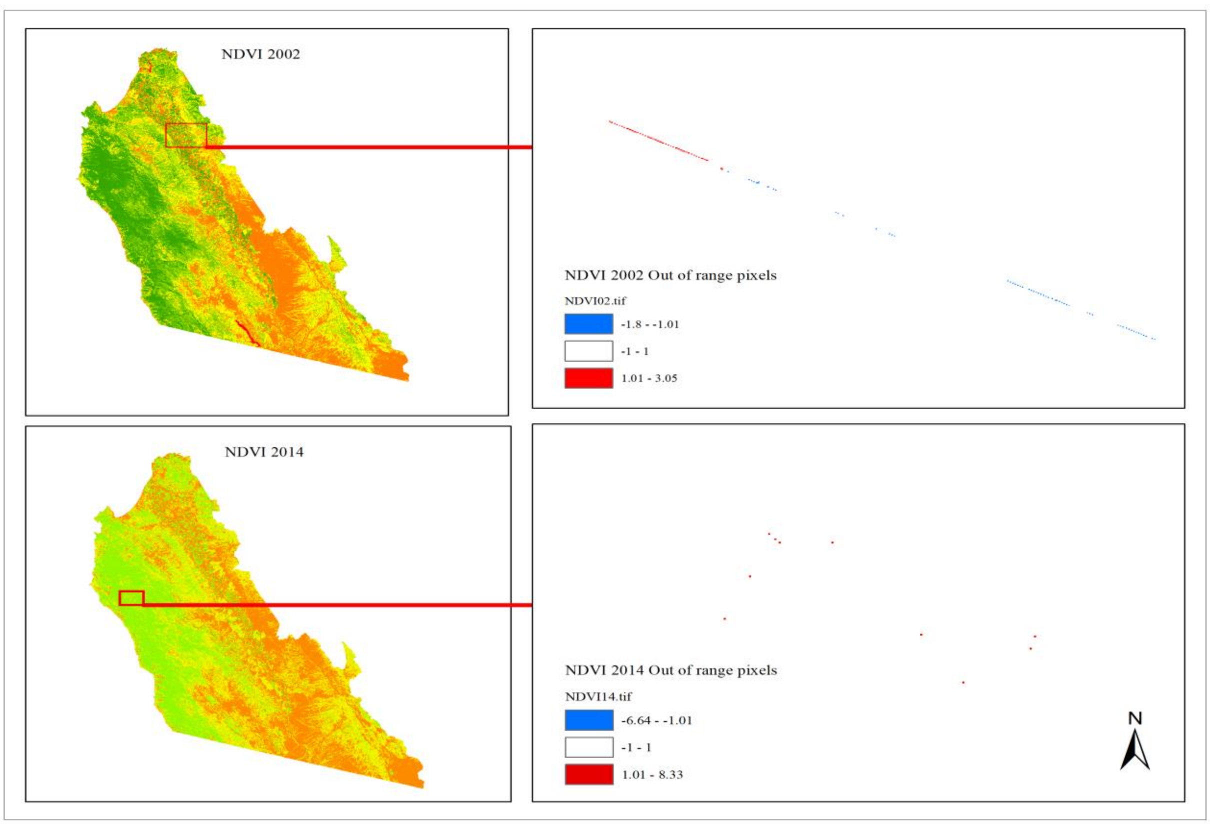


Figure 8: Out of Range NDVI values of 2002 and 2014 NDVI images

color'. The out of range NDVI values are not acceptable and their presence in the image affects the median and mean values, and the resultant values during differencing of two NDVI images.

The Mask function in the Arc GIS was used to remove the unusual (out of range) pixel values. Using the Mask function, a range of specific values can be mentioned and, any value outside the minimum of maximum value of the range mentioned will be returned as No-Data. Thus, the resulting NDVI maps had the values between −1 to 1.

To analyze the change from Year Y_1 to Year Y_2, image differencing technique was used (Equation 2). NDVI image differencing indicates the change in the vegetation at pixel level (30m) (SINGH 1989; Forkel et al. 2013; Ehsan and Kazem 2013).

$$\Delta NDVI = NDVI_{Y1} - NDVI_{Y2}$$

Equation 2: NDVI Image Differencing

NDVI differencing involves subtracting two different date NDVI images. The pixel by pixel subtraction of the NDVI image results in NDVI value ranging from −1 to +1, negative value indicating positive change, values near zero indicate no change and positive values indicate negative change . The resultant NDVI difference values were further reclassified into four categories: Increase in healthy vegetation, increase in moderate vegetation, land cover unchanged, and decrease in vegetation (loss). The reclassified categories in pixels were used to represent percent change. Raster Calculator in Spatial analyst toolbox was used to subtract NDVI images of two subsequent years (Fig 10).

NDVI image differencing using the raster calculator was used to create a difference image. For example, NDVI 1994 image was subtracted from 1998 image to identify the land use change over the 4 years. Similarly, 1998 image was subtracted from 2002 image and so on.

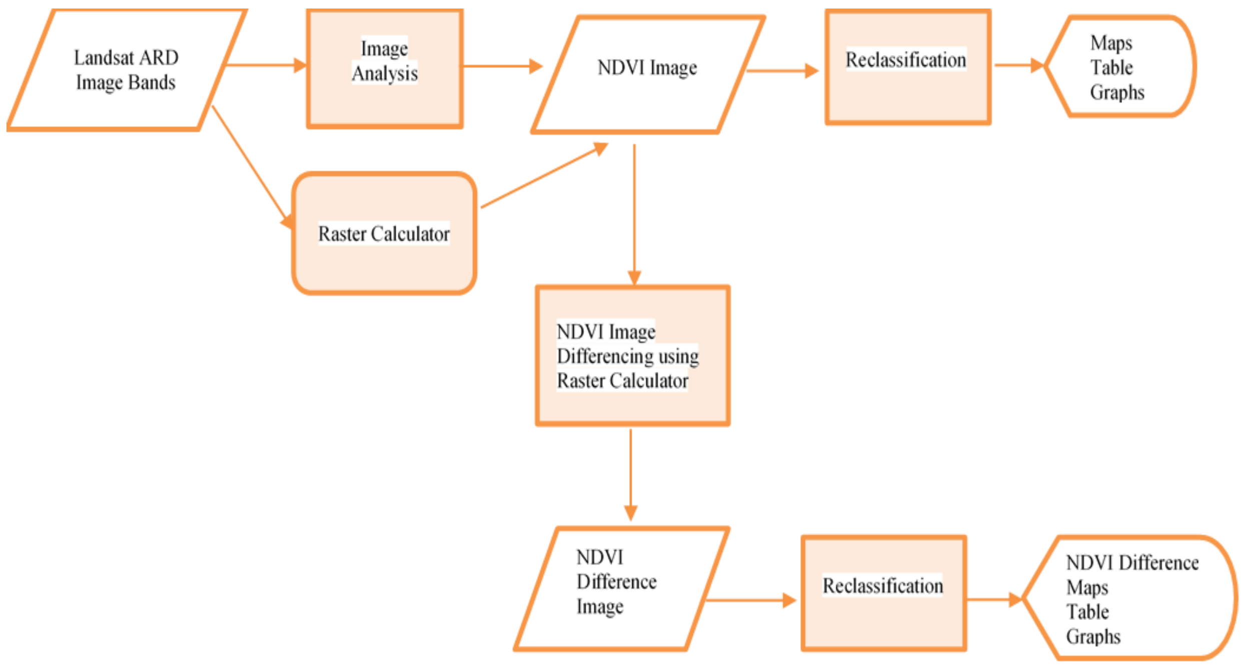


Figure 9: NDVI image and NDVI differencing process

3.3.2. Digital elevation model map

USGS National map 3D Elevation Program provides Digital elevation models at 30-meter resolution. The elevation represents the topographic bare-earth surface. These maps are used for hydrologic modeling and land use applications. In this project, the Landsat imagery was overlaid on DEM to understand the topography of the habitat and detect the changes over the temporal period.

During overwintering, monarchs need shelter from wind, direct sunlight, and precipitation. Terrain plays an important role for monarchs in their selection of sheltering trees. The eastern monarchs are regularly found roosting on trees on the south-west slope in their overwintering sites in Mexico (Oberhauser and Peterson 2003). Similarly, the western monarchs prefer Monterey pine and eucalyptus tree cluster groves at a lower elevation, situated on south, west or south-west slopes, for overwintering (Lane 1993; Frey et al. 1992). The slope, and elevation of host trees in the overwintering sites along depends on the angle of the sun, the wind direction, and the cluster of the surrounding trees (Leong 1990).

Monarch butterfly move between the cluster of trees when there is a change in wind direction, precipitation or if there is direct sunlight, as they need protection to survive weather changes during winter (Leong et al. 2004). However, the wintering sites in Monterey county are very small in area comprising of few trees. The ground coverage of many sites could be less than one pixel of Landsat image. Analyzing such microhabitat changes requires high resolution topographical data, and satellite or aerial images. In this project, Landsat resolution could not indicate the percent change in the tree density and landscape changes in the winter sites, but changes at the county level was analyzed effectively. This study concentrated on changes in the tree groves located in south and southwest direction and slope as the monarch butterfly prefer such terrain. However, due to the size of sites and the image resolution, analysis could not indicate any change.

3.3.3. Weather data

Weather change also play an important role in ecological niche of a species. Severe weather change events can lead to decline of the species and unusual weather patterns and events could lead to massive mortality of the species. Monarch butterfly is one such sensitive species. 50% of the monarch population can freeze at 24^0 F when their bodies are wet due to precipitation and 100% mortality occurs at 18^0 F (Anderson and Brower 1996). Calvert et al. (1983) estimated that around 2.5 million butterflies did not survive the 1980-1981 winter storm, followed by snow fall and below freezing temperatures during the month of January. Another inclement event in 2002 reported to have killed nearly half a billion butterflies (Brower et al. 2004). It was therefore imperative to know the unusual weather events during the last two decades (from 1990-2018) in the wintering sites of western monarchs.

Station	Date_record	Month	Precip	Temp_max	Temp_min	Wind_dir	Wind_speed	Solar_rad	ETo	Humidity_max	Humidity_min
Monterey	1-Jan-97	1	0.29	67	61	SE	10	97	0.03	92.8	83.7
Monterey	2-Jan-97	1	0.55	65	57	SE	9	75	0.02	96.1	85.6
Monterey	3-Jan-97	1	0.01	61	44	NW	6	281	0.05	94.7	52.7
Monterey	4-Jan-97	1	0.03	51	39	S	3	97	0.02	93.7	71.7
Monterey	5-Jan-97	1	0.12	55	43	NW	7	290	0.05	95.7	58.2
Monterey	6-Jan-97	1	0	57	35	N	6	301	0.08	77.2	35.3
Monterey	7-Jan-97	1	0	59	31	S	4	275	0.05	90.8	42.6
Monterey	8-Jan-97	1	0	61	33	S	4	266	0.05	93.8	50
Monterey	9-Jan-97	1	0	62	34	S	4	281	0.05	96.3	50.5
Monterey	10-Jan-97	1	0	61	35	NW	4	273	0.05	97.2	60.6
Monterey	11-Jan-97	1	0.01	52	39	S	4	61	0	98.1	82.6
Monterey	12-Jan-97	1	0.27	55	44	SE	4	156	0.03	95.7	82.5
Monterey	13-Jan-97	1	0	51	39	NW	4	235	0.05	84.7	36.6
Monterey	14-Jan-97	1	0.28	47	34	SE	7	116	0.03	95.4	67
Monterey	15-Jan-97	1	0.15	63	45	S	4	215	0.04	96.9	66.7
Monterey	16-Jan-97	1	0	59	42	S	4	218	0.04	97.8	75.3

Figure 10: Sample of daily weather data of the Monterey county from 1997-2016

The daily weather data was collected in non-spatial text format from the nearest weather station to the study area. These weather stations are monitored by University of California statewide Integrated Pest Management (UC IPM). UC IPM weather data includes maximum and minimum temperature values, precipitation, wind speed, wind direction, and solar radiation (Fig 7). The weather data was exported to MySQL, and queries were built to identify the days with below freezing temperature, days with below freezing temperature (24^0 F) and precipitation. Monarch population is also affected by above normal winter temperatures. It can accelerate the spending of their lipid reserves (Anderson and Brower 1996; Brower 2004). Weather data was queried to identify days with above normal winter temperature.

```
Select Date_record, Precip, Temp_max, Temp_min from weather_monteryfinal
where Temp_min<= 33
order by Temp_min asc, Precip;
/* different temperature values for Temp_max and Temp_min was used in the query */
```

3.3.4. Pesticide Use Report

The state of California is one of largest agricultural producer in the country. One-third of the country's vegetable and two-third country's fruit and nuts are grown in California. The production of corn was in the 1993 crop year was 430,804 tons and in 2016 the corn production was 13,490,064 tons, according to the California department of food and agriculture reports. As the total production of corn and other crops increased from 1993 to 2016, the production of other crops has increased over time, indicating increase in the rate of cultivation in California.

Milkweed plants are found in abundance in corn and soybean croplands apart from the milkweeds found near the right of ways and in the open areas (Pleasants and Oberhauser 2013; Pocius et al. 2017; Oberhauser et al. 2001, Hartzler and Buhler 2000).). Monarchs depend on milkweed for nectar and plant leaves during spring and summer migration for survival and breeding. Monarch butterflies lay their eggs only on milkweed plants. The abundance of this host plant species is essential for the entire monarch lifecycle (Ljiljana et al. 2016; Pleasants and Oberhauser 2013; Hartzler 2010; Flockhart et al. 2012). Since the cultivation of genetically modified crops of corn and soybean increased, the use of weed killing pesticides and herbicides has increased over time. One such herbicide which has been observed to decrease milkweed abundance is the use of glyphosate. Glyphosate is known to kill all the plant species when it applied. Therefore, it is used with the herbicide resistant crops like genetically modified corn, soybean, and cotton (Pocius et al. 2017). This herbicide is used in the agricultural lands where genetically modified corn, soybean and cotton, which are resistant to glyphosate are grown in California.

