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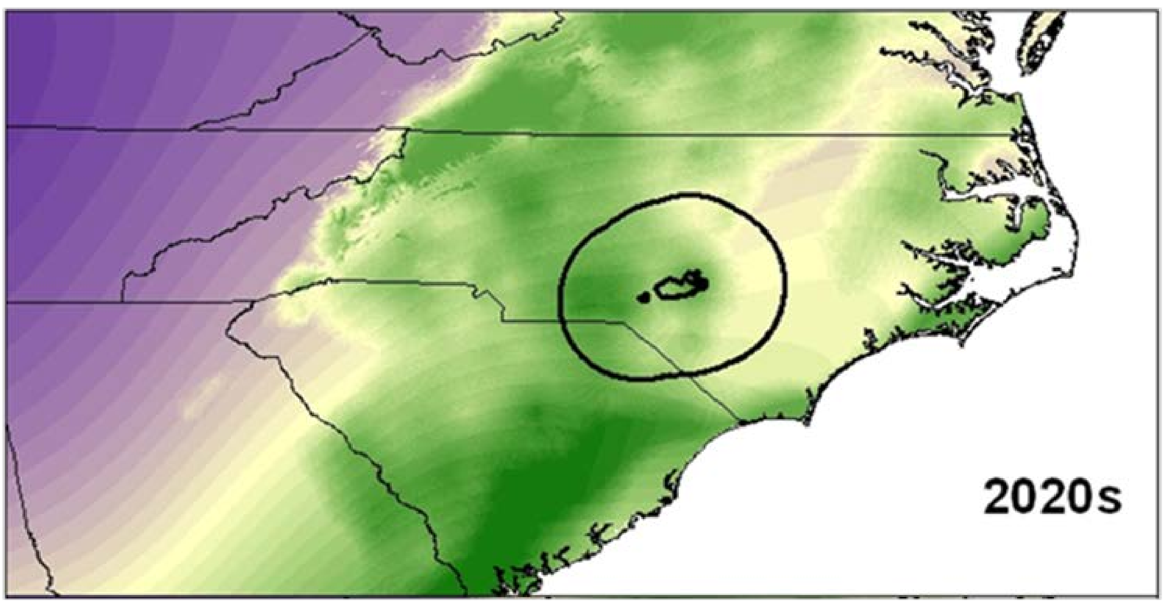
Climate Change Impacts on Fort Bragg, NC

Robert C. Lozar, Matthew Hiett, and James D. Westervelt

October 2013



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Final Report

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Abstract

Current guidance requires that climatic change must be considered in the Army's Integrated Natural Resources Management Plan (INRMP), the goal of which is to ensure good stewardship of natural resources that is compatible with the military mission, and that prevents the net loss of the lands required to complete that mission. Military land managers deal with their lands in the context of the local ecosystem in which they reside. If that ecosystem changes, the land manager must determine how to care for those changing lands while still supporting the installations military mission. Consideration of local consequences of climate change must begin with a review of the local manifestations and implications of climate change. This document uses an installation-specific evaluation and analysis of climate change forecasts for Fort Bragg, NC using currently available climate change data to provide a forecasting approach suitable for land-locked terrestrial Army installations.

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Preface

This study was conducted for the Engineering Research and Development Center (ERDC) under the project, "Framework for Forecasting Climate Change Effects on Installation Natural Resources" as part of the "Prediction and Adaptation of Military Natural Infrastructure in Response to Climate Change" work package under the direction of Dr. Timothy Hayden, CEERD-CN-N. The technical monitor was Alan Anderson, CEERD-CV-T.

The work was performed by the Environmental Processes Branch (CN-N) of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Dr. Timothy Hayden. Gratitude is extended to Julian Ramirez-Villegas, a PhD and Research Assistant in Decision and Policy Analysis at the International Center for Tropical Agriculture (CIAT, Cali, Colombia) and Carlos Navarro, research assistant at CIAT, for all their work in helping to provide both data and subsequent support of that data. This report would not have been possible without their important contributions. William Meyer is Chief, CEERD-CN-N, and Dr. John Bandy is Chief, CEERD-CF. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the US Army Engineer Research and Development Center (ERDC), US Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Kevin J. Wilson, and the Director of ERDC is Dr. Jeffery P. Holland.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
feet	0.3048	meters
gallons (US liquid)	0.003785412	cubic meters
inches	0.0254	meters
miles (US statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

1.1 Background

In February 2010, the President's Council on Environmental Quality (CEQ) issued draft guidance to all Federal agencies concerning the manner in which climate change should be included in the evaluation of environmental effects under the National Environmental Policy Act (NEPA) (OSD 2010). Under NEPA, Federal agencies are required to evaluate the environmental impacts of proposed Federal actions. Specifically, the guidance states that:

> With regard to the effects of climate change on the design of a proposed action and alternatives, Federal agencies must ensure the scientific and professional integrity of their assessment of the ways in which climate change is affecting or could affect environmental effects of the proposed action …
>
> Climate change can increase the vulnerability of a resource, ecosystem, or human community, causing a proposed action to result in consequences that are more damaging than prior experience with environmental impacts analysis might indicate …
>
> Agencies should consider the specific effects of the proposed action (including the proposed action's effect on the vulnerability of affected ecosystems) …

In the Quadrennial Defense Review (QDR) the Department of Defense (DoD) explicitly acknowledged that climate change will likely affect the nature and scope of future missions, as well as training and testing assets of military installations (OSD 2010). Specifically it says the military must:

- reliably assess the causes and consequences of climate change
- arrive at a coherent and robust understanding of a broad range of possible response options that *minimize adverse environmental consequence* and *maximize the likelihood of mission success* around the globe.

Current guidance requires that climatic change must be considered in the Army's Integrated Natural Resources Management Plan (INRMP). The purpose of the INRMP is to allow natural resource planners the ability to plan and implement landscape or ecosystem level management and to coordinate with other stakeholders in the region. INRMPs recognize that natural communities require multiple decades to mature and evolve. The INRMP's goal is to ensure good stewardship of natural resources that is compatible with the military mission, and that prevents the net loss of the lands required to complete that mission.

Military land managers deal with their lands in the context of the local ecosystem in which they reside. If that ecosystem changes, the land manager must determine how to care for those changing lands while still supporting the installations military mission. Consideration of local consequences of climate change must begin with a review of the local manifestations and implications of climate change. This work was undertaken to provide an initial, sample evaluation and analysis of currently available climate change data, and to offer an approach suitable for land-locked terrestrial Army installations.

1.2 Objective

The objectives of this work were to:

1. Perform an installation-specific analysis of climate change forecasts for Fort Bragg, NC
2. Evaluate the effects of those forecasts on:
    a. Fort Bragg's mission
    b. nearby ecosystems and forestry character
    c. specific environmental issues of concern to the military, including:
        (1) erosion
        (2) Threatened and Endangered Species (TES)
        (3) Invasive Species (IS).

1.3 Approach

This study used data derived from previous studies that predict climate characteristics and apply those metrics to the likely response of natural systems and how they might affect an Army installation's military mission. General Circulation Model outputs of temperature and precipitation were the basic metrics available. (Chapter 2 presents an abbreviated review of climate change research, specifically as it relates to the predicted spatial distribution of expected changes.)

Because installations must operate within living communities, these metrics were expanded by adopting a set of 20 derivative climate characterizations that have importance to living communities. The 20 metrics are more or less in line with an “industry standard” set used by many climate-biological researchers. (Chapter 3 briefly characterizes the installation, its mission, and the region. Chapter 4 describes the basic data used and its characteristics. Chapter 5 summarizes the results of many General Circulation Models and scenarios on 20 climate characteristics of importance to living communities for Fort Bragg.)

This report highlights the major changes that are projected to occur in the near term (by roughly 2025). Appendixes A-C include full descriptions of additional data and charts, covering time periods from 1990 (the baseline year) to 2099 (last year of the climate model forecasts).

Chapter 6 gives conclusions and recommendations regarding how climate change is likely to affect Fort Bragg, its lands, and its current mission.

1.4 Scope

This investigation reviewed the available literature that specifically supports the spatial distribution of climatic change predictions. No attempt was made to generate new predictions.

This study also assumed that the military missions at installations will remain the same as they are today. Specifically, this report focuses on Fort Bragg’s current mission and land management concerns, and how the installation will be affected by climate change.

1.5 Mode of technology transfer

This report will be made accessible through the World Wide Web (WWW) at URLs:

http://www.cecer.army.mil

http://libweb.erdc.usace.army.mil

2 A Brief Primer on Climate Change Research

2.1 General background to climate modeling

The most respected General Circulation Models generate predictions based on a set of conventions disseminated through the Intergovernmental Panel on Climate Change (IPCC 2007a), which acts as a coordinating organization, and which publishes reports intended to reflect the scientific consensus of the experts in the field. Standardization of the General Circulation Models is meant to facilitate comparison between models.

2.2 The scenarios upon which climate modeling efforts are based

One of the primary responsibilities of the IPCC is the arrangement of a series of standard future scenarios to assist with coordination and comparison between modeling efforts. This international standard set of scenario types is named after *The Special Report on Emissions Scenarios (SRES)*. The SRES was prepared by the IPCC for the Third Assessment Report (TAR) in 2001 on future emission scenarios to be used in Global Climate Models (GCMs) to develop climate change results. The SRES were also used for the Fourth Assessment Report (AR4) in 2007. Table 1 lists the four scenario families.

Table 1. The four *SRES* scenario families of the *Fourth Assessment Report* with associated projected global average surface temperature increase by 2099.

Homogenous: Global*	A1 Rapid economic growth (includes groups: A1T; A1B; A1FI) +1.4 – 6.4 °C	B1 Global environmental sustainability +1.1 – 2.9 °C
Heterogeneous: Regional/Local	A2 Regionally oriented economic growth +2.0 – 5.4 °C	B2 Local environmental sustainability +1.4 – 3.8 °C
*Table format drawn partially from IPCC (2011)		

This report used the three grayed blocks in Table 1:

A1(B): Globally homogenous rapid economic growth with a balanced usage of both fossil and non-fossil fuel energy sources

A2: Locally heterogeneous, regionally oriented economic growth

B1: Globally homogenous sustainable economic growth.

Note that all models are likely to predict changes between 1.1 to 6.4 °C increase by 2099. To interpret this in a slightly different perspective, the community agrees that there will be a change and that the temperature will increase no matter which alternative is followed.

2.3 The major climate models

Since the 1990s, the international climate change science community has participated in a series of efforts (often called *campaigns*) to carry out major, mostly coordinated attempts to exercise their best available modeling capabilities under similar sets of SRES scenarios. The most recent model results (the AR4) were used in this study (OSD 2009). About 21 major models were exercised while participating in AR4.

This research chose to use those models having had the greatest number of validation studies and those with the longest-period of development (1 to 2 decades):

1. GFDL Model – NOAA Princeton (gfdl_cm2_1)
2. NASA GISS (giss_model_er)
3. United Kingdom Hadley Model (ukmo_hadcm3)
4. Canadian (CCCma) Model (cccma_cgcm3_1_t47)
5. National Center for Atmospheric Research (NCAR) Boulder (ncar_ccsm3_0)
6. Australian Model (csiro_mk3_5).

2.4 Climate models and the data used in this report

GCMs geographically referenced data are gross in size. In fact, most GCMs output their results in a grid format that is roughly 3 by 3 degrees (~330 km at 30° north) in size (Figure 1). While potentially useful in describing regional changes (see Section 3.2, "Climate Change in the southeast United States," p 9), it was felt that using such generalized data would be less than satisfactory for military installation applications.