The California State Department of Pesticide Regulation (DPR) started reporting the pesticide use in 1990. Under this program, pesticide use is reported monthly to the County agriculture commissioner, with the application information such as: date and location of application, type and amount of pesticide used (in pounds), type of crop for the pesticide application, plant acreage, identification (ID) of the site, operator (pesticide user) and method of application (ground or aerial). The pesticide application report also includes application in parks, golf course, range lands, and right of ways. The report includes geographic location where the pesticide was used, at the section level and includes, township.

For this project, only herbicide glyphosate application data from 1991 to 2015 (98423) records) was downloaded in the non-spatial format with spatial representation of section level GIS layer, making spatial display and GIS analysis possible. The California DPR also provides shapefiles of the sections and townships for each county, which helped to create a relationship between the tabular data of the PUR and section and township shapefile.

Studies indicate that the use of glyphosate in the cropland areas in the mid-west is the main cause for the decline of milkweed in the cropland areas (Hartzler and Buhler 2000; Hartzler 2010; Wyrill and Burnside 1977). Quantifying the trend and rate of application over the last two decades (1990-2018) in the study area was executed through GIS methodologies and querying techniques.

The purpose of the PUR was to analyze the agricultural crop types in the Monterey county and the amount of pesticide used by each crop type and its frequency. The PUR data table contains the crop type, time of application, type of pesticide used, amount of pesticide used, areal or ground application type, and Section ID. Shapefiles of township and section, and PUR table was used to create a geodatabase. A simple relationship was created between PUR to section and township shapefiles using the function ‘Relate’, for visualization purposes. The sections where the pesticide glyphosate is used every year are highlighted in the Figure 12.

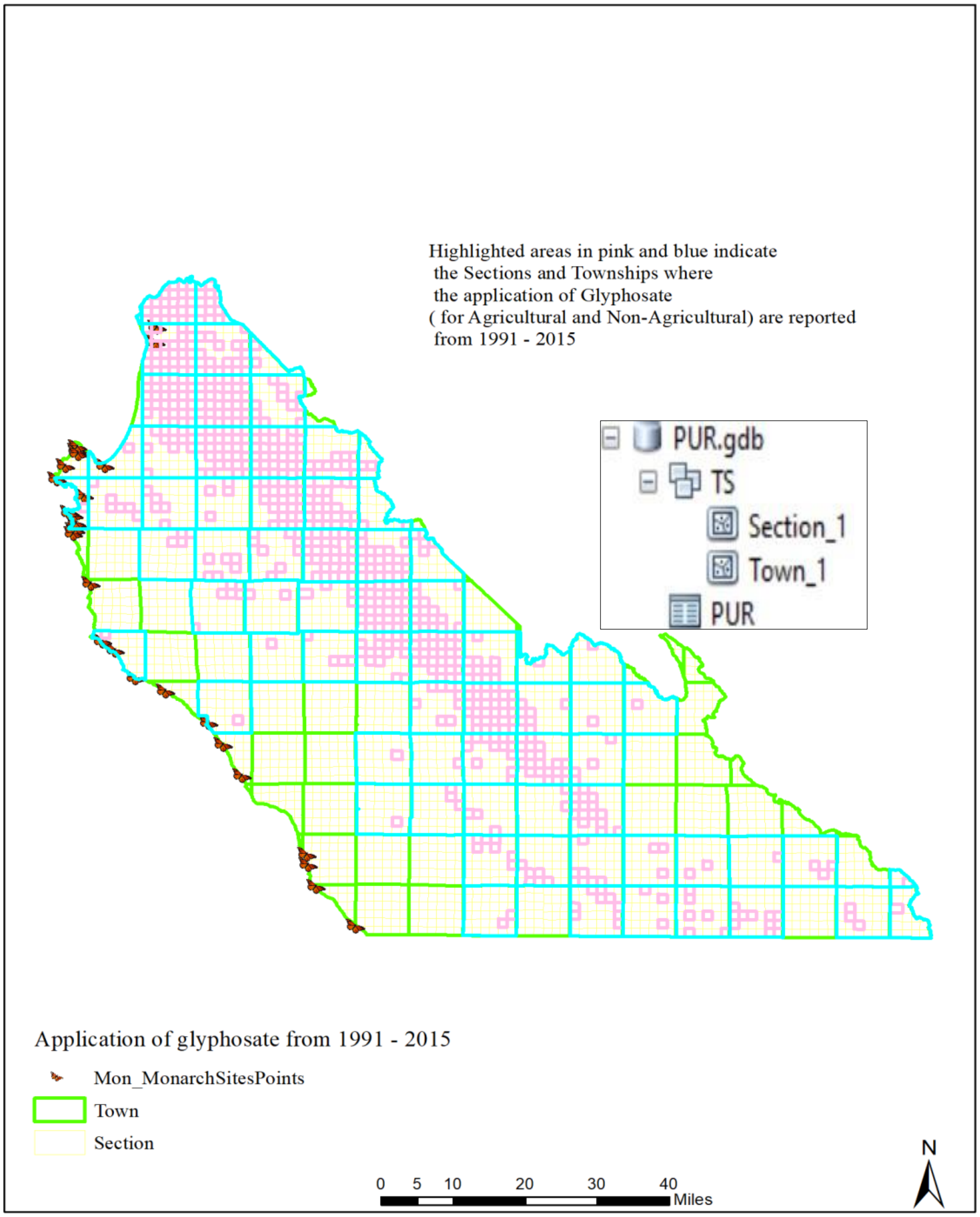


Figure 11: Glyphosate application from 1991 - 2015

PUR table (Fig 13) was exported into MySQL where queries were built to analyze the crop type, pounds of pesticide used by crop type and year-wise, and the sections where the

Table

PUR

OBJECTID *	YEAR	DATE	COMTRS	SITE_NAME	CHEMI	POUNDS_C	UNIT_TREA	AERI	AERIAL_GROUND_DESCRIPTI	AG_NONAG	LICENSE_NUMBER
66113	2009	29-JUL-09	27M12S01E01	UNCULTIVATED AGRICULTUR	1855	20.250966	ACRES	G	GROUND	AG	<Null>
12893	1998	23-JAN-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	10.309409	ACRES	G	GROUND	AG	<Null>
12964	1998	09-MAR-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	32.606562	ACRES	G	GROUND	AG	<Null>
12965	1998	09-MAR-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	13.426229	ACRES	G	GROUND	AG	<Null>
14510	1998	05-MAR-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	15.584018	ACRES	G	GROUND	AG	<Null>
15134	1998	23-JAN-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	15.584018	ACRES	G	GROUND	AG	<Null>
15135	1998	23-JAN-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	13.426229	ACRES	G	GROUND	AG	<Null>
16566	1999	25-FEB-99	27M12S01E24	LETTUCE, HEAD (ALL OR UNS	1855	3.436456	ACRES	A	AERIAL	AG	<Null>
34050	1998	23-JAN-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	10.309409	ACRES	G	GROUND	AG	<Null>
34121	1998	09-MAR-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	32.606562	ACRES	G	GROUND	AG	<Null>
34122	1998	09-MAR-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	13.426229	ACRES	G	GROUND	AG	<Null>
35667	1998	05-MAR-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	15.584018	ACRES	G	GROUND	AG	<Null>
36291	1998	23-JAN-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	15.584018	ACRES	G	GROUND	AG	<Null>
36292	1998	23-JAN-98	27M12S01E24	UNCULTIVATED AGRICULTUR	1855	13.426229	ACRES	G	GROUND	AG	<Null>
37723	1999	25-FEB-99	27M12S01E24	LETTUCE, HEAD (ALL OR UNS	1855	3.436456	ACRES	A	AERIAL	AG	<Null>
54661	2005	18-MAR-05	27M12S01E24	UNCULTIVATED AGRICULTUR	5820	56.877363	ACRES	A	AERIAL	AG	<Null>
55225	2005	18-MAR-05	27M12S01E24	UNCULTIVATED AGRICULTUR	5820	13.791791	ACRES	A	AERIAL	AG	<Null>
1469	1992	28-FEB-92	27M12S01E25	LETTUCE, HEAD (ALL OR UNS	1855	2.05	ACRES	A	AERIAL	AG	<Null>
1481	1992	04-MAR-92	27M12S01E25	SPINACH	1855	16.3918	ACRES	G	GROUND	AG	<Null>
1609	1992	16-MAR-92	27M12S01E25	SPINACH	1855	14.3459	ACRES	G	GROUND	AG	<Null>
1631	1992	11-MAR-92	27M12S01E25	LETTUCE, HEAD (ALL OR UNS	1855	11.2709	ACRES	A	AERIAL	AG	<Null>
2003	1992	11-MAR-92	27M12S01E25	LETTUCE, HEAD (ALL OR UNS	1855	13.3209	ACRES	A	AERIAL	AG	<Null>

1 (98423 out of 98423 Selected)

Figure 12: PUR Table in ArcMap

pesticide was applied. Some of the queries are listed below:

- Sections where glyphosate was used frequently and the crop type:

```
SELECT COMTRS, COUNT (COMTRS), SITE_NAME,
SUM(POUNDS_CHEMICAL_APPLIED) FROM monarch_db.pur
GROUP BY COMTRS, SITE_NAME
ORDER BY COMTRS, SITE_NAME;
/*COMTRS is Section number; SITE_NAME is Crop type */
```

- Pounds of glyphosate applied each year:

```
SELECT YEAR, SUM(POUNDS_CHEMICAL_APPLIED) FROM monarch_db.pur
GROUP BY YEAR;
```

- Crop-wise glyphosate applied each year

```
SELECT YEAR, SITE_NAME, SUM(POUNDS_CHEMICAL_APPLIED) FROM monarch_db
.pur91_05
GROUP BY YEAR, SITE_NAME;
```

The results and maps of the PUR analyses are discussed in chapter 4.

3.3.5. Over wintering sites and Yearly count

There are over 400 overwintering sites along the California coast and there are over 200 active sites are where monarchs have been observed more than once since 2010 (Xerces Society. Monterey county hosts up to 15 active sites, where monarchs have been sighted annually. For this project, overwintering sites in Monterey county were selected from spatial data of sites provided by Xerces Society. The yearly Thanksgiving count for these sites was used to analyze population trend over the years.

3.4 Output Results and Maps

The results from all the analyses mentioned section 3.3in are discussed in detail in Chapter 4. The results of land use land cover change analyses used maps, table, and graph options to display the results. Displaying the results in map format provide better visualization tools. Queries used for assessing PUR and weather data are displayed in Chapter 4 in the relevant sections. All results are displayed using maps, tables, and figures to understand the trend in the land use change over from 1990 to 2018.

Chapter 4 Results

This chapter reviews the outcome and results of the land use land cover analysis using NDVI differencing method, pesticide application trend, and weather change analyses. The change in each land use category is quantified and displayed in map, table, and graph format. The results of PUR analyses and querying method used are also displayed in map, table, graph format and the queries used are listed in relevant section. The weather change analysis to identify the inclement weather conditions are displayed in table format and queries used are listed in the subsequent sections.

4.1 Land use land cover change analyses

To analyze and quantify the land use land cover change, NDVI image of all the years were classified based on the suitable NDVI value range and further reclassified into 5 categories, using the Reclassify tool. The reclassified image was merged based on the grid values. The merged pixels were used to derive the land use land cover category in percentage.

Image analysis and Raster calculator tools in Arc GIS were used to generate NDVI images of 1994, 1998, 2002, 2006, 2010, 2014 and 2018. Image analysis tool uses composite band imagery and NIR and IR bands were selected manually. Raster Calculator from the Spatial Analyst toolbox and Image Analysis tool generated similar NDVI images and the results showed similar NDVI value. Both the tools generate NDVI raster image with pixels denoting vegetation index values ranging from −1 to 1. The images were reclassified based on the pixel range (Table 3, below) and the land use land cover category was created in the raster table. The resultant maps created showed different land use land cover category. Number of pixels in each category was used to create percentage of each land use land cover type and the results were displayed in table and graph format.

Table 3: NDVI pixel range and land use land cover categories

NDVI range	Category
-1 to 0.1	Water and built-up
0.1 to 0.25	Built-up and Open area
0.25 to 0.35	Poor Vegetation
0.35 to 0.628	Moderate vegetation
0.628 to 1	Healthy Vegetation

4.1.1. NDVI image generation and results

The NDVI image showed different land use land cover patterns, reclassifying the image based on the determined pixel range helped to categorize the land use land cover categories uniformly for all images. Reclassification helped to aggregate all the pixels belonging in the NDVI range selected into one category. Land use land cover percentage in the study area were further derived from the merged pixels (Ehsan and Kazem 2013). Figure 14 to 17 show the NDVI reclassified images from 1994, 1998, 2002, 2006, 2010, 2014 and 2018. The NDVI images were classified into different category based on the pixel range mentioned in the Table 3. The range was decided based on the visual interpretation of the composite image and the Landsat NDVI value representing greenness of the vegetation.

The Land use land cover change was observed in 2002, with decrease in moderate vegetation and healthy vegetation compared to 1998 and 1994. The decrease was more than 5% in both the categories and open areas or barren lands increased by 10%. However, moderate vegetation and healthy vegetation showed improvement in 2006, 2010, and 2014. In 2006, there was an increase in area in the waterbody due to rainfall during the season.

Table 3: NDVI Class and Land Cover Percentage

		NDVI_1994		NDVI_1998		NDVI_2002		NDVI_2006		NDVI_2010		NDVI_2014		NDVI_2018	
Value	**LC_type**	**Count**	**LC_%**	**Count**	**LC_%**	**Count**	**LC_%**	**Count**	**LC_%**	**Count**	**LC_%**	**Count**	**LC_%**	**Count**	**LC_%**
1	Built-up and Water Body	54203	1	75968	1	143267	2	433266	5	55775	1	48208	1	59557	1
2	Built-up and Open Area	2895047	30	2686666	28	3750053	39	3059710	32	2473662	26	2372259	25	2847067	30
3	Poor Vegetation	1661525	17	1658590	17	1666032	17	1358309	14	1915216	20	2050051	22	1881760	20
4	Moderate Vegetation	3247964	34	3323822	35	2828117	30	3275265	34	3776191	40	3331241	35	3314380	35
5	Healthy Vegetation	1675267	18	1785054	19	1146402	12	1407151	15	1208054	13	1732194	18	1427973	15

LC_type	Land Cover Type
Count	NDVI Pixel Count
LC_%	Land Cover Percentage

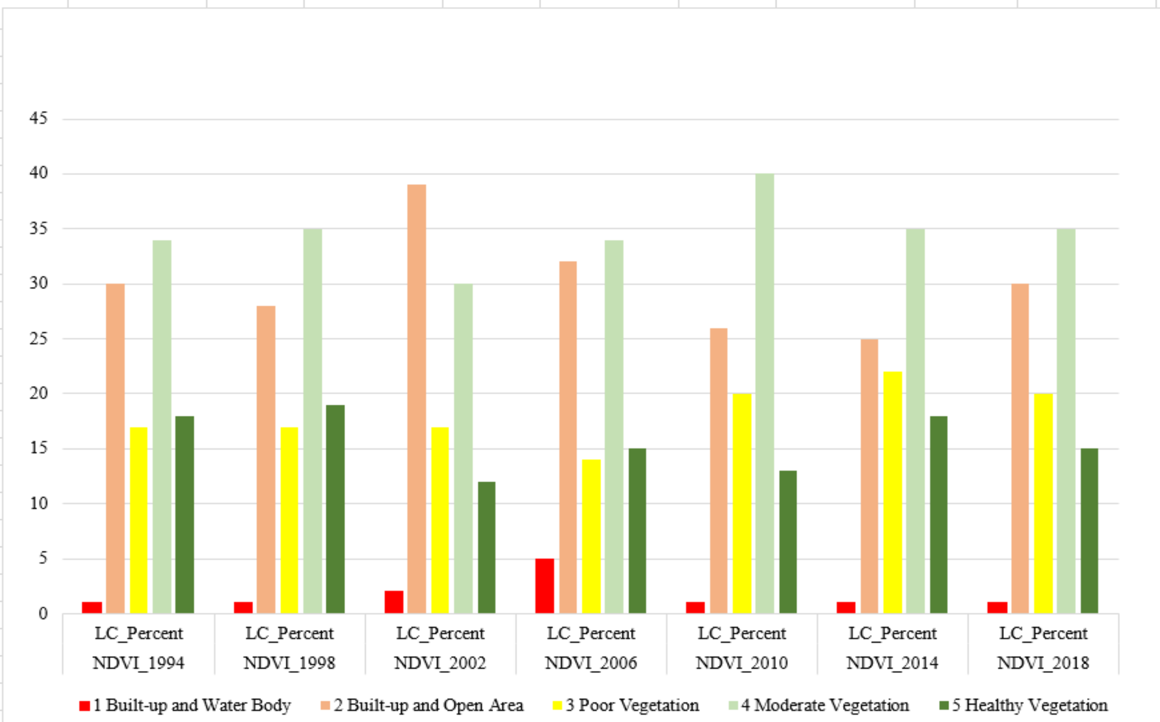


Chart 1: Land use land cover percentage.