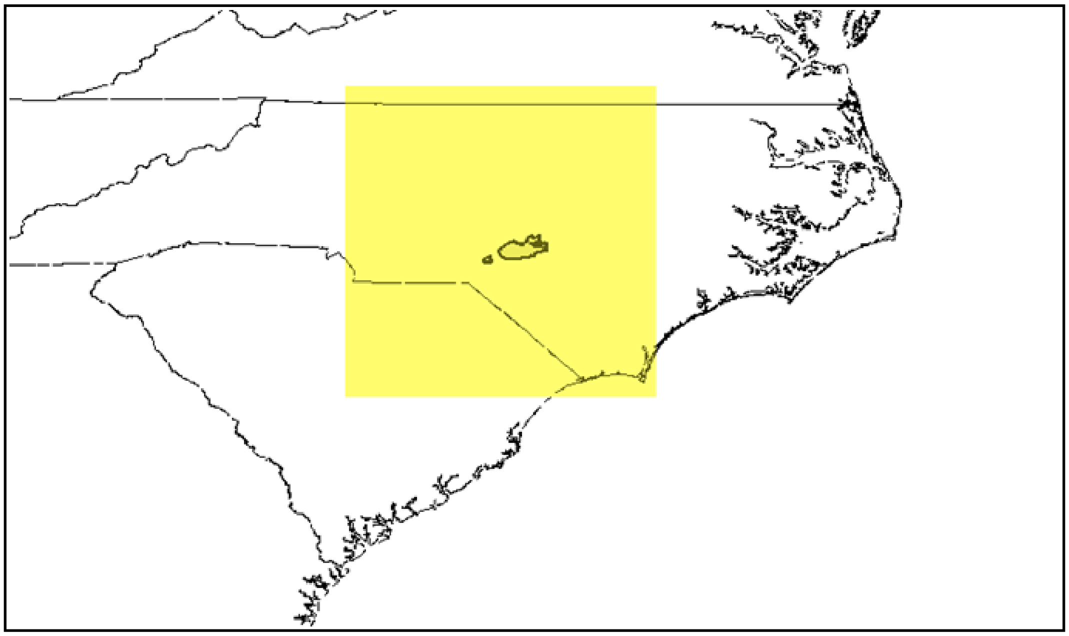

Figure 1. The coverage of a single temperature data point from Canadian cgcm3 model is shown in green.

Others in the field agreed that lack of local detail was an issue that needed to be addressed by the community (CC-LLNL 2012, CCAFS 2011), and have carried out "downscaling" on the GCM data. "Downscaling," or refining, the climate model results to specific regions involves considering more local concerns such as topography, surface winds, evaporation, and local precipitation (CC 2012). Downscaling of future climate scenarios using statistical approaches produces bits of information down to 1/8 degree resolution (about 13 km). Date at this scale becomes more interesting to specific locations and is the data scale used in this report. Figure 2 illustrates how improved the resolution is for the Fort Bragg area.

Another issue is that the GCMs generate values that represent weather conditions rather than climate conditions. That is, the intent of a GCM is to have built into the model a certain amount of randomness in the annual cycle. However, to characterize Fort Bliss, NC, this work required data that better represented climatic averages. Fortunately, others have perceived that there was a need to overcome these issues (Climate Central et al. 2012, CCAFS 2011) and have carried out the required data manipulations to generate predictive climatic data. The data used here are averaged over a 30-year period. Often, this report refers to the entire period explicitly, but for shorthand also uses the midpoint of the period instead. For example the period of 2010 to 2039 will be referred to as "2025." Also, in this report, the year 2025 refers to the "near term" or "planning time horizon."

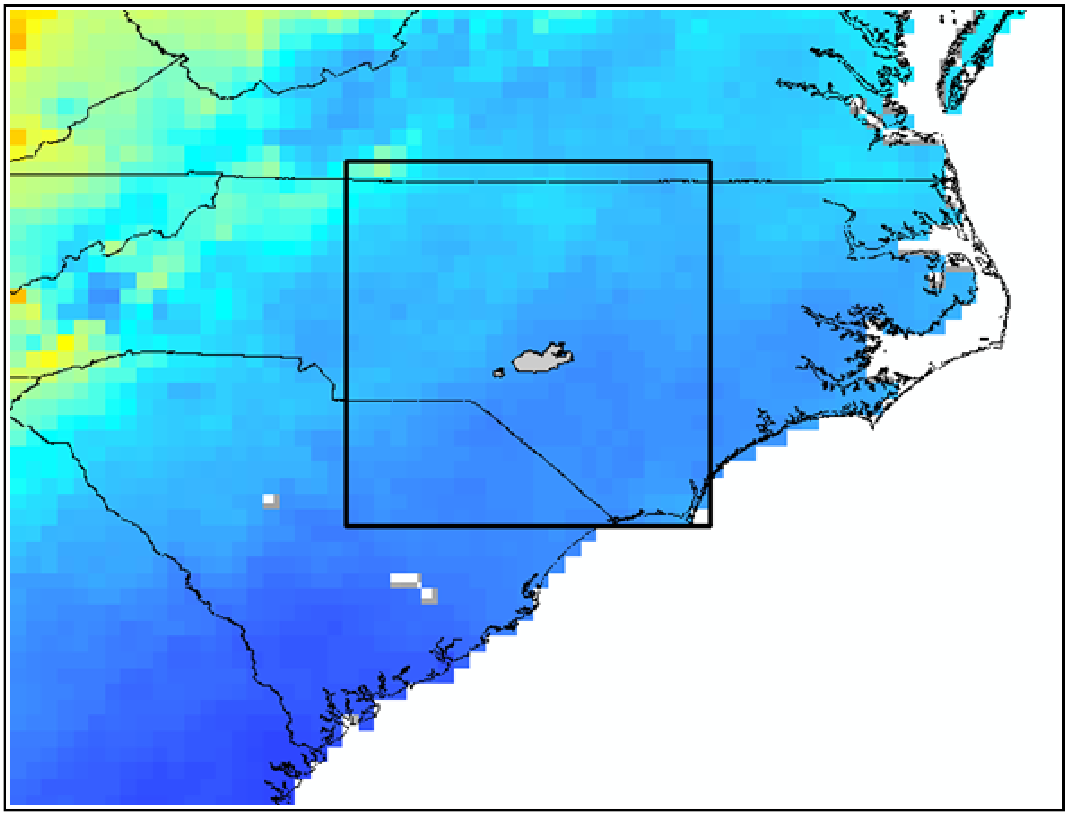

Figure 2. Improved resolution of “downscaled” data at ⅛ degree resolution. The square around Fort Bragg is 3° on edge - one GCM pixel. One can see the much greater detail available when downscaling is carried out on the same model for the year 2000 for monthly precipitation.

3 Fort Bragg Regional Characterization

3.1 Fort Bragg at the landscape scale

Fort Bragg is one of the Army's key installations. It is located in the southeast portion of the United States at the northern edge of an ecosystem called the "Sandhills" (Figure 3). It shares its ecosystem with several other major Army installations because when the reservations were established, the large areas of land in the Sandhills were inexpensive and available.

Fort Bragg is one of the homes of the standing Army (i.e., US Army Forces Command [FORSCOM]) with active lands for continuing military training. Its current mission is to support the Army's only airborne corps and airborne division, the elite "Green Berets," and the Army's largest support command.

A previous national scale review of climate impacts on military installation (Lozar et al. 2011) did *not* find that Fort Bragg was included among those Army installations at greatest risk because of climatic change. Thus, this report's analyses can be considered to be dealing with an installation with "average" climatic change issues.

Figure 3. The Sandhills ecosystem runs from Georgia to North Carolina and includes five major Army installations.

3.2 Climate Change in the southeast United States

Karl et al. (2009) describes regional climatic changes in the southeast United States. From the report's gross Southeastern regional perspective the major changes will be:

- The increase in the Southeastern summer heat index simulated by both the Hadley and Canadian models will likely affect human activity and possibly demographics in the Southeast during the 21st century.
- Agriculture could possibly benefit from increased CO_2 and modest warming (up to 3 to 4 °F, or 2 °C) as long as rainfall does not decline, but individual crop responses differ. Management adaptations could possibly offset potential losses in individual crop productivity due to increased evapotranspiration.
- Biological productivity of pine and hardwood forests will likely move northward as temperatures increase across the eastern United States. Hardwoods are more likely to benefit from increases in CO_2 and modest increases in temperature than pines. Physiological forest productivity and ecosystem models suggest that, without management adaptations, pine productivity is likely to increase by 11% by 2040 and 8% by 2100 across the Southeast compared to 1990 productivity. These models suggest that hardwood forest productivity will likely increase across the region, by 25% by 2090 compared to 1990 regional hardwood productivity.
- Water and air quality are concerns given the changes in temperature and precipitation that are simulated by climate models.
- Changes in minimum temperature, rainfall, and CO_2 will likely alter ecosystem structure, but interactions are difficult to model or predict, particularly relative to disturbance patterns.

Useful as regional analyses such as these may be, installation planning will benefit from an even more localized analysis. Thus the following chapters examine and evaluate downscaled data specifically for Fort Bragg.

4 Description of GCM Data Used To Characterize Fort Bragg

4.1 Data that characterize recent conditions (baseline)

To understand potential climate change, it is necessary to establish equivalent data and forecast metrics that will be used to compare the measured past with the forecasted future. Fortunately such datasets already exist. To represent "current" conditions, this work used the WorldClim dataset, which represents downscaled data from weather stations averaged over the period 1950-2000 (WorldClim 2012).

This dataset provides weather data at 30 arc-seconds (~8 km) resolution for average monthly minimum, maximum, and median temperature and average rainfall over the 50-year time period. These data were generated by establishing values at weather stations across the globe and then creating 3-dimensional spline equations that allow for interpolation for any terrestrial area on earth. The end result provides virtual weather station for any land area on earth. In addition to the monthly temperature and rainfall averages, bioclimatic data layers (described below) were also produced.

4.2 Data that predict climate conditions

Using the mathematical approaches used to generate the WorldClim dataset, the International Centre for Tropical Agriculture (CIAT) has downscaled future climate projections from the IPCC. Not only has CIAT downscaled and averaged GCM data, but it also makes available sets of the 20 bioclimatic parameters ("bioclim" data) that are useful in characterizing the biological environment and the predicted GCM changes (CCAFS 2011). These parameters (Table 2) represent many of the environmental factors that are considered to drive ecosystems and when changed, might have a stressing effect on the living environment in a locality. They are derived directly from the base temperature and precipitation data. Characteristics of the data are well documented at the CIAT web site.

The following sections describe some of the important characteristics of both the "current" and "predicted" data.

Table 2. Bioclimatic categories used for climate change evaluations.

Derived from Maximum and Minimum Temperature:		
BIO1	=	Annual Mean Temperature (C x 10)
BIO2	=	Mean Diurnal Range (Mean of monthly (max temp -min temp))
BIO3	=	Isothermality (mean diurnal range/temperature annual range)
BIO4	=	Temperature Seasonality (standard deviation *100) (C° x 10)
BIO5	=	Max Temperature of Warmest Month
BIO6	=	Minimum Temperature of Coldest Month
BIO7	=	Temperature Annual Range (P5-P6)
BIO8	=	Mean Temperature of Wettest Quarter
BIO9	=	Mean Temperature of Driest Quarter
BIO10	=	Mean Temperature of Warmest Quarter
BIO11	=	Mean Temperature of Coldest Quarter
Derived from Precipitation:		
BIO12	=	Annual Precipitation (in millimeters)
BIO13	=	Precipitation of Wettest Month
BIO14	=	Precipitation of Driest Month
BIO15	=	Precipitation Seasonality (Coefficient of Variation)
BIO16	=	Precipitation of Wettest Quarter
BIO17	=	Precipitation of Driest Quarter
BIO18	=	Precipitation of Warmest Quarter
BIO19	=	Precipitation of Coldest Quarter
Additional Datasets Available:		
BIO20	=	Consecutive Months – the maximum number of consecutive dry months of <100 MM in a year
Precipitation by Month (12 layers)		
Temperature Maximum by Month (12 layers)		
Temperature Mean by Month (12 layers)		
Temperature Minimum by Month (12 layers)		

4.2.1 Data are averaged over a few decades to get climatic data

The WorldClim site provided historical data that had been averaged over the course of 50 years between 1950 and 2000. The CIAT data are averaged over 30 years of GCM data with the average centered with 15 years of data on either side of the midpoint date. That is, the data meant to represent the “2025s” are an average of GCM output from 2010-2039.

4.2.2 Data include the six most respected GCMs of the IPCC models.

CIAT has processed forecasted climate data from many of the 21 major GCMs. This work extracted the data for the six most respected:

1. GFDL model (NOAA Princeton)
2. GISS Model e (NASA GISS)
3. UKMO (Hadley UK)
4. CCCMA (Canadian model)
5. CCSM3 (NCAR Boulder)
6. CSIRO (Australia).

4.2.3 Data includes three SRES scenarios

Each of the six GCMs was run with respect to these three greenhouse gas emission scenarios:

A1(B): Globally homogenous rapid economic growth (with B variation = a balanced usage of both fossil and non-fossil fuel energy sources)

A2: Locally heterogeneous, regionally oriented economic growth

B1: Globally homogenous sustainable economic growth.

4.2.4 Focus on reasonably near term data

With the baseline data from the 20th century, the time horizon and intervals for the data used are:

- Late 20th century or "current" also called 1990
- 2010-2039 (nominally2025)
- 2040-2069 (nominally2055)
- 2070-2099 (nominally2085).