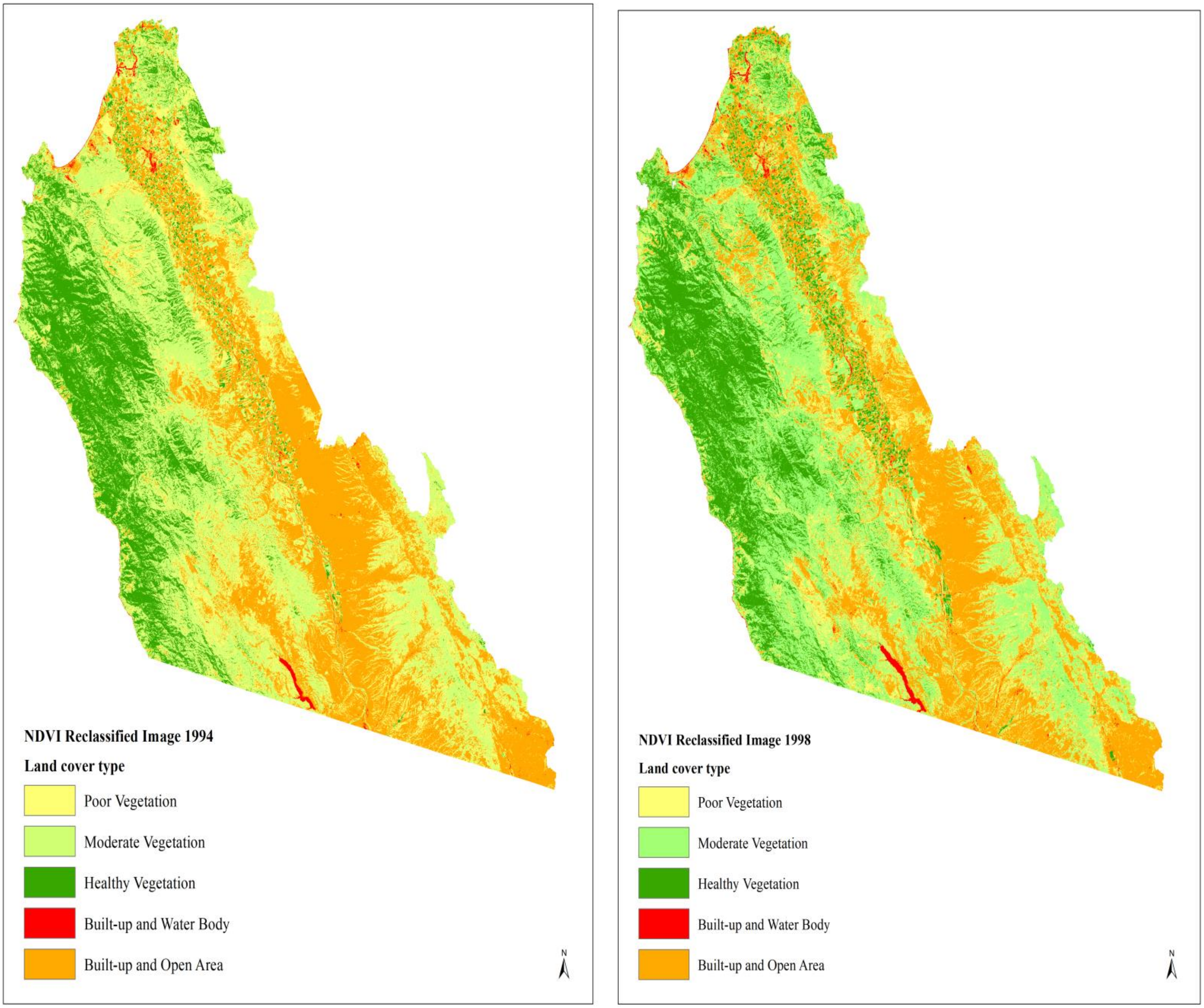


Figure 13: NDVI Image Reclassified 1994 and 1998

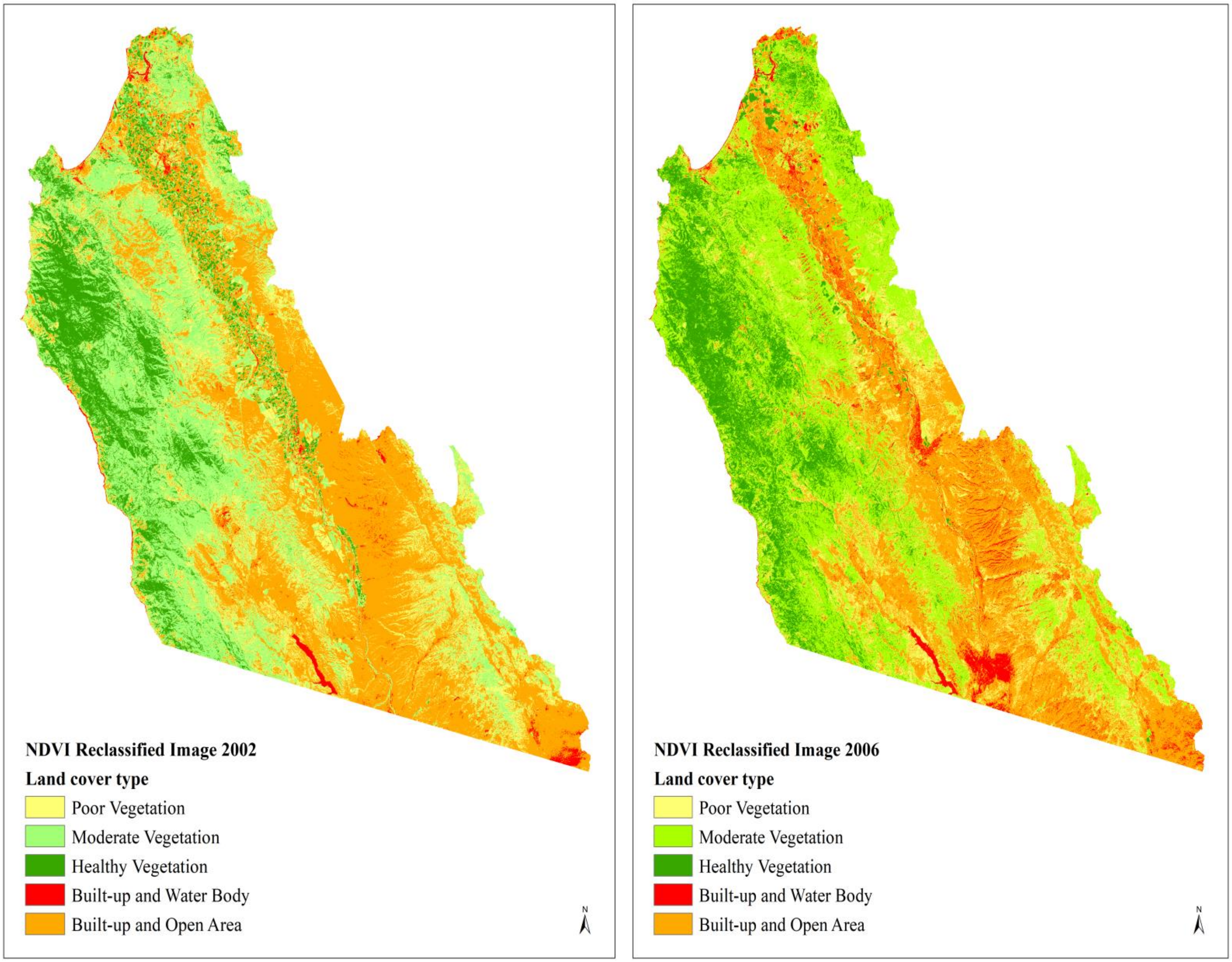


Figure 14:NDVI Image Reclassified 2002 and 2006

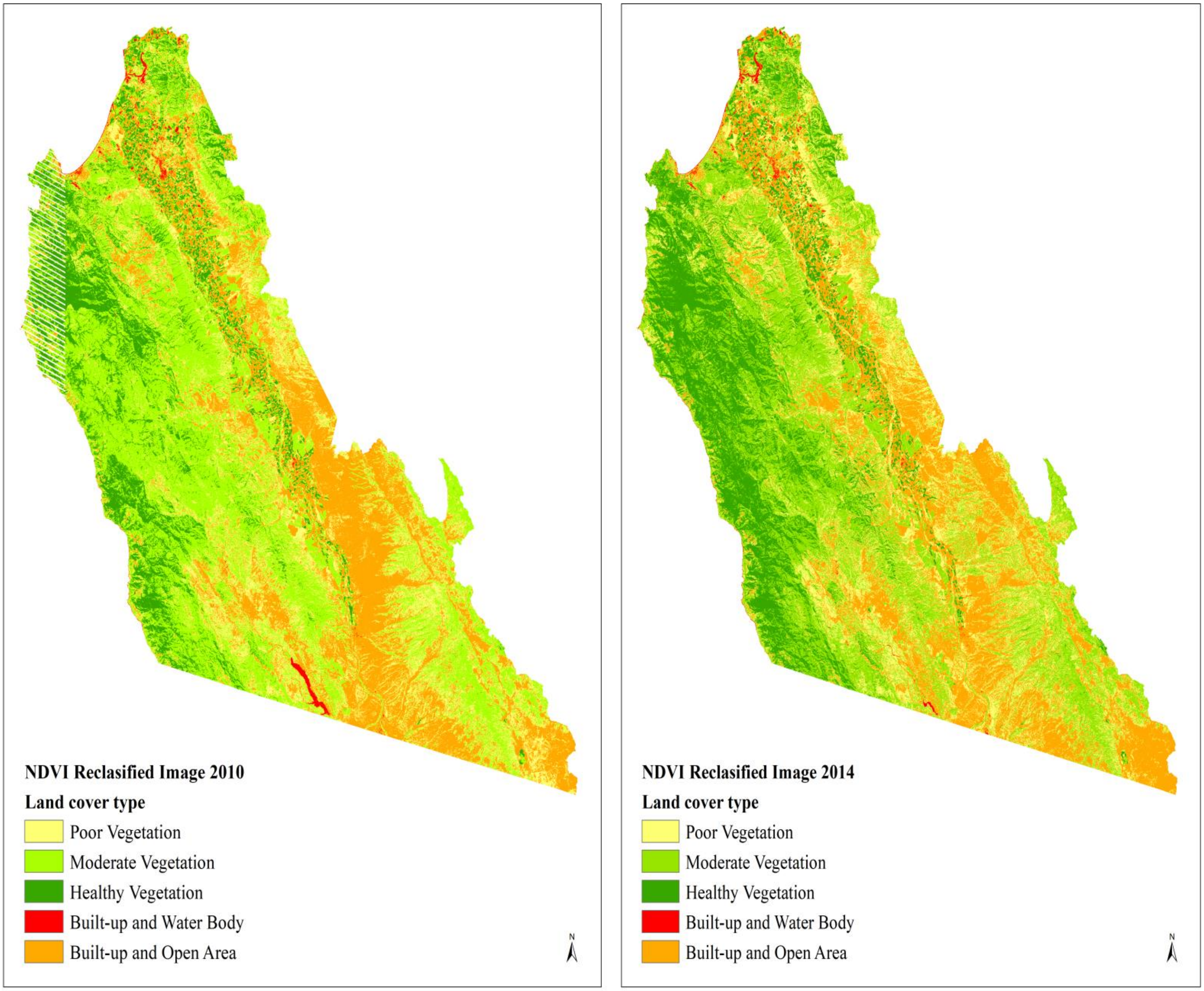


Figure 15: NDVI Image Reclassified 2010 and 2014

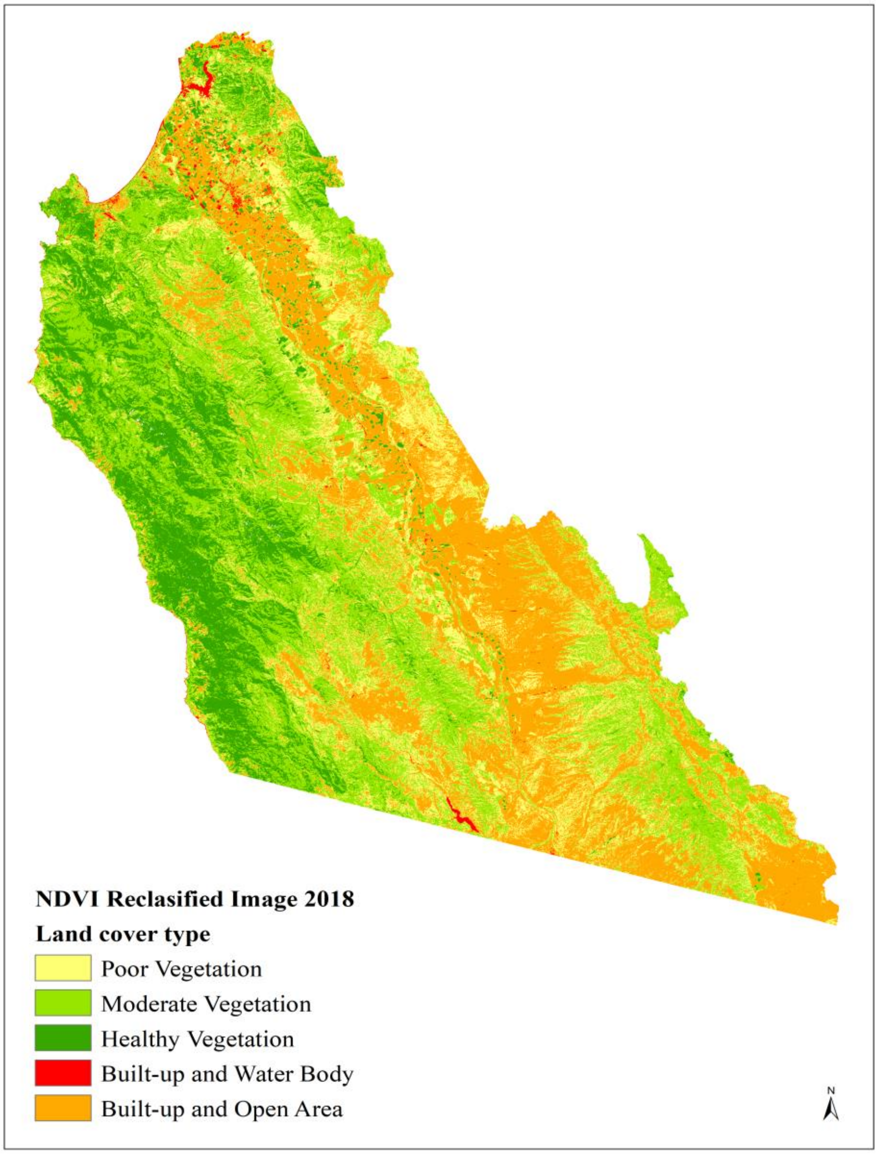


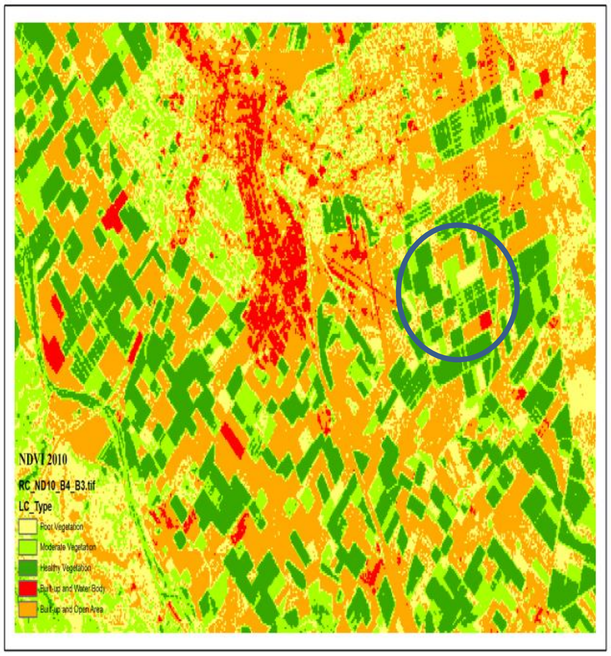
Figure 16: NDVI Image Reclassified 2018

4.1.2. NDVI image differencing and results

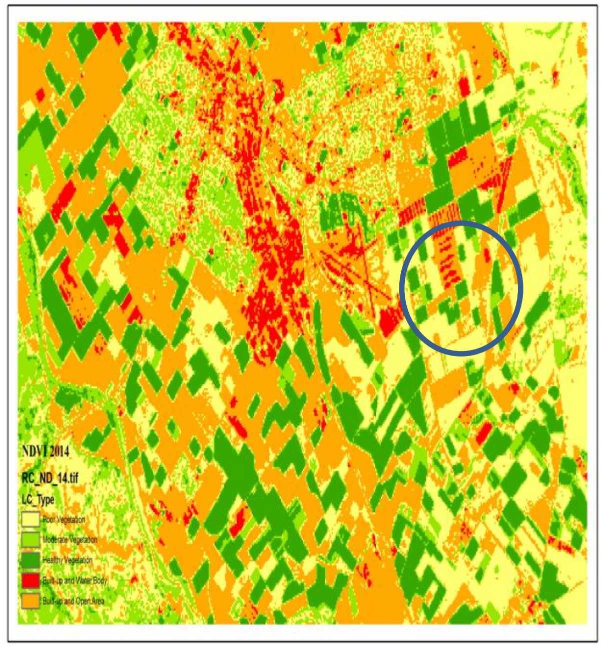
The NDVI differencing method involves subtracting $NDVI_{(t\text{-}4)}$ with $NDVI_{(t)}$. The difference in the image shows how the land use land cover has changed from the previous year. Raster Calculator from the Spatial Analyst toolbox in Arc GIS was used create the difference image. Difference images of 1994-1998, 1998-2002, 2002-2006, 2006-2010, 2010-2014 and 2014-2018 were created.

When two NDVI images are differenced, the NDVI values at each pixel is differenced with the other image. The resultant NDVI values of land cover with no change remains to be around zero. The gain in vegetation tends to have higher positive value and the loss or degradation in vegetation have values below zero. The waterbodies in the NDVI difference image have values in range of 0 to −1. If the water body has reduced in size, then the change in the NDVI values depend on the latest land cover trend. If there is gain in vegetation growth, it is shown to have positive value range, and if the area has changed to open barren land, then it shown to have values close to zero.

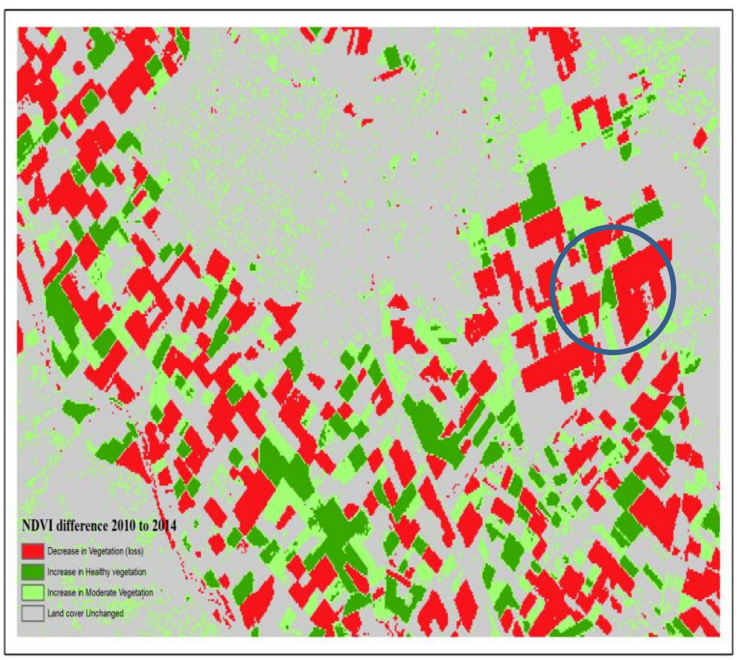
After the image differencing of the NDVI images, the difference image was compared with the two NDVI images used. Figure 16 shows the glimpse of NDVI image of 2010 (a) and 2014(b), and the difference image (c). Area under the blue circle in all three images can be observed to understand the land use change. Some areas which were green in image (a) has lost vegetation (degradation or loss) in the image (b). Therefore, the image (c) shows those areas as vegetation loss (in red). Similarly, increase vegetation cover is indicated by green color in the image (c).



(a)



(b)



(c)

Figure 17: NDVI Images of 2010 (a), 2014 (b) and NDVI difference image of 2010-2014 (c)

Land use land cover gain and loss has been fluctuating from 1994 to 2018. The vegetation loss in agricultural areas from 2002 to 2006 and 2014 to 2018 have been prominent. The vegetation gain could be seen from 2006 to 2010. Similarly, vegetation loss in open lands next to California coast was observed from 1998 to 2002 and 2002 to 2016. Observing the vegetation near the agricultural areas and open areas (forest lands) is important as it might indicate the availability of the milkweed plants in these areas. Analysis results indicate that the size of water bodies has been reducing since 2006. The vegetation around some the monarch sites have remained unchanged. The surrounding areas of the monarch sites have shown fluctuations in vegetation cover. Thus, indicating that monarch sites have not been affected negatively from 1994 to 2018.

The NDVI difference images were reclassified based on the pixel range and with visual verification with NDVI images of two years. The reclassified maps have been displayed in Figure 19 to 21.