Thus, the 2025 data represent a time frame of just over a dozen years from now, a time frame within a reasonable planning horizon for installations.

4.2.5 Dataset size

The complete dataset consists of 3740 maps that cover the world in a consistent manner. Therefore, each time a point is queried (e.g., the central point of Fort Bragg, the "centroid"); 3740 pieces of climatic data related to that point were received. Broken down, this is:

68 Current maps: 20 Bioclim + 12 months * 4 Temp-Rain Measures
204 Maps for each of 18 model/scenario combination:
(3 Time Periods * (20 Bioclim Maps + (12 Months * 4 Temp-Rain Maps))
A total of 3720 maps (68 + 18 * 204)

These maps provide a consistent dataset that allows comparison, for any land location on earth, of the past 50 years with climate forecasts generated by six GCMs for three different emission scenarios that cover three time periods during the 21st century. The next chapter examines this information for a single location in detail (data from Lozar, Hiett, and Westervelt 2012).

5 Change at Fort Bragg: the Big Picture

5.1 Percent changes

For each of the WorldClim/CIAT bioclim layers, Table 3 lists the consensus change at Fort Bragg. Each predictive box (uncolored) shows the value for that year that is the average of the prediction of the six GCMs and three scenarios (18 values each). Although a good deal of controversy may exist when examining a particular model, this work proposes that an average of 18 values represents a strong scientific consensus. This simple, easily understood technique, yields characterizations will be very close to reality, particularly in the near term (2025s). A color-coded percentage change value is presented to distinguish where the larger changes are projected to occur. Note that percent changes in temperature are based on Celsius and represent different magnitudes of change over the Celsius. The equation that generates the values in Table 3 is:

$$([\text{Value at } T_N - \text{Value at } T_{1990}]/[\text{Value at } T_{1990}])*100$$

Table 3. Average climate values for all 6 GCMs and three scenarios; green is less Than 10% change; yellow is 10-20% change; red is more than 20% change from the 1990 starting value.

Climatic Concern	1990	%chng 90-25	2010_2039	%chng-90 55	2040_2069	%chng-90 85	2070_2099
Annual Mean Temperature (x10)	157	7.0	168	13.8	179	18.5	186
Mean Diurnal Range (x10)	126	4.9	132	6.5	134	4.2	131
Isothermality(P2/P7) (* 100)	38	0.7	38	0.3	38	-2.5	37
Temperature Seasonality (SD *100)	7464	2.0	7613	4.3	7788	5.2	7854
Max Temperature of Warmest Month (x10)	315	4.9	331	9.1	344	11.9	352
Minimum Temperature of Coldest Month (x10)	-10	-52.8	-5	-102.8	0	-171.1	7
Temperature Annual Range (P5-P6) (x10)	325	3.2	335	5.6	343	6.2	345
Mean Temperature of Wettest Quarter (x10)	250	4.5	261	9.0	273	12.0	280
Mean Temperature of Driest Quarter (x10)	110	8.5	119	26.3	139	31.7	145
Mean Temperature of Warmest Quarter (x10)	250	5.1	263	10.0	275	13.5	284
Mean Temperature of Coldest Quarter (x10)	58	15.0	67	29.2	75	39.9	81
Annual Precipitation	1194	6.5	1272	10.0	1314	12.3	1341
Precipitation of Wettest Month	148	9.7	162	14.0	169	15.6	171
Precipitation of Driest Month	71	2.9	73	9.1	77	8.2	77
Precipitation Seasonality (Coefficient of Variation)	21	14.3	24	13.5	24	14.8	24
Precipitation of Wettest Quarter	394	9.1	430	11.5	439	13.1	446
Precipitation of Driest Quarter	235	5.1	247	10.0	259	10.0	259
Precipitation of Warmest Quarter	394	8.6	428	10.8	437	11.4	439
Precipitation of Coldest Quarter	272	3.6	282	8.1	294	10.8	301
Consecutive Dry Months	6	-33.3	4	-33.3	4	-50.0	3
Precipitation - January	91	2.1	93	2.3	93	8.9	99

Climatic Concern	1990	%chng 90-25	2010_2039	%chng-90 55	2040_2069	%chng-90 85	2070_2099
Precipitation - February	99	-0.8	98	4.8	104	6.8	106
Precipitation - March	104	5.5	110	10.7	115	16.5	121
Precipitation - April	80	10.3	88	21.7	97	22.8	98
Precipitation - May	93	7.8	100	9.1	101	13.7	106
Precipitation - June	117	9.5	128	9.6	128	10.7	130
Precipitation - July	148	9.2	162	13.2	168	15.6	171
Precipitation - August	129	7.1	138	9.1	141	8.3	140
Precipitation - September	98	4.3	102	5.6	104	7.0	105
Precipitation - October	82	3.3	85	0.3	82	4.9	86
Precipitation - November	71	8.4	77	17.8	84	16.4	83
Precipitation - December	82	10.7	91	18.5	97	17.6	96
Temperature Maximum - January (x10)	110	9.9	121	19.0	131	20.8	133
Temperature Maximum - February (x10)	128	7.0	137	14.8	147	19.3	153
Temperature Maximum - March (x10)	173	6.8	185	13.1	196	16.5	202
Temperature Maximum - April (x10)	228	6.1	242	10.4	252	12.5	257
Temperature Maximum - May (x10)	269	4.5	281	9.4	294	11.7	300
Temperature Maximum - June (x10)	300	4.7	314	8.9	327	11.5	335
Temperature Maximum - July (x10)	315	4.7	330	8.6	342	11.3	351
Temperature Maximum - August (x10)	310	5.7	328	9.4	339	12.6	349
Temperature Maximum - September (x10)	280	5.6	296	10.2	309	12.3	315
Temperature Maximum - October (x10)	228	6.8	244	13.5	259	15.9	264
Temperature Maximum - November (x10)	176	8.8	192	14.4	201	18.4	208
Temperature Maximum - December (x10)	124	10.4	137	19.4	148	22.9	152
Temperature Mean - January (x10)	50	17.1	59	32.3	66	40.9	70
Temperature Mean - February (x10)	64	11.1	71	22.8	79	36.5	87
Temperature Mean - March (x10)	106	9.2	116	17.8	125	25.6	133
Temperature Mean - April (x10)	158	7.1	169	13.1	179	17.2	185
Temperature Mean - May (x10)	203	5.4	214	10.8	225	14.9	233
Temperature Mean - June (x10)	240	4.4	251	9.5	263	13.1	272
Temperature Mean - July (x10)	258	4.7	270	9.5	283	12.9	291
Temperature Mean - August (x10)	254	5.8	269	10.5	281	13.9	289
Temperature Mean - September (x10)	221	5.3	233	11.0	245	14.3	253
Temperature Mean - October (x10)	160	8.3	173	17.0	187	21.8	195
Temperature Mean - November (x10)	108	11.2	120	19.7	129	27.0	137
Temperature Mean - December (x10)	62	15.2	71	30.5	81	40.1	87
Temperature Minimum - January (x10)	-10	-57.8	-4	-108.3	1	-175.6	8
Temperature Minimum - February (x10)	1	366.7	5	883.3	10	2038.9	21
Temperature Minimum - March (x10)	40	16.0	46	34.2	54	60.6	64
Temperature Minimum - April (x10)	89	7.5	96	18.0	105	27.1	113
Temperature Minimum - May (x10)	138	5.8	146	12.4	155	20.2	166
Temperature Minimum - June (x10)	180	3.6	187	10.2	198	15.5	208
Temperature Minimum - July (x10)	202	4.0	210	10.2	223	14.6	232
Temperature Minimum - August (x10)	198	5.6	209	12.1	222	15.7	229
Temperature Minimum - September (x10)	162	4.3	169	12.1	182	17.2	190
Temperature Minimum - October (x10)	93	10.2	102	23.5	115	34.3	125
Temperature Minimum - November (x10)	41	17.8	48	38.6	57	59.3	65
Temperature Minimum - December (x10)	-1	-644.4	5	-1438.9	13	-2200.0	21

Table 3 provides multiple insights into projected major climate changes at Fort Bragg. Almost all of the values are positive, indicating that over time there will be a continuous, though not necessarily large, increase in temperature and precipitation and related indicators. As projections move further out into the 21st century, more of the table turns yellow and red because, as change continues, more of the cells displayed move up to the next percentage change category.

Precipitation in the spring is projected to increase, but the most dramatic changes by far (the red) indicate that in the near term, the minimum temperatures for the winter months of December and January may significantly increase and that the consecutive dry months in the winter may also decrease. At Fort Bragg, the spring may become a little wetter, but the depth of winter would be warmer and the length of the dry season may decrease. Since the average winter low temperature is near freezing, this increase may have a significant effect if harmful insects normally removed by a regular hard freeze are able to survive.

5.2 Notable and near term changes

This section examines the highlighted data a little more closely. (Appendix A to this report details the concerns not discussed in this section.) The minimum temperature of the coldest month (Bio 6) showed up as important. Figure 4 summarizes the data. (Note that all of the following similar charts are derived from the same data as that listed in Table 3. Points that are averages and standard deviations are derived from 18 values each, and maximums and minimums are from single values.)

Figure 4 shows an average trend to increased temperature of the coldest month (an average of 0.9 °C), which is not as great as the change in the mean annual temperature trend. The standard deviations stay constant among the GCM predictions. What may be significant here is that one model (NCAR) predicts a large drop in the minimum in the immediate future. If the NCAR prediction is to be believed, Fort Bragg will experience much colder winters in the near term; certainly a change that will significantly affect the flora and fauna of the region. Only the NCAR GCM predicts a very low winter minimum. The fact that the average is not much affected by this anomaly and that the other GCMs values are in line with each other, indicate that the minimum winter temperature may rise slowly but significantly above the freezing point.

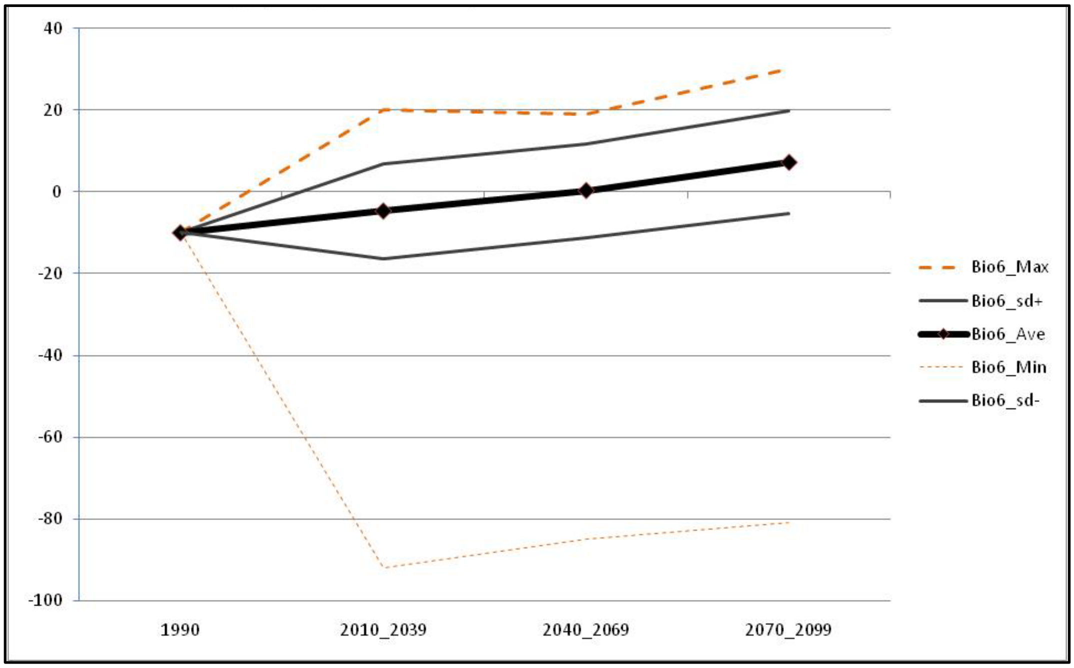

Figure 4. Minimum temperature of coldest month (°C x 10): average, SD, maximum, minimum all GCMs and scenarios.

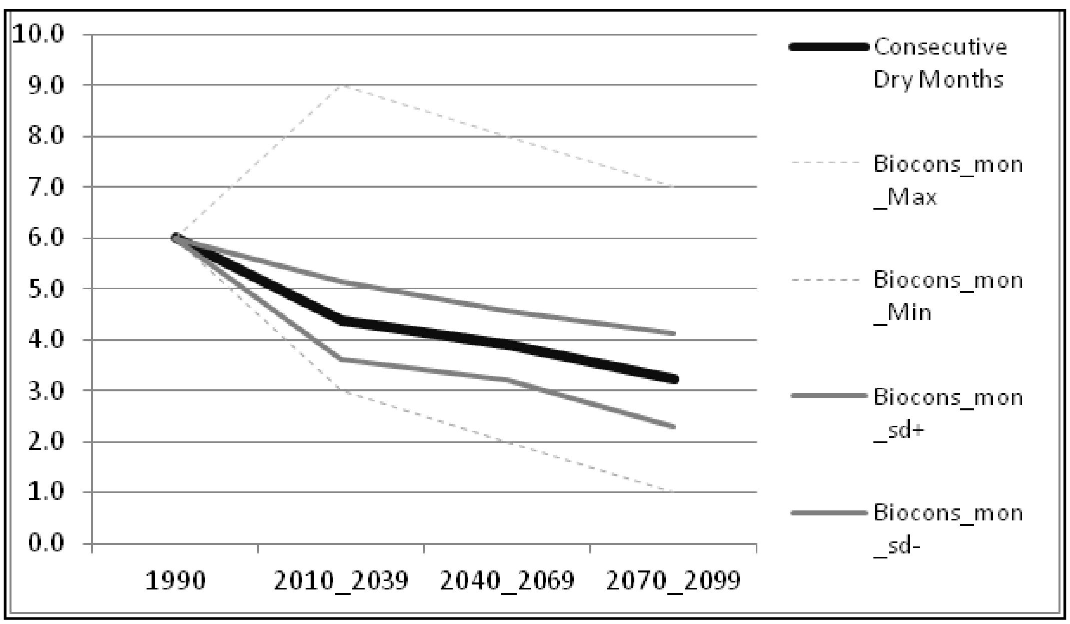

Figure 5. Bio 20 consecutive dry months: average, SD, maximum, minimum all GCMs and scenarios.

The chart shown in Figure 5 is striking in that the changes in the consecutive dry months are so great and that they happen principally in the near term. By about 2025, the normal number of successive dry months is projected to drop from a normal of 6 in a row to only 4.5, and this trend continues on into the future. This means that the normally long dry winter period will eventually be shorten by a half at Fort Bragg. This is an effect of a small change in the increased precipitation. For the mission at Fort Bragg this means there would be fewer days when fugitive dust is an issue, but many more days when mud on personnel and vehicles will be a problem for training and operations. All of the maximum values are estimated by the csiro_mk3_5 model in the A1B scenario while the minimums come from several model/scenario combinations.

Overall, long term climatic changes at Fort Bragg may include:

- Temperatures may go up by about 3 °C through the century.
- Winter minimum temperatures, which average near freezing, may rise so freezing days may become less numerous.
- Overall precipitation may increase so summer days in particular may become even hotter and muggier.
- Precipitation may increase more in the near term than in the long term.
- The winter dry season may decrease significantly in the near term.

Overall, short term changes at Fort Bragg increase more before 2025 than later in the century:

- Winter Lowest Temperatures may increase.
- Annual Precipitation may increase in the near term.
- Precipitation of Wettest Month (July) may increase in the near term.
- Precipitation of Wettest Quarter (summer) may increase in the near term.
- Precipitation of Warmest Quarter (summer) may increase in the near term.
- The winter dry season may shorten significantly in the near term.

An interpretation of near term changes suggests that those changes of significance that may occur at Fort Bragg will tend to mostly occur by 2025 rather than waiting until the end of the 21st century.

5.3 Climate change map interpretations

Data were acquired from many climate models and multiple SRES scenarios. It would be overwhelming (and not terribly helpful) to map every single combination of data, scenario, and model; instead, a “middle of the road” model and a single scenario were chosen to demonstrate projected changes at Fort Bragg in an cartographic format. All maps represent the A1b scenario in the CCCMA CGCM3.1/T47 from the Canadian Centre for Climate Modeling and Analysis. The values in all maps represent the difference between the indicated time period and the “baseline” representing the second half of the 20th century.

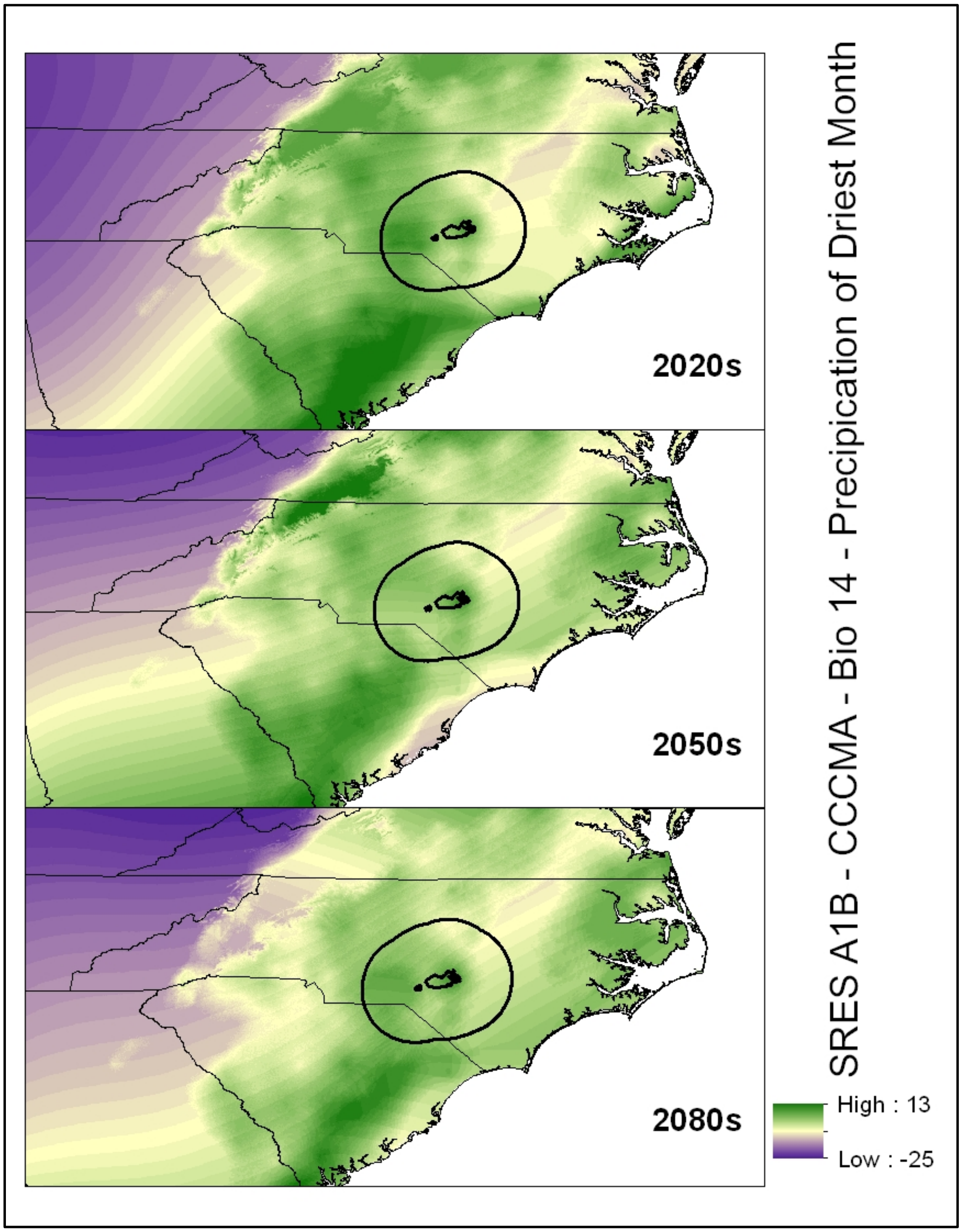

Figure 6. Map of Bragg region for Bio 14 - precipitation of driest month.

Figure 6 (in which measurements are given in millimeters) shows that precipitation in the driest month, usually November, is not projected to change dramatically in the future. The Fort Bragg area is due to gain some precipitation during the driest month, but only a maximum amount of 13 mm. Furthermore, the amount of increased precipitation is not expected to change dramatically between the 2025s and the 2085s indicating a moderated trend during that later time horizon.

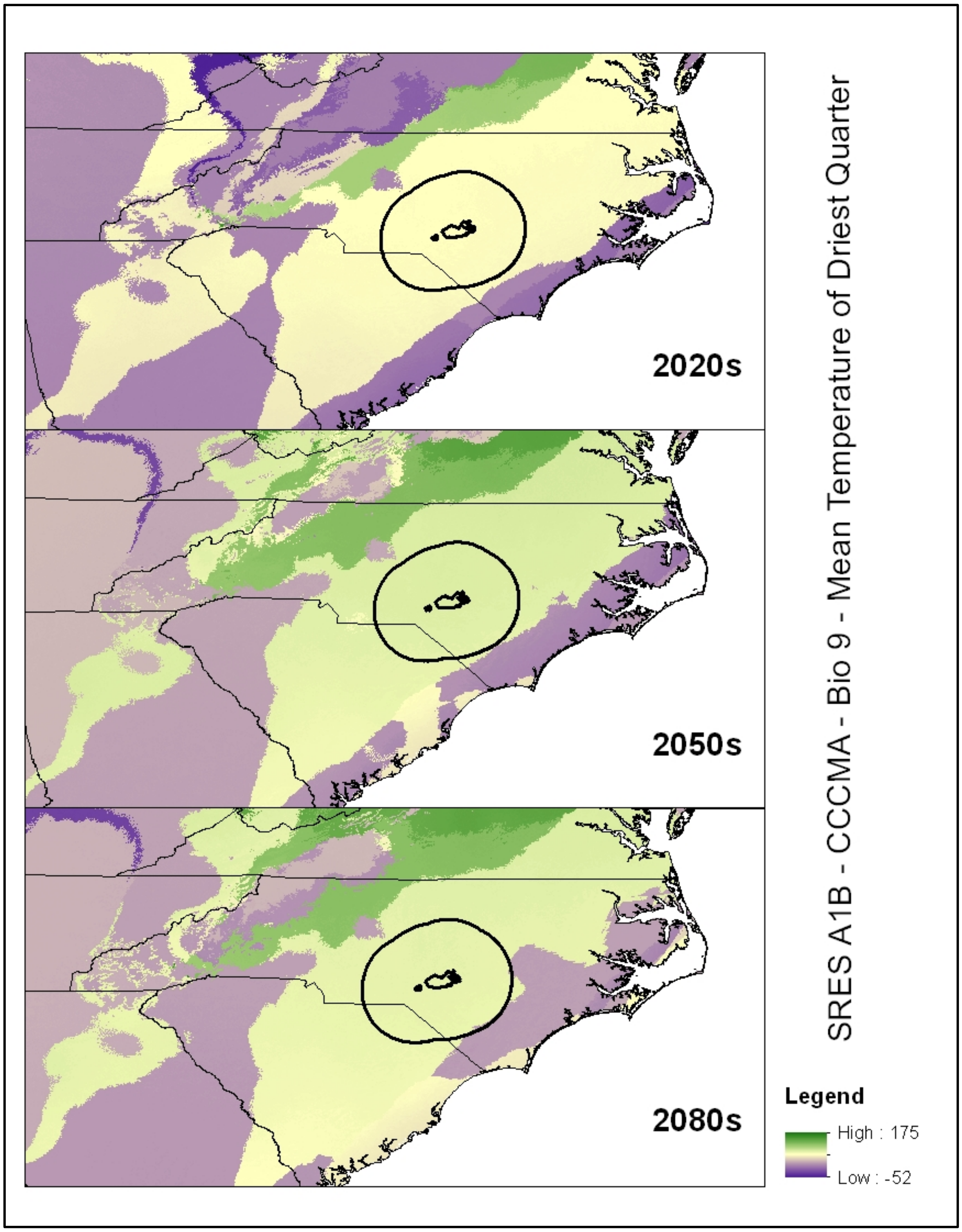

Figure 7. Map of Bragg region for Bio 9 — mean temperature of the driest quarter.

Figure 7 shows that the mean temperature of the driest quarter has the most distinct boundaries between values of any of the bioclimatic data. Fort Bragg is clearly included in a large area of very moderate change. By the 2025s, there appears to be no change at all from current conditions while the two later time steps show a very moderate increase.

5.4 Ecosystem changes

Historical climate change has had a profound effect on current biogeography; consequently, any ongoing and rapid climate change may be expected to have as great an effect. (Note that the following discussion was partly derived from BGCI [2012].)