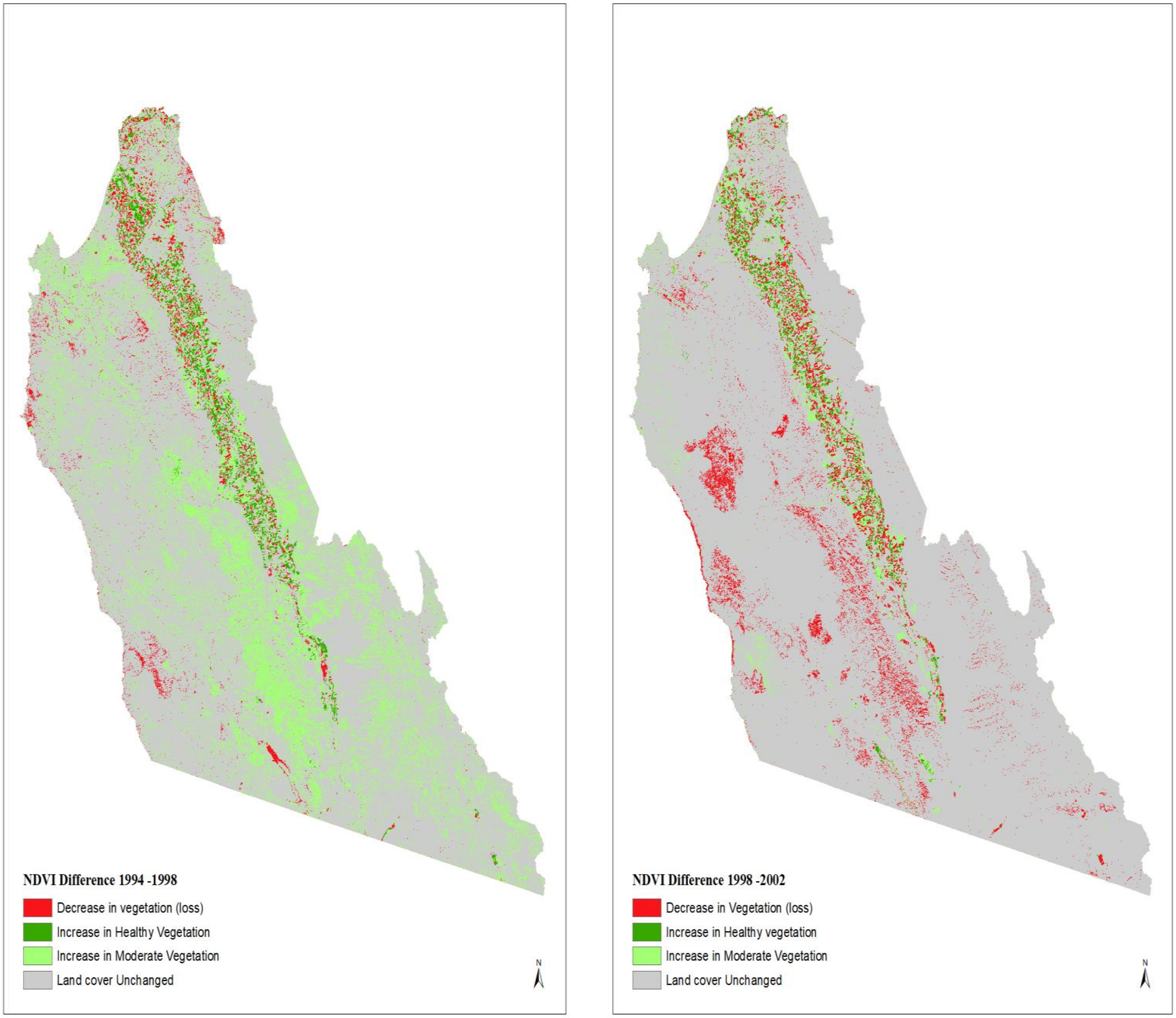


Figure 18: NDVI Difference Image

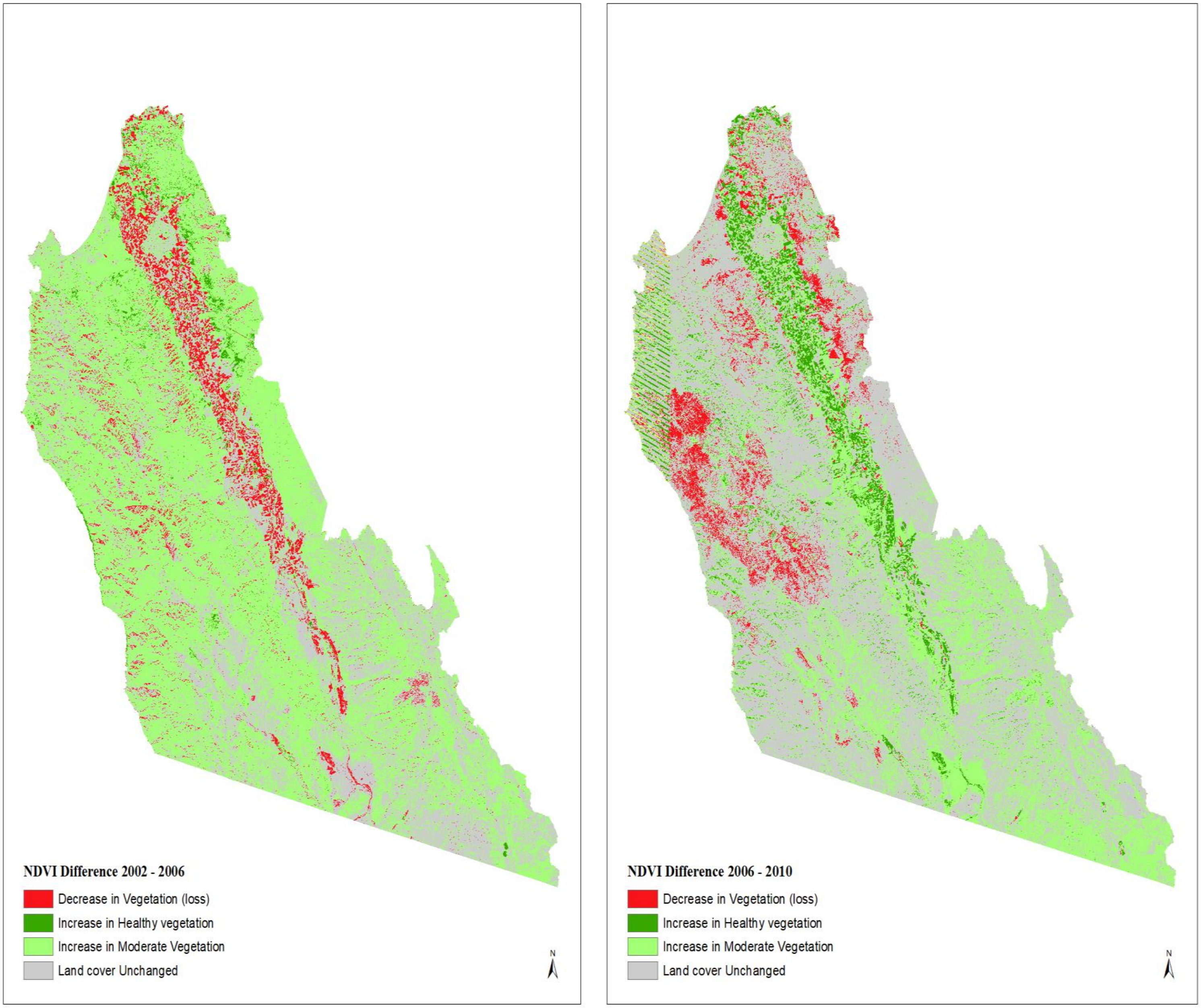


Figure 19: NDVI Difference Image

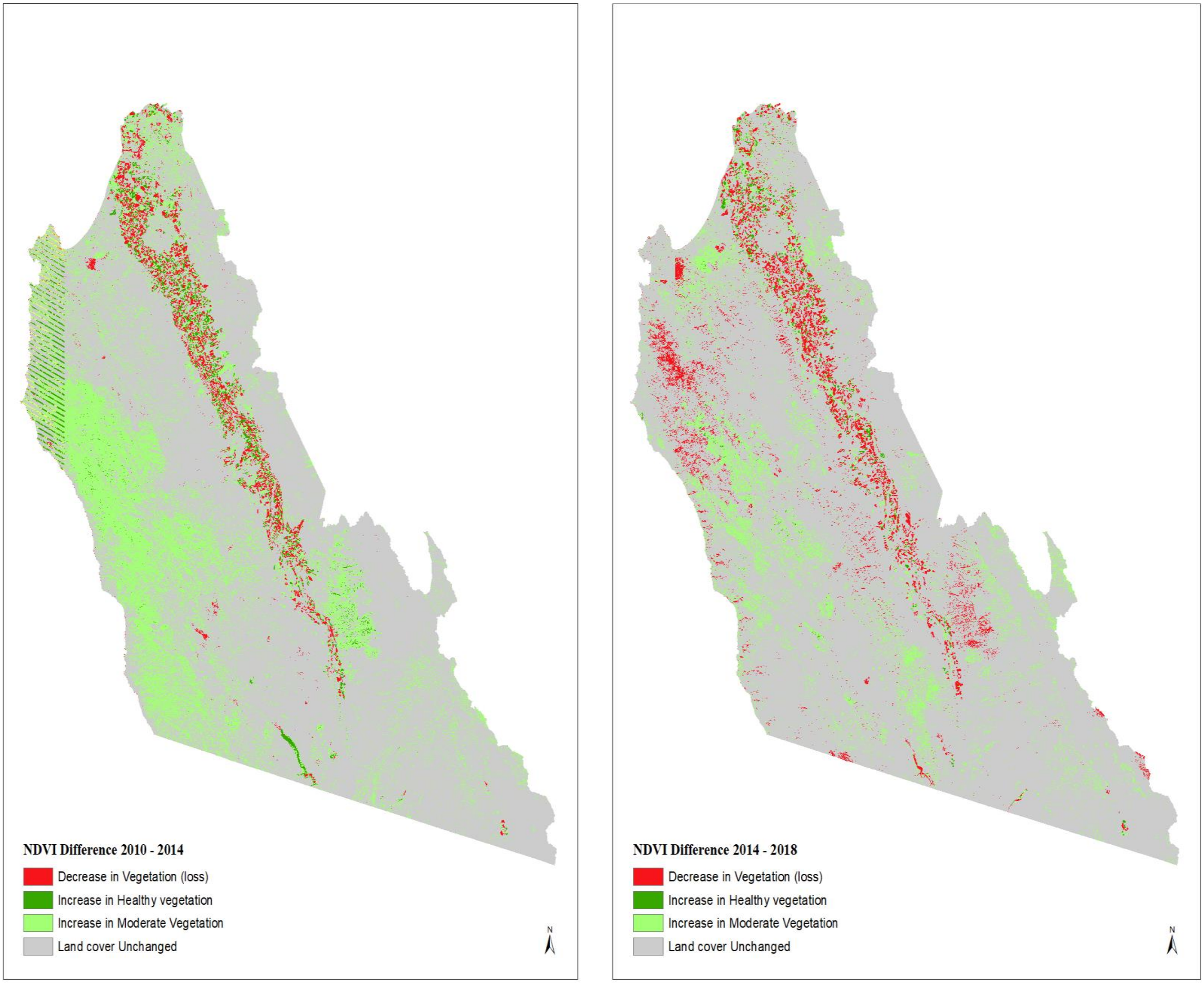


Figure 20: NDVI Difference Image

The Chart. 2 shows the change in land use land cover every four years. The raster table from the reclassified image was used to derive the percent change in the land cover. To simplify the land use land cover change, the reclassified image was divided into four categories: Increase in healthy vegetation; Increase in moderate vegetation; Land cover unchanged and Decrease in vegetation (or loss). From year 2002 to 2010 moderate vegetation cover increased in open areas, where as the healthy vegetation decreased significantly. The land cover changes from 1994 to 1998, and 2010 to 2014 have the same trend.

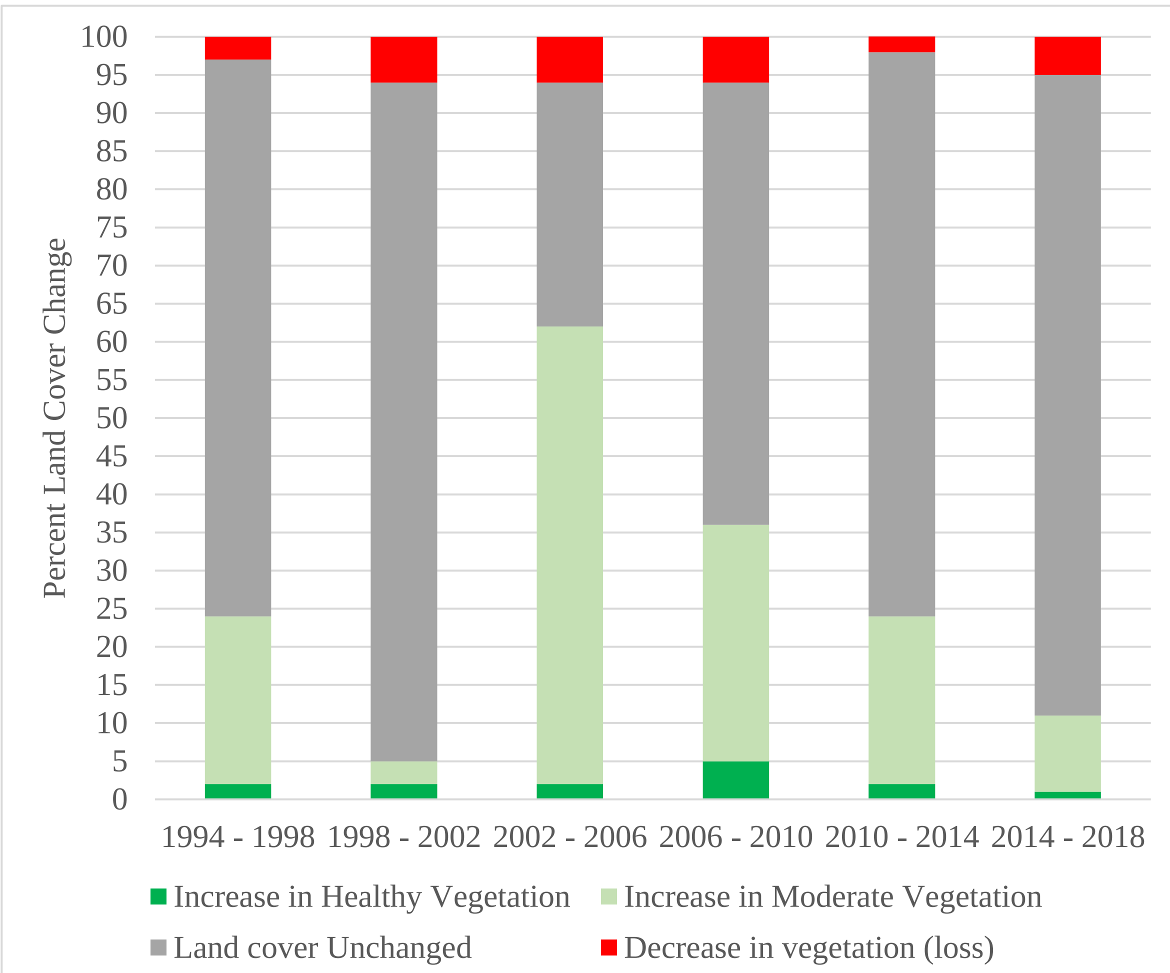


Chart 2: Land use land cover change in percentage derived from the reclassified NDVI difference image

4.2 Pesticide Use Report analysis

The purpose of this analysis was to find the geographical locations inside the county where the pesticide glyphosate was used, amount applied each year, the types of crop grown in the county, application method, and the trend of glyphosate use over the years. Each application of glyphosate reports the Section ID where it was applied, chemical name of herbicide, pounds and gallons applied, crop type (Site name), aerial or ground application method indicator, permit number, etc.