Temperature effects (average, minimum, or maximum) are important determinants of plant distribution. For example, some plants are intolerant to cold as their single meristem is susceptible to frost. Since the winter temperature at Fort Bragg is projected to increase, this may be one of the major motivating concerns for change. Many boundaries between vegetation types are generally determined by summer warmth, which is expected to increase. Rainfall affects the balance of grasses to woody vegetation. This can be important for the change in landcover at the installation.

Climate change can affect local plant diversity. Some plant communities or species associations may be lost as species move and adapt at different rates. As the climate changes, some species are expected to be "left behind" as they are unable to respond in their distribution fast enough. Species with long life cycles and/or slow dispersal are particularly vulnerable. Further, isolated species like Red-cockaded woodpeckers are particularly vulnerable, as they may have "nowhere to go." Plant genetic composition may change in response to the selection pressure of climate change. Increased invasions by alien species may occur, as conditions become more suitable for exotic species while native species become less suited to their environment. This is especially true given human interventions that have deliberately and accidentally facilitated the spread of species across the globe.

CERL has developed future ecosystem maps for the Continental United States (CONUS) installations based on forecasts from GCMs and habitat classifications developed by the USGS GAP Analysis Program (GAP) program as correlated with William Hargrove's notional ecosystem maps (Hargrove and Hoffman 2004) based on the Hadley Centre model (HadCM3) and the NCAR Parallel Climate Models. The Hargrove approach applies a Multivariate Geographic Clustering (MGC) procedure simultaneously using nine sets representing the current global state and the eight forecasted future states. Each ecoregion map includes 30,000 unique clusters representing eco-units based on 17 input map layers. With the clusters, the data were reclassified to generate these analyses (explained in more detail in Lozar et al. [2011]). The result for Fort Bragg is very instructive (Figure 8).

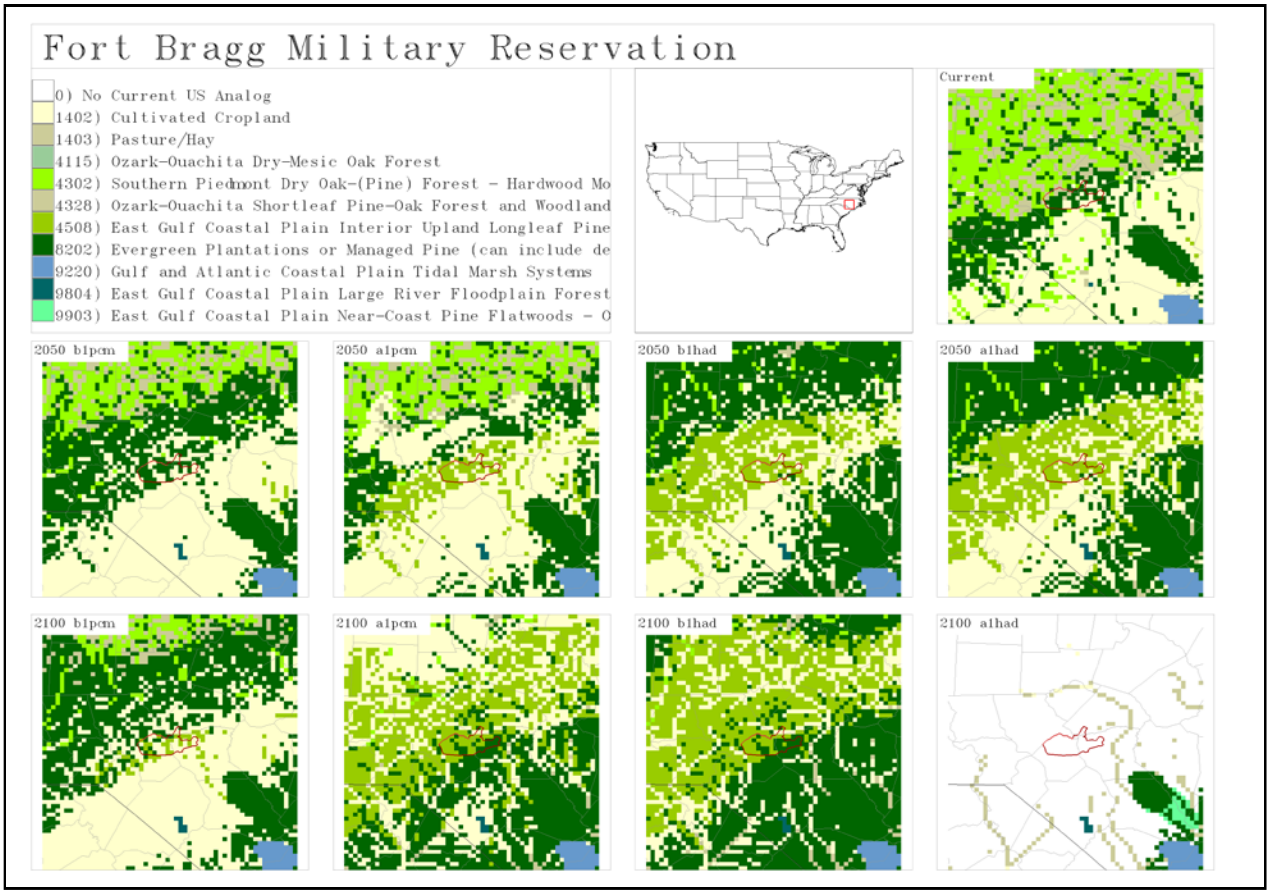

Figure 8. Predicted ecosystem types changes based on two models and two scenarios.

Fort Bragg currently resides in the Evergreen Plantations or Managed Pines landcover class and includes some cropland cover (Figure 8, upper right).* According to the B1 scenario (global environmental sustainability) in the conservative Parallel Climate Model (PCM) model (first column), the climate shift will favor something along the lines of Cultivated Cropland intermixed with East Gulf Coastal Plain Interior Upland. In the A1 scenario (rapid economic growth) in the PCM model (second column) the climate shift appears to favor a change to the East Gulf Coastal Plain Interior Upland with some Evergreen Plantations or Managed Pine Forest. Similarly, the B1 scenario (global environmental sustainability) in the more aggressive Hadley model (third column) predicts that climate change may again favor the change to an East Gulf Coastal Plain Interior Upland with some Evergreen Plantations or Managed Pine Forest ecosystem. Finally, the A1 scenario (rapid economic growth) in the Hadley model (fourth column) predicts that climate change might initially favor the East

* Note that classification of an ecosystem defined by anthropogenic intervention (agricultural lands and managed forests) does not imply that the model predicts future human behavior; rather, the closest current analog to the projected ecosystem has been defined by human modification of the landscape.

Gulf Coastal Plain Interior Upland ecosystem, but may be replaced in the long term by an ecosystem for which there is currently no counterpart (represented by white).

No matter whether the model under consideration is conservative or less moderate, the ecosystem at Fort Bragg is projected to change to something different, most likely to the currently more East Gulf Coastal Plain Interior Upland ecosystem.

5.5 Forest species migration studies

5.5.1 Migration studies background

An effort parallel to this work that deals primarily with Forest Service concerns has used similar background data and methods to generate species-specific changes over time (Hargrove Undated). The introduction for Dr. Hargrove's work states that:

> The maps in this atlas forecast future suitable habitat for North American forest tree species under two climate change models, and predict the parts of tree ranges that may be under the greatest climate change pressure. They have been generated using the multivariate spatio-temporal clustering (MSTC) technique.
>
> These maps are being used to assess the risk posed by climate change to the genetic integrity of North American forest tree populations. An additional objective is to make these maps available to scientists and policy-makers attempting to determine which species and populations should be targeted for monitoring efforts, conservation actions, and genetic diversity studies.

This section focuses on midterm (2050) predictions for the Hadley B1 Scenario. This can be seen as the model/scenario combination projecting the greatest changes. If Dr. Hargrove's maps suggest significant changes in distributions at Fort Bragg, they are presented here. If the maps are of interest, but are not significant to installation activities, they are presented in Appendix B.

5.5.2 Significant forest species changes at Fort Bragg by 2050

The blue outlined areas on the following maps indicate existing distributions; colored areas show likely future distributions. All images are based on the predicted future ranges as from scenario B1 in the Hadley model for 2050.

Fort Bragg is currently on the edge of the range of the Longleaf pine (*Pinus palustris*). In the near future (Figure 9), the range may expand to include the installation completely. This is important because a TES, the Red-cockaded Woodpecker (*Picoides borealis*), nests heavily in this tree species.

Fort Bragg is currently on the edge of the range of the Loblolly pine (*Pinus taeda*). In the near future (Figure 10), the range may expand to include the installation completely.

Currently, the range of the Bald Cypress (*Taxodium distichum*) barely includes Fort Bragg (Figure 11). Soon the Bald Cypress may expand that range to better include the installation.

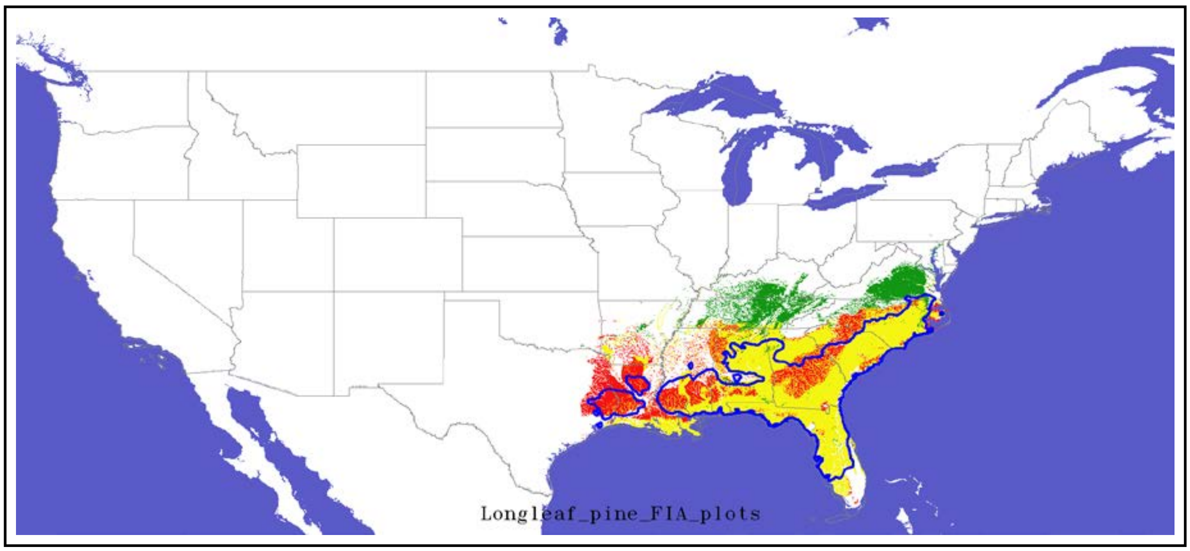

Figure 9. Climate affects on Longleaf pine (*Pinus palustris*).

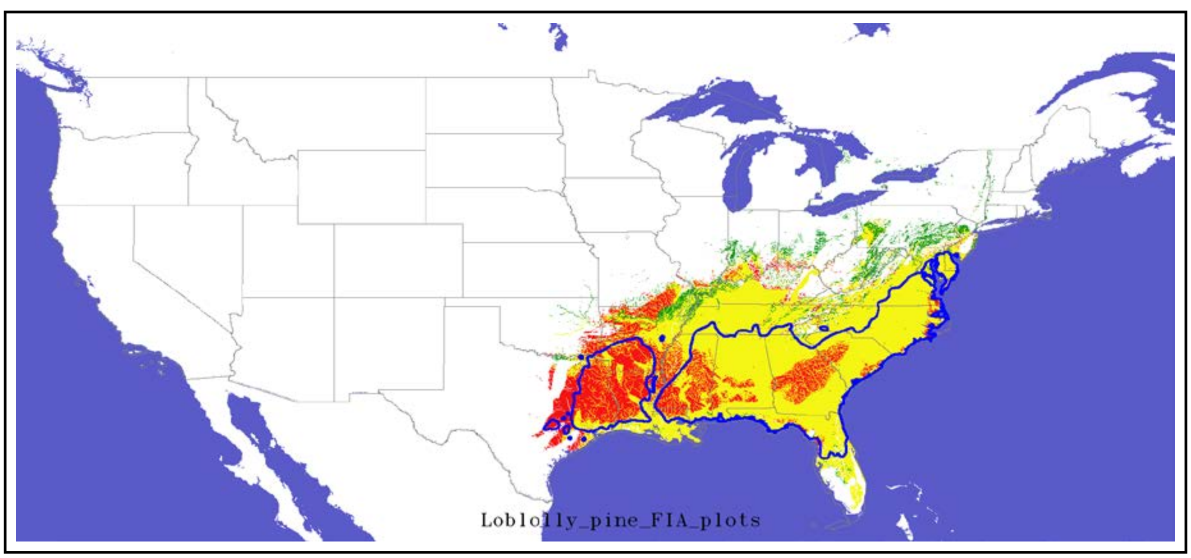

Figure 10. Climate affects on Loblolly pine (*Pinus taeda*).

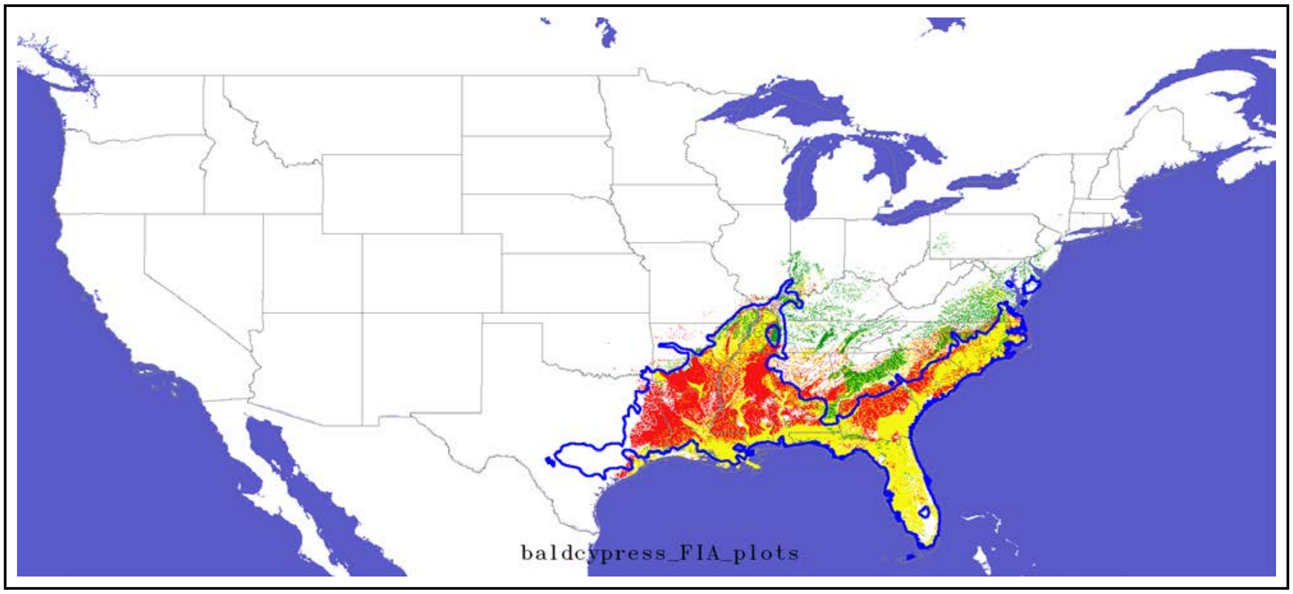

Figure 11. Climate affects on Bald Cypress (*Taxodium distichum*).

5.5.3 Summary of forest migration changes near Fort Bragg

By the year 2050, climate conditions are projected to change enough to encourage a set of tree species changes in or near Fort Bragg (Table 4).

Table 4. Forest migration changes near Fort Bragg.

Ranges likely to increase to better include Fort Bragg:	
Loblolly bay	Water oak
Longleaf pine	Northern red oak
Pond pine	Bald Cypress
Loblolly pine	Eastern hemlock
Swamp chestnut	
Ranges likely to stay the same at Fort Bragg:	
Mockernut hickory	American sycamore
Sugarberry	Cherrybark oak
Atlantic white cedar	Southern red oak
Flowering dogwood	Overcup oak
Sweetgum	Willow oak
Tulip poplar	Chestnut oak
Shortleaf pine	Black willow
Virginia pine	
Ranges likely to decrease near Fort Bragg:	
American chestnut	Eastern cottonwood
Carolina silver bell	White Basswood

5.6 Implications for TES

5.6.1 Red-cockaded Woodpecker (RCW)

Knowledge of how the climate might change makes it possible to predict where ecosystems may be in the future. Section 5.5, “Forest species migration studies” (p 23) predicts that the preferred RCW nesting tree species, Longleaf pine (*Pinus palustris*), may expand its range to more fully include Fort Bragg. At least on this issue, climate change might encourage more/better RCW habitat.

1.1.1 Federally endangered plants

Federally endangered plants of concern include:

- Rough-leaved loosestrife (*Lysimachia asperulifolia*), which requires regular fires. With increased rainfall at Fort Bragg, natural fires would become less common. Greater expense would be incurred to carry out controlled burns.
- Michaux’s sumac (*Rhus michauxii*), which also requires regular fires. With increased rainfall at Fort Bragg, natural fires would become less common. Greater expense may be incurred to carry out controlled burns. Rust fungi that attack the plant appear worse during wet summers. Since the summers may be wetter at Fort Bragg, it may become more difficult to preserve this plant.
- American chaffseed (*Schwalbea americana*), which also requires regular fires. Increased rainfall at Fort Bragg would make natural fires less common. It would become more expensive to carry out controlled burns. Fires resulting from the installation bombing range particularly favor this plant. Longleaf pine habitat management would benefit this plant. Since Longleaf pine habitat may improve due to climatic change, continued Longleaf pine habitat management would also help this plant.

5.6.2 State protected or Federal plant species of concern.

Four plants occur almost exclusively on Fort Bragg:

- Sandhills pyxie moss (*Pyxidanthera barbulata* var. *brevifolia*), which grows in wet sands and peaty sands; increased yearly rainfall might benefit this species.
- Georgia lead plant (*Amorpha georgiana*), which is a shrub that requires occasional controlled burns at the yearly high water mark near rivers that overflow their banks. Controlled burns at Fort Bragg and increasing yearly rainfall are likely to favor this species.

- Sandhills milk vetch (*Astragalus michauxii*), for which prescribed burning programs are required, although not during reproduction period. This vetch is a plant of sandy xeric Longleaf pine sites so even the increased rainfall may have no effect on the plant.
- Pickering's dawn flower (*Stylisma pickeringii* var. *pickeringii*), which is a trailing vine that can often be found around the Fort Bragg drop zones. This plant requires frequent fires on its sandy soils.

All of these species are associated with the Longleaf pine forests of the Sandhills region. All require fire to clear the understory to give them an advantage. Managing for Longleaf pine forest health may benefit these four species. Since climate change might favor Longleaf pine habitat at Fort Bragg, this should be good news for these four plants as long as prescribed burning (not during flowering time) is continued.

5.7 Implications for IS change

5.7.1 Invasives and the military mission

Fort Bragg is one of a dozen installations for which a complete floristic inventory has been carried out (HQUSACE 2007). The installation is host to a total of 217 IS. Appendix C to this report includes an abridged list.

Invasives affect military training and land management by:

- increasing fire potential (and making rehabilitation more difficult)
- obscuring line-of-sight, which is important for ground training and artillery
- obscuring landscape, which makes it difficult to see changes that can led to safety issues
- affecting human health (e.g., thistle can cut the skin)
- aggravating human allergies from toxins produced by the plants
- restricting vehicle movements by
    - blocking access
    - collecting large amounts of plant fragments in vehicle wheel wells
- negatively impacting TES habitat resources
- making it difficult to rehabilitate an area once an invasive is established
- generating high costs (millions of dollars) to control and remove.

5.7.2 Specific invasives at Fort Bragg and climate change

Species of greatest concern for managing training lands are:

- Perennial Kudzu (*Pueraria lobata*), a legume, aggressively covers native vegetation, sometimes so thickly that it obscures the sunlight enough to kill the native plant (often a pine). Kudzu has become a safely issue on Fort Bragg because it grows so thickly that it can thoroughly disguise landscape features. (A vehicle could drive over a cliff hidden by thick Kudzu.) It may also grow so thickly that it denies local fauna normal habitat food resources. This is particularly a problem to TES that are already stressed. Kudzu is a member of the C3 plant group, which has a tendency to do better as CO_2 atmospheric concentrations increase (as is projected to occur under climatic change in this region). Also, the increased temperature, particularly during the winter, may favor Kudzu growth.
- Chinese Bush Clover (*Lespedeza cuneata*) is called the "Kudzu of the 21st century." It was originally planted as erosion control and habitat food resources, but it now aggressively covers the native vegetation impacting line-of-sight training at the installation and TES food resources. In addition, some humans exhibit allergic reactions to the volatiles it emits to the air, which can be particularly dangerous if burnt. Chinese Bush Clover is also a member of the C3 plant group, which has a tendency to do better as CO_2 atmospheric concentrations increase.
- Cogongrass (*Imperata cylindrica*) is a plant so highly tolerant to shady conditions that it can completely cover a forest floor. It is a member of the C4 group, which does better in warmer climates. As Fort Bragg's temperature increases, one can expect Cogongrass to spread. Often northern varieties of a species will be more freeze tolerant, so as the winter temperature rises above freezing, Fort Bragg may become even more inviting to this IS. If its material above ground dries, it will easily promote destructive fires. At such periods, it would become necessary to restrict military training that might spark a fire. Fires make rehabilitation of the land for training more difficult. A potential rise in precipitation combined with a shorter winter dry period would tend to mitigate unintended ground fires.

5.7.3 The future for IS

Often, as the existing established local community or ecosystem is encouraged to migrate, those less healthy residents will be giving up their current ecological niche. In a stressed community (e.g., one that is migrating out of an area) the opportunity arises for other, new non-native invasives. The implication is that new IS may now have a new location to populate so that the installation can expect to find new species on its grounds not currently recognized. This implies that the installation will require more funding for IS control and mitigation.

In Section 5.4, "Ecosystem changes" (p 21), one of the scenarios showed that a currently non-existing ecosystem would populate the area of Fort Bragg. If this were to occur, it would be a prime opportunity for a massive incursion of IS. Some of the invading types may be native or native to nearby regions; others may be non-native in which case the IS issues would be like those never before faced at the installation.

5.8 Soil erosion at Fort Bragg

There is a direct link between precipitation amount, event intensity, and erosion. Primary GCM inputs are limited to temperature and precipitation changes; however, fluvial erosion increases as the intensity of a rainfall event increases. So when dealing with erosion, an overall increase in precipitation volume is relatively meaningless — only a change in precipitation intensity is relevant.

Studies that look into the precipitation patterns from the 20th century consistently reaffirm the IPCC's projection of increasingly variable precipitation. Over the course of the 20th century, annual precipitation increased, and a significant portion of that increase came in the form of extreme rainfall events. Since precipitation is projected to increase slightly at Fort Bragg, slightly more severe rain events and therefore slightly increased erosion can be expected.

Lozar et al. (2011) used this erosion risk analysis in an attempt to use projected precipitation intensity data to determine possible changes in erosion rates based on the same assumptions found in the framework of the Revised Universal Soil Loss Equation (RUSLE). Future erosion potential was determined solely by projected increases in precipitation intensity. The results were used to determine the relative climate-induced erosion levels at 34 Army installations.

This soil erosion evaluation ranked Fort Bragg 13th of 34. Of the categories of risk (very high, high, moderate, and low), Fort Bragg was ranked between moderate and high risk (Table 5). A different classification method could easily have classified it as having a high risk of increased erosion due to climate change.

Table 5. Erosion risk on Tier 1 & 2 installations.

Key Installations	Rank
Fort Dix Military Reservation	
Fort Indiantown GAP Military Reservation	
Fort Lewis Military Reservation	
Fort Drum	
Camp Atterbury Military Reservation	
Yakima Firing Center	
Fort A.P. Hill Military Reservation	
Fort McCoy	
Fort Knox	
Fort Pickett Military Reservation	
Fort Campbell	
Camp Grayling Military Reservation	
Fort Bragg Military Reservation	
Hunter-Liggett Military Reservation	
Camp Ripley	
Camp Bullis	
Fort Jackson	
Fort Stewart	
Fort Leonard Wood Military Reservation	
Fort Hood	
Fort Benning Military Reservation	
Fort Chaffee	
Gowen Field Training Area	
Fort Irwin	
Fort Polk (Pelham Range)	
Fort Rucker Military Reservation	
Fort Sill Military Reservation	
Fort Polk Military Reservation	
Camp Shelby	
Fort Riley Military Reservation	
Camp Blanding Joint Training Center	
Fort Bliss	
Fort Bliss McGregor Range	
Fort Carson (Pinyon Canyon)	
Fort Carson Military Reservation	
	= “Very High Risk”
	= “High Risk”
	= “Moderate Risk”
	= “Low Risk”

Thus, by the best estimate at this time, soil erosion at Fort Bragg will likely become a larger concern in the future. Nevertheless, it will probably not be the largest issue experienced on the installation due to climate change.