Analysis of the PUR table showed that approximately 68 crop types use the herbicide glyphosate in the county, almost each year (Table 5 below). The analysis indicated herbicide glyphosate was used in agricultural, commercial or institutional areas, structural areas, right of ways, agricultural research commodity crops, aquatic areas and other application through fumigation, each year.

Studies indicate that glyphosate is used where herbicide resistant, genetically modified crops such as corn, soybean, and cotton are grown. Therefore, identifying the crop types which use glyphosate was pertinent as part of the herbicide analysis. In this analysis, no records of use of glyphosate in corn (exception for year 2006), soybean and cotton crops were found. The results inferred either these crops are not grown in the county or these crops did not use glyphosate. Further investigation of California Department of agriculture and Monterey county crop reports (Yearly) showed (corroborated) that these crop types are not cultivated in the county from 1991 to 2015. However, glyphosate was applied on corn only once in 2006 in one section of the county, and approximately 52 pounds of chemical was used.

The herbicide analysis showed huge amount of glyphosate was used on grapes, uncultivated agricultural and non-agricultural lands, a total of 1451965, 568613 and 230805 pounds of glyphosate respectively, from 1991 to 2015. Each year, these areas use high amount of glyphosate

Chart 4 below, shows the crop type and pounds of glyphosate used each year. This chart gives an insight into different crop types and the usage of glyphosate. It also shows increase in use of glyphosate over the year for crops like grapes, citrus, lemons, right of ways and uncultivated agricultural areas. Application of glyphosate increased from 1996 to 2001 and from 2004 there has been a steady increase each year till 2015 (Chart. 4 and 5).

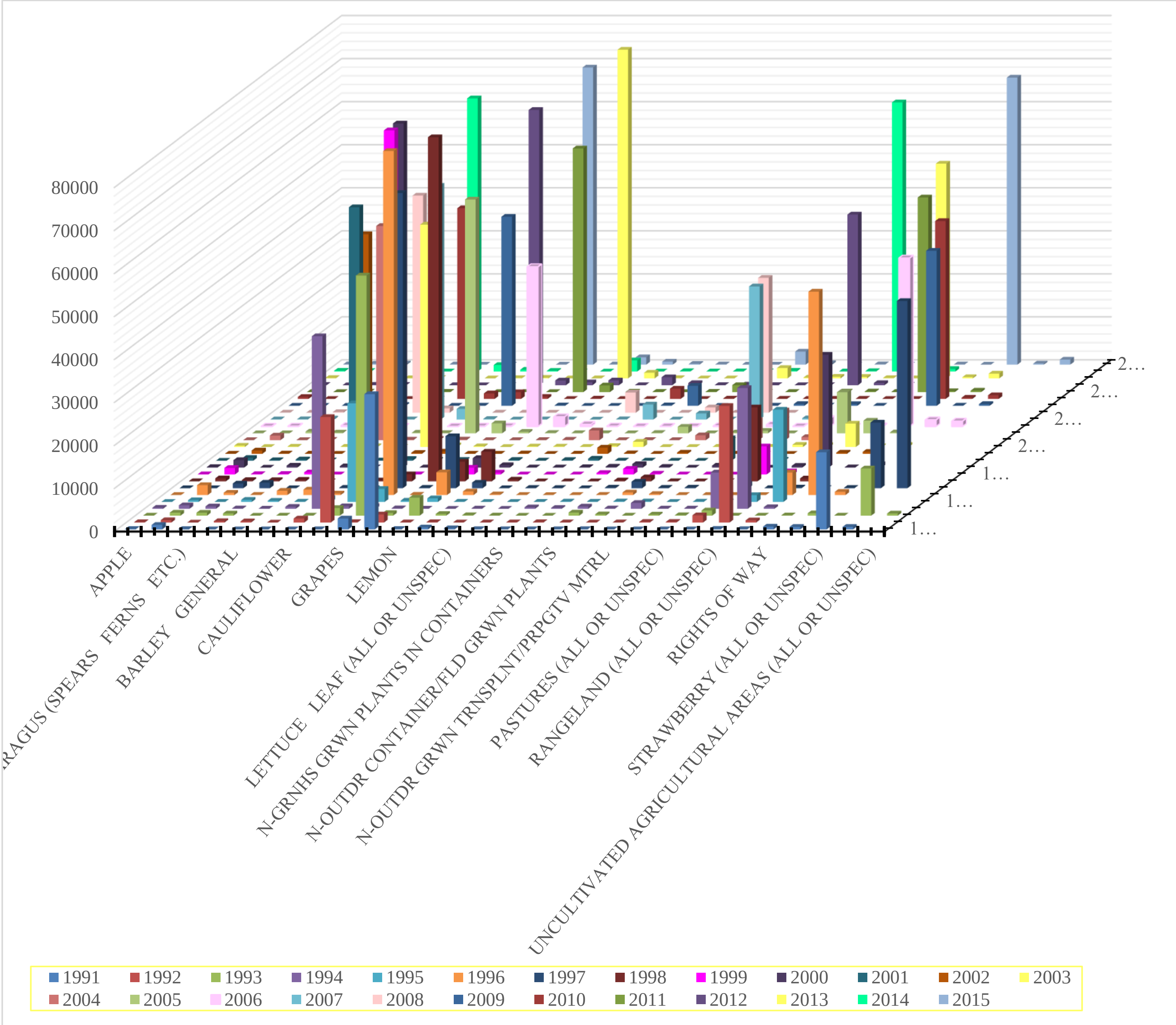


Chart 3: Crops and year wise pesticide glyphosate applied

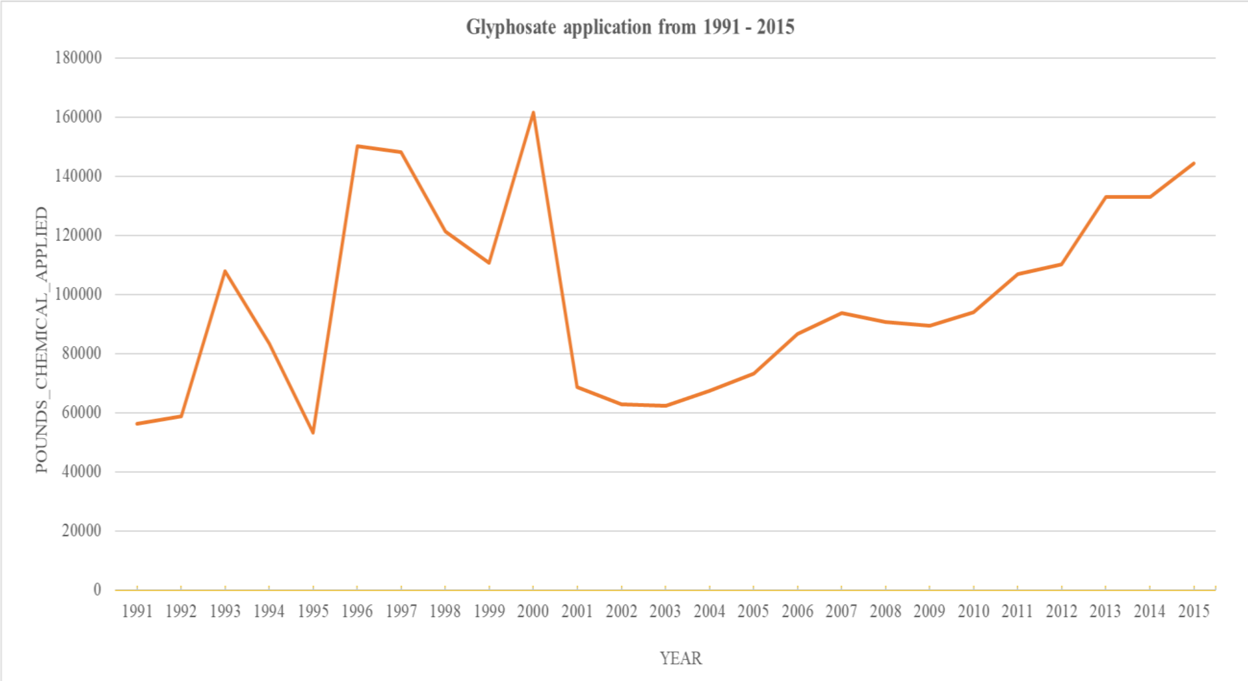


Chart 4: Pounds of Glyphosate applied each year

The types of crops grown in Monterey county are listed in the Table 5. Grapes, uncultivated agricultural areas and uncultivated non-agricultural areas are reported to use high amounts of glyphosate each year. Table 2 shows the cumulative pesticide used from 1991 to 2015 by each crop type. These are the same areas which use

Table 4: Crop Type and Pounds of Chemical Used

Site_Name	Sum(Pounds_Chemical_Applied)
Grapes, Wine	1,451,965
Uncultivated Agricultural Areas	568,613
Uncultivated Non-Ag Areas	230,805
Lettuce, Head	43,763
N-Outdoor Grown Transplant	31,174
Lemon	27,078
Asparagus (Spears, Ferns, Etc.)	15,415
Rangeland	14,170
Walnut (English Walnut, Persian Walnut)	13,065
N-Outdr Grwn Cut Flwrs Or Greens	12,974
Grapes	11,248

Approximately 98000 records in the PUR table were queried in MySQL and the results are displayed in Chart 3 and 4 and Table 5. Some of the queries designed are listed below:

```
SELECT YEAR, SITE_NAME, SUM(POUNDS_CHEMICAL_APPLIED) FROM PUR
Group by YEAR, SITE_NAME;
```

Data for the Chart 3 was derived from this query

```
SELECT YEAR, SUM(POUNDS_CHEMICAL_APPLIED) FROM PUR
Group by Year
Order by SUM(POUNDS_CHEMICAL_APPLIED) desc;
```

Data for the Chart 4 was derived from this query

```
SELECT COMTRS, Count (COMTRS), SITE_NAME,
SUM(POUNDS_CHEMICAL_APPLIED) FROM PUR
GROUP BY COMTRS, SITE_NAME
ORDER BY COMTRS, SITE_NAME;
```

Data to derive the pesticide use at section level was derived from this query. The result table was exported to Arc GIS where relationship between this table and section shapefile was created for further querying and analysis.

The results from queries were exported as table to Arc GIS to understand the geographical locations where glyphosate was applied. Initially, all the Section id listed in PUR were selected and displayed on map (Figure 12, Chapter 3). Though some of the areas are close to monarch winter sites, correlation could not be established with the monarch population decline. Grapes, uncultivated agricultural and non-agricultural lands, which use high amount of glyphosate is located geographically on the map in Figure. 22 and 23