5.9 Climate change and the military mission at Fort Bragg

In 2012, Fort Braggs' mission is to support the Army's only airborne corps and airborne division, the elite "Green Berets," and the Army's largest support command. Some potential changes that would affect the mission are:

- Winter Lowest Temperatures may increase.
- Annual Precipitation may increase.
- Precipitation of Wettest Month (July) may increase.
- Precipitation of Wettest Quarter (summer) may increase.
- Precipitation of Warmest Quarter (summer) may increase.
- The winter dry season may shorten significantly.
- More rain implies difficulties for vehicle movement.
- More rain implies some moderately increased issues with soil erosion.
- More rainfall suggests that weather might limit airborne training more in the future.
- Increased rainfall would favor woody plants over grasses.
- Longleaf pine may be more common. The need for controlled burns may be enhanced.
- The warmer and more humid climate in both summer and winter means there is a better chance for fungus to grow, a particularly annoying concern for foot soldiers.
- More rain suggests fewer problems with fugitive dust issues.
- More rain suggests there would be more mud problems for tracked and wheeled vehicles.
- Higher temperatures would require more drinking water for troops, particularly in the summer.
- A much shorter winter dry season would restrict maneuver scheduling, which is now taken for granted.
- The average minimum temperature in the winter is near 0 °C. A potential shift to a slightly higher temperature means that winter freezing would become less common. For vegetation and many animals that means a higher survival rate than has existed in the past.
- One might expect an invasion of plants and animals from more southerly locations.
- TES will be more challenged as the ecosystem changes.
- Greater funding and management may be required to preserve current TES.

- For RCW, climate change might favor a wider spread of its preferred nesting trees Longleaf and Loblolly Pine.
- Current TES species tend to require controlled burns so managing for Longleaf Pine forests may benefit many species.
- IS may have new opportunities to establish themselves as native species may become stressed.
- Increased CO_2 levels may enhance the vitality of C3 plant group members particularly Kudzu and Chinese Bush Clover.
- Native species near the edge of their natural ranges may be particularly strained.
- New IS are likely to appear.

6 Conclusions and Recommendations

6.1 Conclusions

This work performed an installation-specific analysis of climate change forecasts for Fort Bragg, NC, and concludes that climate change is projected to affect land management and the military mission at Fort Bragg, an installation considered to have "average" climatic change issues. On many key concerns climate change is projected to occur more acutely in the near term (by the 2025 time frame) rather than the long term (by the 2085 time frame). The consensus prediction of six GCMs and three different future scenarios (ultimately amounting to 64 temperature and precipitation issues) is that the temperature will rise about 3 °C and that precipitation will rise and spread into what is now considered the "dry winter period." Very few model/scenario combinations predict a precipitation decrease or a "no change" scenario for Fort Bragg.

Specifically, near term changes (those concerns that may increase more before 2025 than latter in the century) at Fort Bragg include:

- Annual temperature will rise by 1° C.
- Winter Lowest Temperatures may increase.
- Annual Precipitation may increase.
- Precipitation of Wettest Month (July) may increase.
- Precipitation of Wettest Quarter (summer) may increase.
- Precipitation of Warmest Quarter (summer) may increase.
- The winter dry season may shorten significantly.

The ecosystem within which Fort Bragg resides may migrate away. Current conditions identify the ecosystem (according to the GAP analysis categories) as the Evergreen Plantations or Managed Pines landcover class, including some cropland cover. Several models replace the majority of that type with an East Gulf Coastal Plain Interior Upland ecosystem. For Fort Bragg, this implies that the current land management procedures may need to change.

Individual forest species may diminish significantly and new species may migrate into the installation from the south. Most notable changes include an increased hospitality to Longleaf and Loblolly Pine growth. Both species are associated with forest fire controlled burns so this may become an even more important task for installation land managers.

Survival of currently marginal TES may become more of a challenge. Interestingly, the RCW is likely to benefit from the improved habitat of its favorite nesting trees, the Longleaf and Loblolly Pines. Other TES at the installation are associated with the Longleaf pine forests of the Sandhills region. All require fire to clear the understory to give them an advantage. Managing for Longleaf pine forest health might benefit these species.

Two IS at the installation, Perennial Kudzu and Chinese Bush Clover are both members of the C3 plant group, which has a tendency to thrive as CO_2 atmospheric concentrations increase, which is likely to occur under climatic change in the Fort Bragg region. In a stressed ecosystem (e.g., one that is migrating away from the area it has historically occupied) an opportunity arises for other, new non-native invasives. This implies that different IS may have a new location to populate. The installation can expect to find new IS not currently recognized on its grounds.

Erosion studies suggest that severity of rainfall events is the single largest contributor to erosion. Fort Bragg's erosion risk has been determined to be moderate to high in a four tier classification (very high, high, moderate, and low, see Table 5, p 30).

6.2 Recommendations

The mission at Fort Bragg is to support the Army's only airborne division, the elite "Green Berets," and the Army's largest support command. It is recommended that installation planners anticipate several important changes projected to occur in the nearest timeframe for Fort Bragg. For the military mission this suggests that:

- More rain implies difficulties for vehicle movement.
- More rain implies some moderately increased issues with soil erosion.
- More rainfall suggests that weather may tend to limit airborne training.
- The warmer and more humid climate in both summer and winter means there is a better chance for fungus to grow.
- More rain suggests fewer problems with fugitive dust issues.
- More rain suggests there may be more mud problems for tracked and wheeled vehicles.
- Higher temperatures would require more drinking water for troops, particularly in the summer.

- Higher temperatures would require more air-conditioning in the summer.
- A shorter winter dry season might restrict maneuver scheduling now taken for granted.
- IS that respond positively to increased CO_2 levels (Kudzu and Chinese Bush Clover) are likely to be more of a problem for:
  - Line of site maneuver exercises
  - Landscape obscuration.

For land management concerns:

- Increased rainfall would favor woody plants over grasses.
- Longleaf pine may be more common. The need for controlled burns may be enhanced.
- The average minimum temperature in the winter is near 0 °C. A shift to a little higher temperature means that winter freezing may become less common. For vegetation and many animals that means a higher survival rate than has existed in the past.
- One might expect an invasion of plants and animals from more southerly locations.
- TES may be more challenged as the ecosystem changes.
- Greater funding and management may be required to preserve current TES.
- For RCW, climate change may favor a wider spread of its preferred nesting trees Longleaf and Loblolly Pine.
- Current TES species tend to require controlled burns so managing for Longleaf Pine forests may benefit many species.
- IS may have new opportunities to establish themselves because the native species may be stressed.
- Increased CO_2 levels would enhance the vitality of C3 plant group members, particularly Kudzu and Chinese Bush Clover.
- Native species near the edge of their natural ranges may be particularly strained.
- New IS are likely to appear.

In both cases, land management at Fort Bragg may have to change. It is recommended that installation planners consider that more funds may be needed to deal with the issues of:

- damage to roads and trails caused by increased precipitation
- somewhat increased costs to manage soil erosion
- somewhat lessened airborne time

- more summer demand by troops for drinking water
- more need to clean mud off of tracked and wheeled vehicles
- increased soldier foot care
- increased interference from IS.

Results of a previous study (Lozar, Hiett, and Westervelt 2012) indicate that Fort Bragg does not reside in a region identified as a high impact area. Therefore, although some changes in climate are likely to occur at the installation, Fort Braggs' issues are expected to be more manageable than those issues at other Army installations. Marginally increased costs of military and land management will not likely threaten the installation's ability to carry out its primary mission due to climate change either in the near or long term planning horizons.

Acronyms and Abbreviations

Term	Definition
CCAFS	Climate Change Agriculture and Food Security
CEERD	US Army Corps of Engineers, Engineer Research and Development Center
CEQ	Council on Environmental Quality
CERL	Construction Engineering Research Laboratory
CIAT	International Center for Tropical Agriculture
ERDC	Engineer Research and Development Center
GAP	USGS GAP Analysis Program
GCM	Global Climatic Model
INRMP	Integrated Natural Resources Management Plans
IPCC	Intergovernmental Panel on Climate Change
IS	Invasive Species
LLNL	Lawrence Livermore National Laboratory
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
OSD	Office of the Secretary of Defense
PCM	Parallel Climate Model
QDR	Quadrennial Defense Review
RCW	Red-cockaded Woodpecker
RUSLE	Revised Universal Soil Loss Equation
SD	Standard Deviation
SF	Standard Form
SRES	The Special Report on Emissions Scenarios
TAR	Third Assessment Report
TES	Threatened and Endangered Species
TR	Technical Report
WWW	World Wide Web

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Appendix A: Supplemental Bioclimatic Charts

Summary charts and implications of the 18 Bioclim changes not presented in the body of the report.

At Fort Bragg, the annual and summer temperatures are projected to rise approximately 3°C. The wet summer months and dry winter may become hotter, but the normal daily and seasonal ranges in temperatures may remain stable. Annual precipitation is projected to increase about 147 mm annually, particularly in the summer while increasing only slightly in the winter. Most of this change will likely occur in the near term (by about 2025).

The data in Figure A1 show that that the temperature may rise steadily from about 15.7 to 16.8 °C– over a degree by the year 2025. There is good agreement among the models and scenarios since the SD is very narrow.

Figure A2 shows that the daily range of temperatures widens by about ½ °C/day in the near term, but levels off thereafter to a daily range of little over 13 °C/day. The maximum range soars high in the ncar_ccsm3_0 B1 (global environmental sustainability) scenario. The Canadian model for both Scenarios A1B and A2 predict a smaller daily range change.

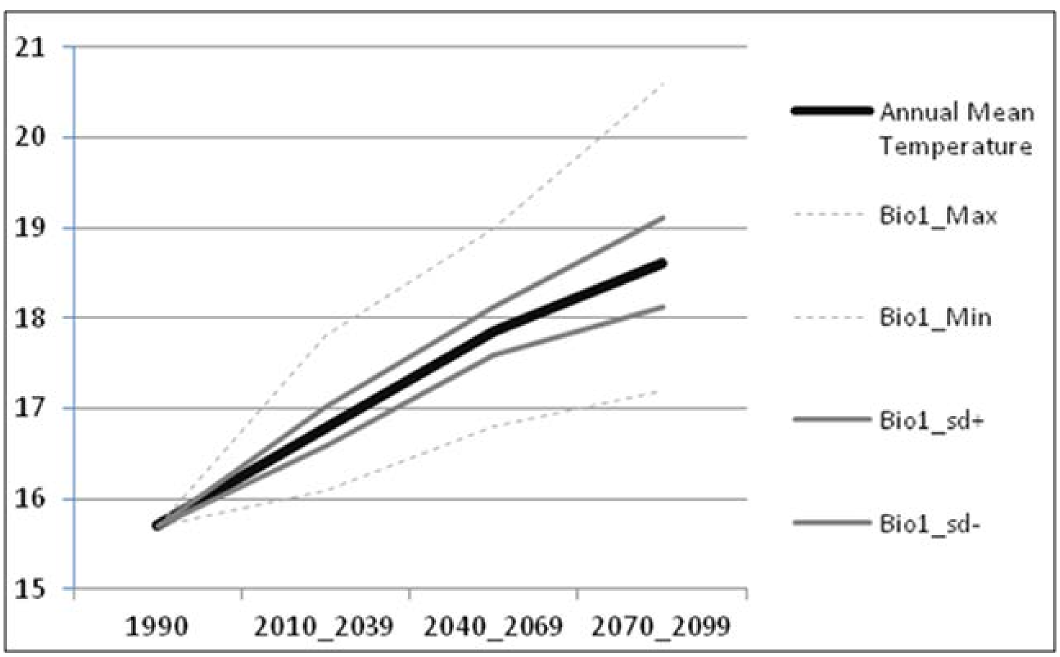

Figure A1. Fort Bragg Bio 1 — Annual Mean Temperature (°C), all GCMs and scenarios.