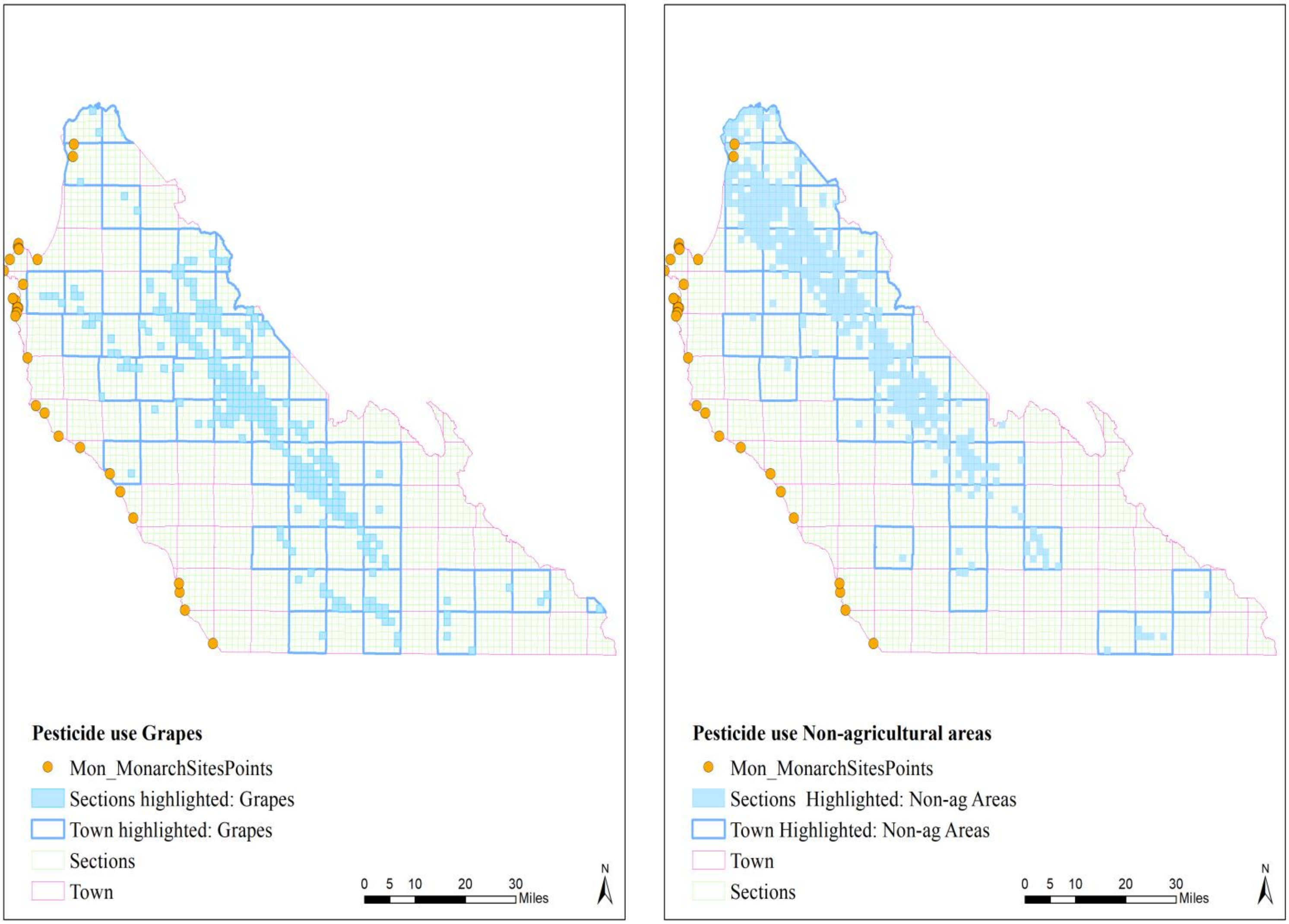


Figure 21: Glyphosate application in sections and towns based on crop type

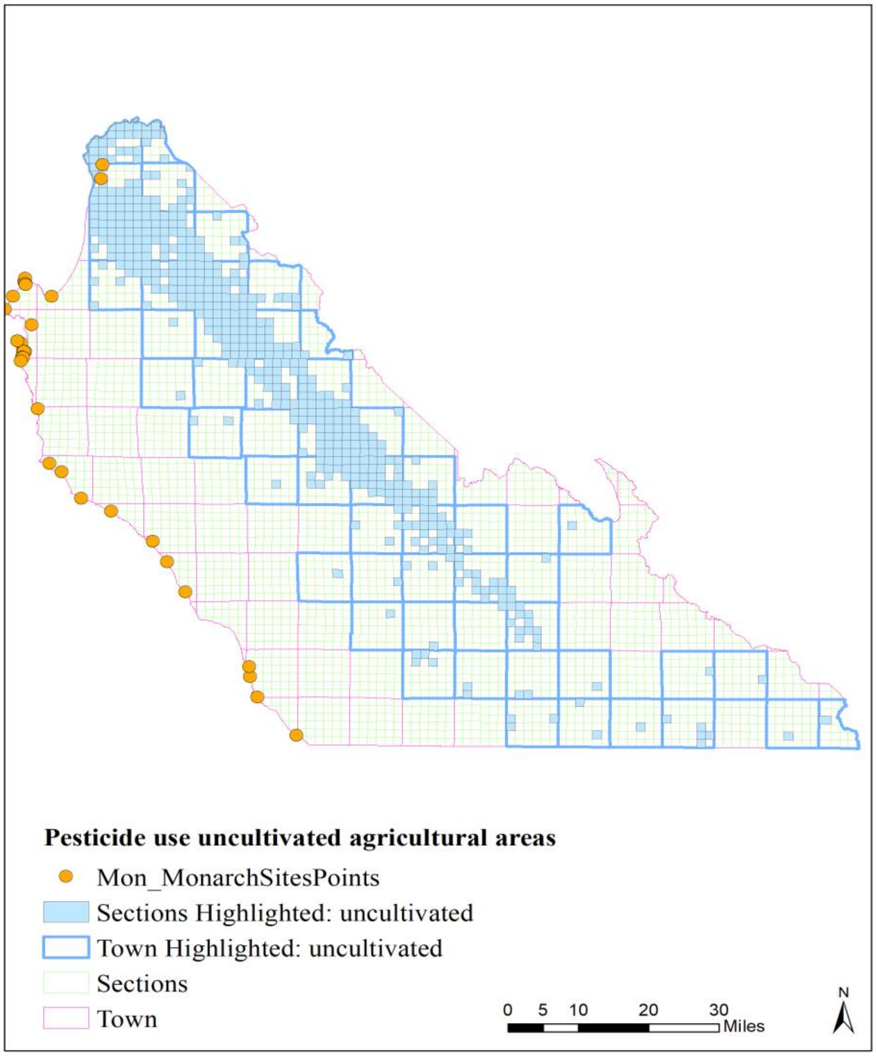


Figure 22: Glyphosate application in sections and towns based on crop type

4.3 Weather change analysis

The daily weather data from nearest weather stations located inside the Monterey county, managed by Institute of Pest Management, was used to identify the days of inclement weather in the past, i.e. from 1991 to 2015. The weather data table was queried in MySQL and the intent was to find the number of days during over wintering season which had either below freezing temperature with precipitation or days with above normal winter temperature. The query looked for days with below freezing temperature (24^0 F to 16^0 F) with precipitation, which could be catastrophic to monarch butterflies. Monarchs cannot survive when their wings are wet in freezing temperature as the water droplets from ice crystals and reduces the butterfly's body temperature. The query also searched for temperatures of 60^0 F and above as it tends to exhaust lipid reserves in the monarch body and forces them to come out of hibernation and look for food source (nectar and fresh water source), thus, burning their energy reserve (Calvert et al. 1983; Anderson and Brower 1996; Stenoien et al. 2018). Daily maximum and minimum temperature values, and precipitation data from November 1st to March 31st of the following year were queried.

The query designed for this analysis are follows:

```
SELECT Station, Date_record, Temp_max,Temp_min, Precip FROM
monarch_db.weather_montery
WHERE Month IN (1, 2, 3, 11, 12)  /* from November to March of the following year*/
AND Temp_min <= 30
ORDER BY Temp_max asc, Temp_min asc, Precip desc;
```

This query returned 159 records where the minimum temperature values were below 30^0 F, between November to March of the following year. Only two dates Feb-18-2006 and Dec-14-2008 recorded precipitation of 0.14mm and 0.12 mm respectively, with minimum temperature of 29^0 F.

Similar query where the maximum temperature above 70^0 F during winter season (Nov, Dec, Jan and Feb) was executed. The query returned 455 records, each indicating days where the temperature was above 70. The result was further queried to identify the days with highest recorded temperature between November to February. The first two weeks of November 1997, 2005, 2007, 2008, 2009, 2010, and 2014, recorded temperature above 90^0 F (hart 5)

```
SELECT Date_record, Precip, Year, Temp_max, Temp_min, Month FROM
weathertmax70new
 WHERE (Year, Month, Temp_max) in
 (SELECT Year, Month, max(Temp_max) FROM weathertmax70new
  GROUP BY Year, Month
  ORDER BY Year, Month;
```

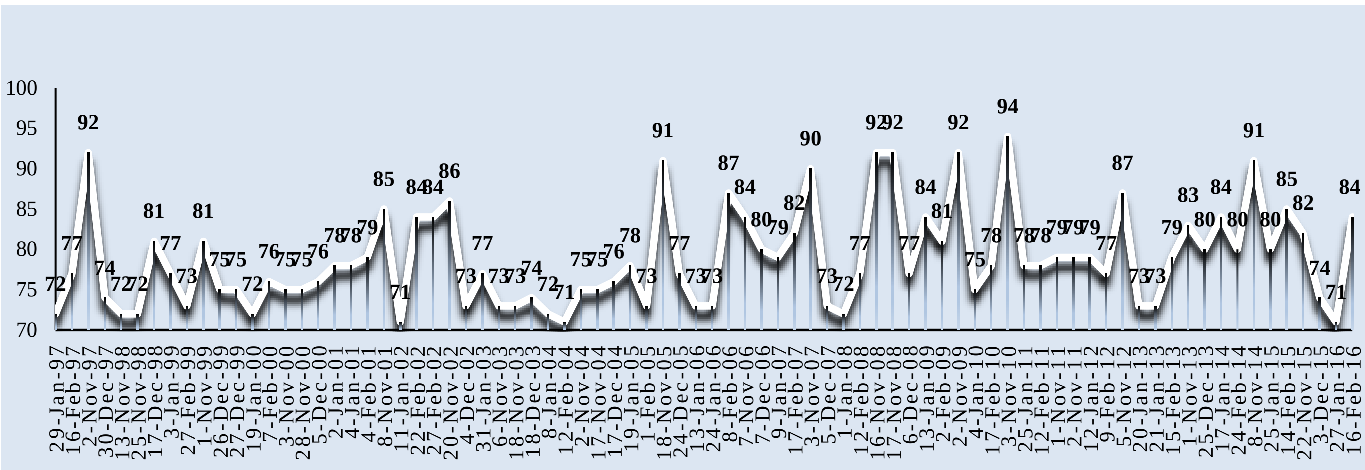


Chart 5: Highest temperature recorded monthly since 1997 to 2016

Temperature above 80^0 F and 90^0 F were observed during the first two week of November when the monarch colonies are not fully formed and the rooster sites are not fully established, and during the last two weeks of February, just before the onset of spring migration. Though studies do not indicate the effect of high temperature days on monarch butterfly during, this analysis is only an observation of the changing temperature pattern during overwintering season. However, studies do indicate that higher temperatures could trigger early onset of spring migration, and warmer temperatures were observed during February, but there is no data as to when the monarchs start their spring migration from overwinter sites in California each year.

This analyses and results were compared with the monarch yearly count (Chart 6) to understand if warmer winter temperatures had any effect on the monarch population.

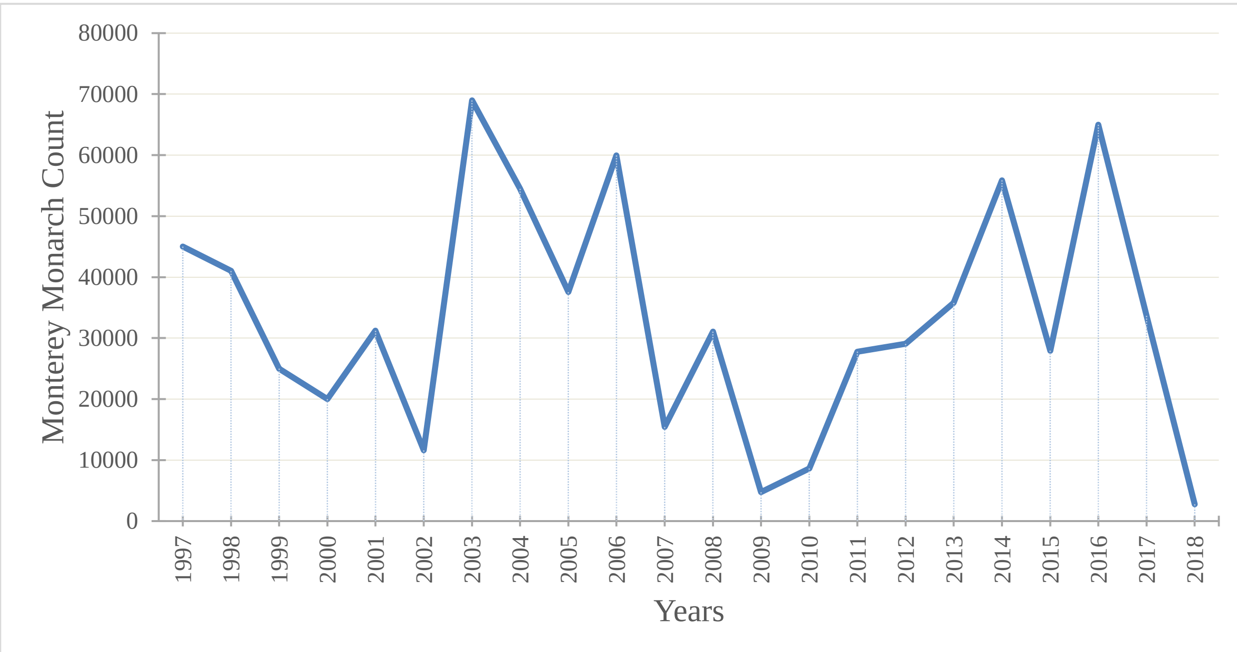


Chart 6: Monarch Yearly Count, Monterey County. *Source: Xerces Society*

Monarch yearly count takes place during the week of Thanksgiving in the month of November. This is the time period when monarch colonies and roosting sites are established for that winter season. Comparing the Thanksgiving count and high temperature data of a specific year do not indicate whether the decrease in population count from the previous year is due to the warmer temperature recorded.

The weather change analyses results did not indicate any above normal temperature days during winter (December January and February) . The historical weather data analyzed did not show unusual weather patterns. Therefore, there no correlation between weather change and monarch count during over wintering season could be established.

4.4 Conclusions

This project aimed to quantify the land use land cover change, analyze the pesticide usage trend, and to identify unusual weather patterns during the over wintering season. All the analyses were successful. The NDVI was a good indicator of the vegetation health, especially in the open areas and agricultural lands. The loss in healthy and moderate vegetation was visible in 2002 (Chart 2), however, there is no significant change in the land use land cover in the successive years. No other type of land cover change was noticed from one year to the other. The NDVI differencing of the two consecutive images showed the trend in vegetation gain, loss and unchanged land use. The vegetation loss from 1998 to 2002 and 2006 to 2010 in open areas and fluctuations in agricultural trend is evident through NDVI differencing. This method could be used in areas where ground truthing measurement is difficult to collect and supervised classification cannot be followed.

PUR analysis provided insights into the glyphosate application trend and types of crops and the geographical locations where they are grown. Some of the sites were close to the pesticide application areas (Fig 22 and 23, above). Grape cultivation is abundant in the county, which indicates the changes of milkweed to be found in those lands are to be low. However, there are many uncultivated agricultural and non-agricultural lands where the glyphosate use has been known to be high. Without ground survey, it is difficult to assume the presence or absence of milkweed in these areas.

Analyzing the weather data was straightforward, as it concentrated on identifying unusual weather pattern. The analysis was satisfactory as the results did not show days with inclement weather, which suggests there no catastrophic weather incidents in the past, which could have been harmful for the western monarchs.

The discussion of results from this project are discussed in the next Chapter. The future scope of research for better understanding the relationship between monarch population and land use land cover change, selecting different data sets, analysis methodologies, modeling and results expected are discussed in Chapter 5.

Chapter 5 Discussion

In this chapter, conclusions from the results of the analyses, and the future research that could be informed by this project are discussed in sections below. The datasets used in this project overall were useful in helping to understand the geographical locations of the monarch butterfly wintering sites and the land use land cover patterns in Monterey county. Analyses at the county level was imperative to understand the changes around the monarch winter sites. Though the data selected was relevant for the analyses and yielded a desirable outcome, due to spatio-temporal issues the results did not show change results at high resolution, specially near the monarch sites. The following sections explain the results from each analysis and their correlation.

5.1 Conclusion

The land use land cover change analysis shows that from 2006 to 2010 there was an increase in healthy vegetation from 2% to 5%, the highest in comparison with all other years examined in this study. The increase was primarily in the agricultural areas. The moderate vegetation cover however was reduced by 30% between 2006 and 2010, as compared to 2002 to 2006. The moderate vegetation was present in open areas and forest lands. Between 2002 and 2006, and 2006 to 2010, PUR analysis indicates that glyphosate use increased after 2006 after a sharp reduction of use in 2002. The monarch count increased in 2003 in comparison to 2002 and previous years. In 2002, 11,593 butterflies were counted for and in 2003 the number grew to 68,970. In 2006 there were approximately 60,000 butterflies and in 2007 only 15,426 butterflies were counted. Similarly, monarch population declined from 1997 to 2002 when the herbicide application peaked during the same time period. This might indicate a reduction in milkweed cover in the agricultural areas in Monterey county. This is a significant finding with an assumption that the milkweed availability decreased when glyphosate application increased, and it in turn was the cause of decline in monarch population. It suggests that the glyphosate application in the previous year either killed or reduced the milkweed abundance and when the monarchs started spring and summer migration the next year, there were few milkweeds nearby. Thus, these analyses might indicate scarcity of milkweeds may have led to the decline in monarch count the next year. Whenever there is a reduction in vegetation in agricultural areas (Figure 20 & 21), there has been reduction in glyphosate use and increase in monarch count. This calls for further analyze the land use land cover change and pesticide application trend of geographical areas which are in the monarch butterfly spring-summer migration path.

The weather change analysis did not show any inclement weather pattern during winter, thus indicating the weather has been conducive for the monarchs without any catastrophic events. No correlation could be established between weather pattern and the monarch count as the warmer temperature were recorded before the roosting sites and colonies were established, and Thanksgiving count. Minimum temperatures below 30^0 F were noticed, however there were no precipitation recorded, and the maximum temperature recorded were in the range of $45\text{-}65^0$ F for those days, which indicated these weather conditions were safe for the monarchs to survive.

This project could establish a relationship between the land use land cover change, pesticide use, and effect on monarch count. However, the land use land cover changes along the spring summer migration should be quantified to understand the cause leading to the decline in monarch population. It should be noted that the land use land cover changes in the winter habitat and spring-summer migration habitat will have an impact on the entire population of western monarch butterfly count.

5.2Future scope of work

There are many change detection techniques which can be applied to assess land use land cover changes, forest or vegetation change, deforestation, landscape, and environmental changes. Some of the change detection provides information about: change and rate of change of an area, spatial distribution, and accuracy of change detection results.

For most change detection techniques, thresholds must be identified to differentiate change from no change. Though algebraic methods such as image differencing, image regression, NDVI, and image ratioing using thresholds are adaptive and commonly used, these methods however cannot provide change matrices, and selecting a suitable threshold to identify the change is challenging (Lu et al. 2004). Selecting a suitable threshold is either through: (i) interactive procedure or manual trial and error by the analyst to reach the suitable threshold or, (ii) statistical method by selecting a suitable standard deviation from a class mean. The limitations of these methods are that the resultant difference might have an influence of atmospheric effect or subjective approach.

For more accurate change detection analysis, different change detections can be combined. The band pair differencing of spectral bands could be used with Principal Component Analysis (PCA) for multi-spectral image difference along with the application of other operations to combine different information from multi-spectral bands to a single image (Gong 1993; Lu et al. 2004). Post classification comparison is another method used for detecting land use change which provides a change detection matrix. This technique is useful for 'from-to' change analysis when used with image differencing. However, post classification is of limited use when used with historical data, as classification technique might not yield accurate results.

More advanced and frequently used models are: Generalized Linear Models (GLM) and integrated GIS and Remote sensing (Weng 2002) The advantage of using GLM for land use change detection is that it could be used in Species Distribution Modelling (SDM). SDM is suitable for distinguishing the factors affecting the ecology of a species suing topo-climatic predictors.

The datasets identified for this project could also be used for habitat suitability mapping (HSM). The habitat suitability model is best utilized when there is significant data on the actual observation of the species. For this project, we have the count of the monarch butterflies observed every year from 1997 to the present to confirm map predictions, as well as an understanding of habitat conditions. The variables used for HSM is like that of SDM, thus the usefulness of this model for this project shall be considered as the future scope of work.

The datasets identified for this project could be potentially used for direct assessment and quantifying the land cover changes in the monarch habitat and the surrounding areas. The change detection and quantifying the change help in understanding the habitat fragmentation (if incorporated in this thesis), which could potentially indicate the cause for absence of monarch butterflies in some of the winter site. Exploring PCA, GLM, suitability of HSM and SDM for identifying the absence of monarch butterflies or milkweed abundance in some of the significant sites shall be undertaken as future scope of work.

Different datasets such as Cropland Data layer (CDL) from National Agricultural Statistics Service, US Department of Agriculture (USDA), to quantify changes in the agricultural areas and high resolution multi-spectral imagery and DEM could be explored to analyze the changes in the monarch winter habitat sites. The Xerces Society for Invertebrate Conservation has been monitoring the tree clusters in the monarch winter sites. High resolution multi-spectral, multi-temporal imagery tiles covering the site location shall be explored for monitoring the changes in the sites, especially in the southward slope areas, where monarchs prefer to roost during winter.

In addition to capturing daily weather data and calculating the growing degree days (GDD) would be the next step in understanding the impact of temperature on the lifecycle of the monarch butterfly. The effects of weather can influence adult monarch activity or juvenile growth, and the growth of milkweeds (Zipkin et al. 2012). It is also helpful in understating the temperature during spring-summer as a form of climate envelop indicating the optimum conditions for the adults and juvenile to thrive. Correlating GDD and PUR might indicate the milkweed abundance and monarch survival capability.

The project focused on identifying days with inclement weather conditions during overwintering months, such as days with below freezing temperature, precipitation and above average winter temperatures. The data and results shall be further studied and queried to understand the cumulative weather conditions, and the trend during overwintering months and spring-summer months for each year. The trend maps then shall be compared with the previous and next year data, to understand the effect of changes in weather conditions during spring-summer and winter, on monarch population and vice-versa. Such analyses when combined with land use lover changes might indicate the vegetation health and host plant quality, both crucial for monarch butterfly to survive. Further analysis of the weather data is therefore crucial to understand cause of monarch population decline.

In this project, herbicide glyphosate application analyzed the crops types and the geographical areas where it was used, and the amount applied. The future work shall include identifying all the agricultural areas in the county where glyphosate is used and overlap with

NDVI images and NDVI difference image to understand the vegetation type (such as: moderate, healthy, open areas, etc.) and amount glyphosate used. Since glyphosate is known to kill all the vegetation present (except herbicide resistant crops), it would be interesting to identify the time period when the large amount of glyphosate is used and analyze the NDVI maps of before and after the application, specially in open areas (uncultivated agricultural areas and non-agricultural areas). As the future scope of the project, this analysis is being executed.

This concludes the project work, the analyses executed, results, and future scope of work. This project helped to understand the main factors affecting the monarch population. The land use land cover change pattern overs the years showed a relation with application of glyphosate, which affected the monarch yearly count. As mentioned in the future scope of work, a combination of change detection methods and datasets could be explored to find a method which could applied to the whole of western monarch spring-summer and winter habitat.

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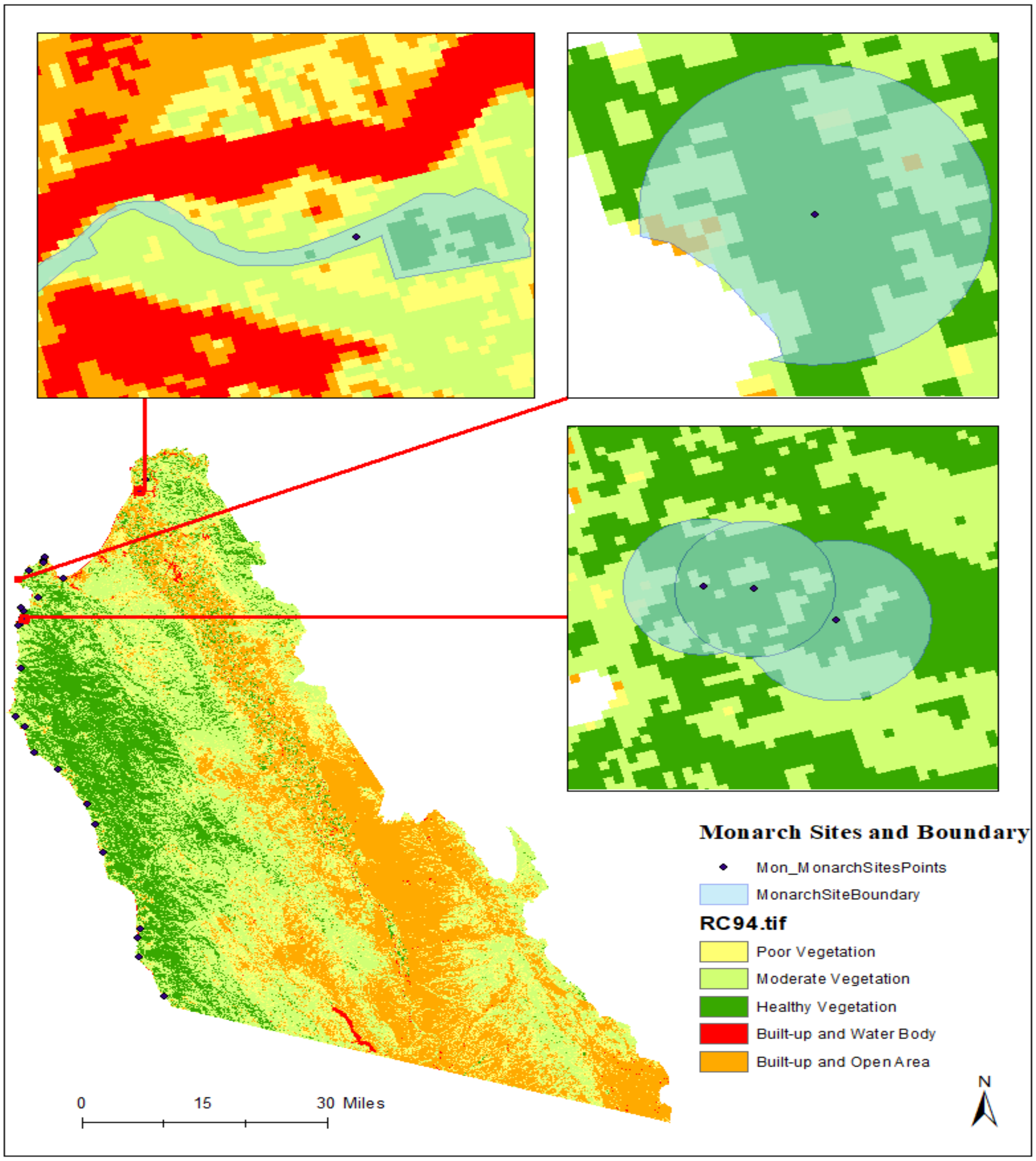
Appendix A: Monarch Sites and Boundary



Appendix 1: Monarch Sites and Boundary size (example)

Appendix Table 1: Monarch Overwinter Site Locations

OBJECTID	SITE NAME
1	Andrew Molera State Park
2	Big Creek Preserve
3	Butterfly Grove Sanctuary, Pacific Grove
4	Cabrillo Highway
5	CH1 Private Site
6	CH2 Private Site
7	Deer Flat Ranch
8	Del Monte Road
9	Los Padres National Forest/Caltrans Grove
10	McWay Canyon
11	Moss Landing Middle School, Moss Landing
12	Pacific Grove Golf Course
13	Palo Colorado, South of Carmel Highlands
14	Plaskett Creek, South of Big Sur
15	Point Lobos State Park, Carmel Bay
16	Prewitt Creek
17	Private Property near Big Sur
18	Sycamore Canyon, Big Sur
19	Washington Park, Pacific Grove
20	Yankee Point