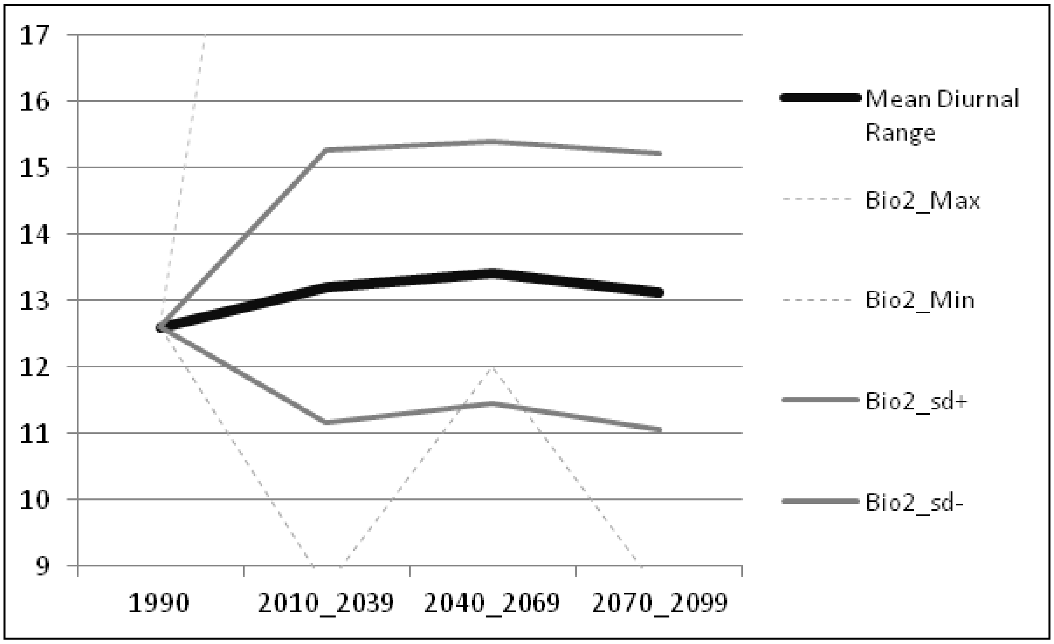

Figure A2. Fort Bragg, Bio 2 — Mean Diurnal Range (°C), all GCMs and scenarios.

In Isothermality, which is the ratio of Range/Day divided by the Range/Year the smaller the ratio, the more similar these two ranges are. Figure A3 shows that the ratio is small and barely changes over time. So even if the temperatures changes, the day vs. yearly relative character barely does. In this concern the maximum values are set by the ncar_ccsm3_0 model in the B1 scenario.

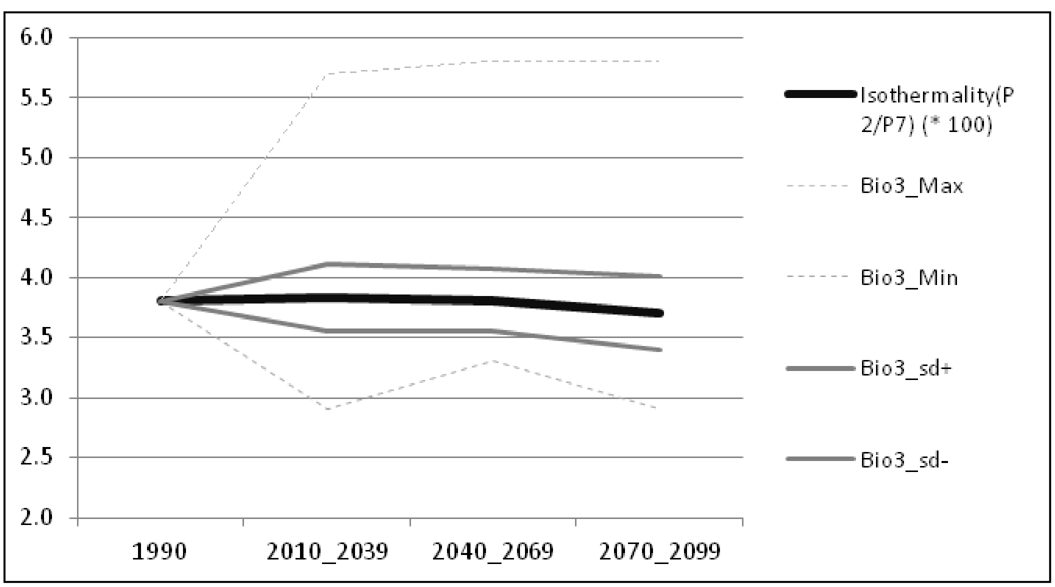

Figure A3. Fort Bragg, Bio 3 — Isothermality = range/day vs. range/year (ratio), all GCMs and scenarios.

Temperature Seasonality is defined as the annual range in temperature. The greater the value, the more variation exists. It is a relative term. For example, the region near Bragg shows little variation compared to the rest of the world. The region near Fort Bragg is of a Moderate level of seasonality. Figure A4 shows that seasonality at Fort Bragg steadily increases over time by over 5%, so slowly over the long term that the variations in the seasonal temperatures may increase only slightly.

Figure A5 shows that the maximum temperature of the warmest month (normally July or August) may slowly increase from just over 31 to just over 35 °C. Four degrees is a considerable amount, although the rise may be slow. Expect soldiers to require more water and increased rest periods in the summer. Once again it is the ncar_ccsm3_0 B1 combination that drives the maximum values and sometimes the Canadian that drives the low values. (Again BIO6 = Minimum Temperature of the coldest month is one of the important concerns at Fort Bragg.)

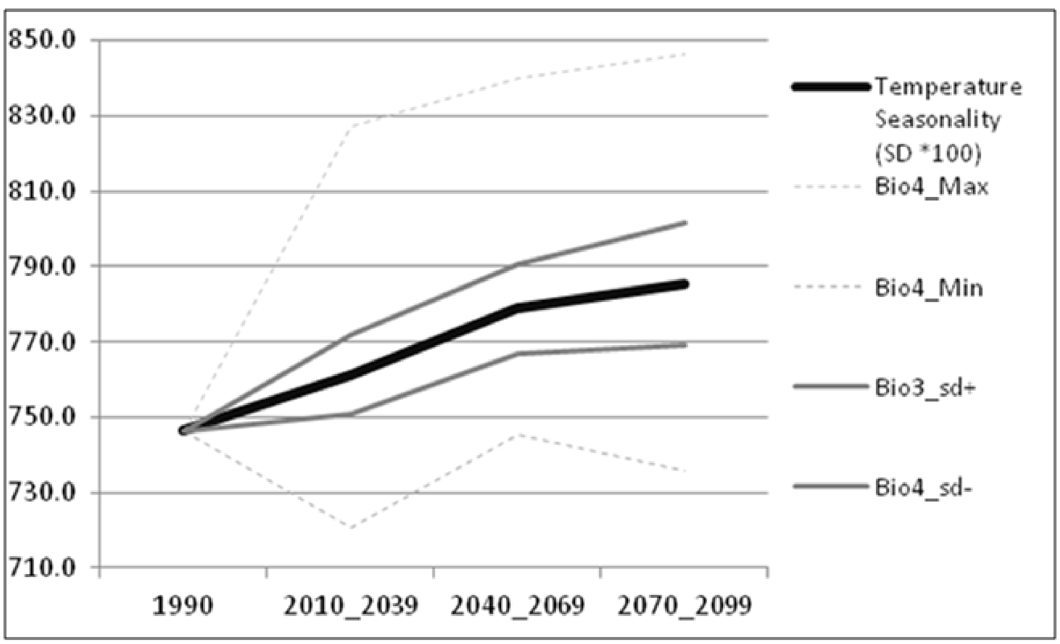

Figure A4. Fort Bragg, Bio 4 — Temperature Seasonality (SD*100), all GCMs and scenarios.

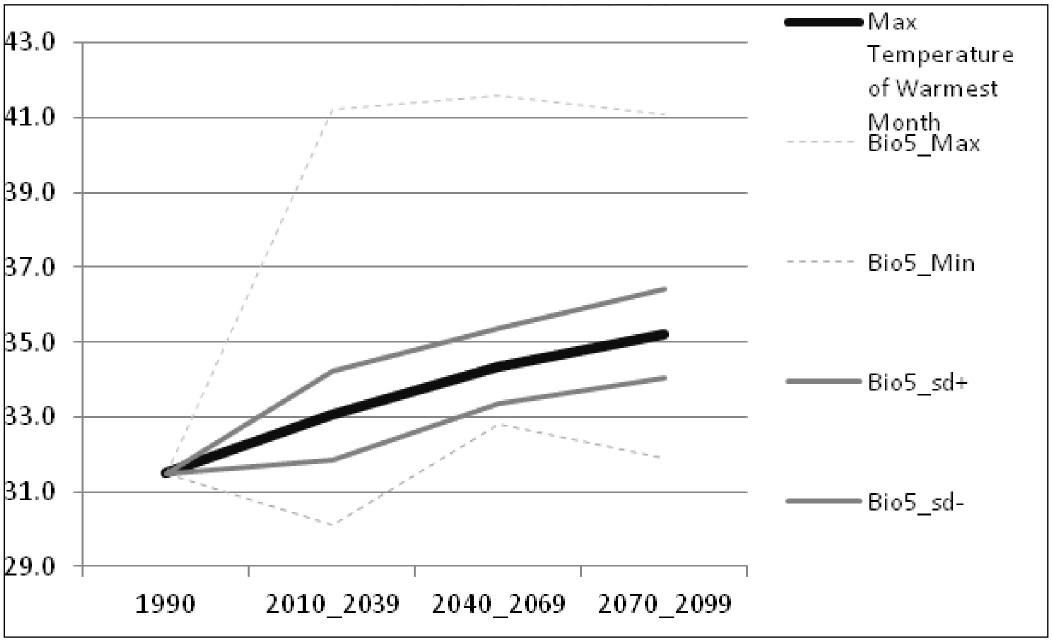

Figure A5. Fort Bragg, Bio 5 — Maximum Temperature of the Warmest Month, all GCMs and scenarios.

As suggested in seasonality (Figure A4) the range of the temperatures may increase a little from a range of 31 °C currently to 35 °C. As usual the ncar_ccsm3_0 B1 scenario predicts the near term sudden increase in annual range and the A2 scenario of the Canadian cccma_cgcm3_1_t47 model occasionally predicts less change in the range (Figure A6).

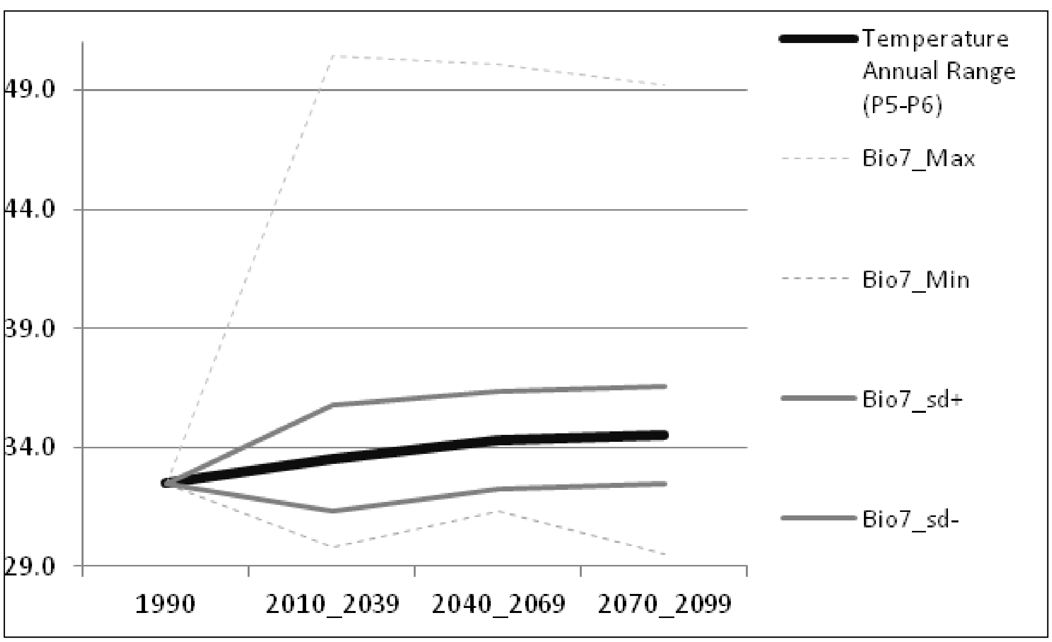

Figure A6. Fort Bragg, Bio 7 — Temperature Annual Range, all GCMs and scenarios.

Figure A7 shows the mean temperature of wettest quarter. As the following chart for Precipitation by Month for 1990 shows, the summer is the wettest quarter at Fort Bragg.

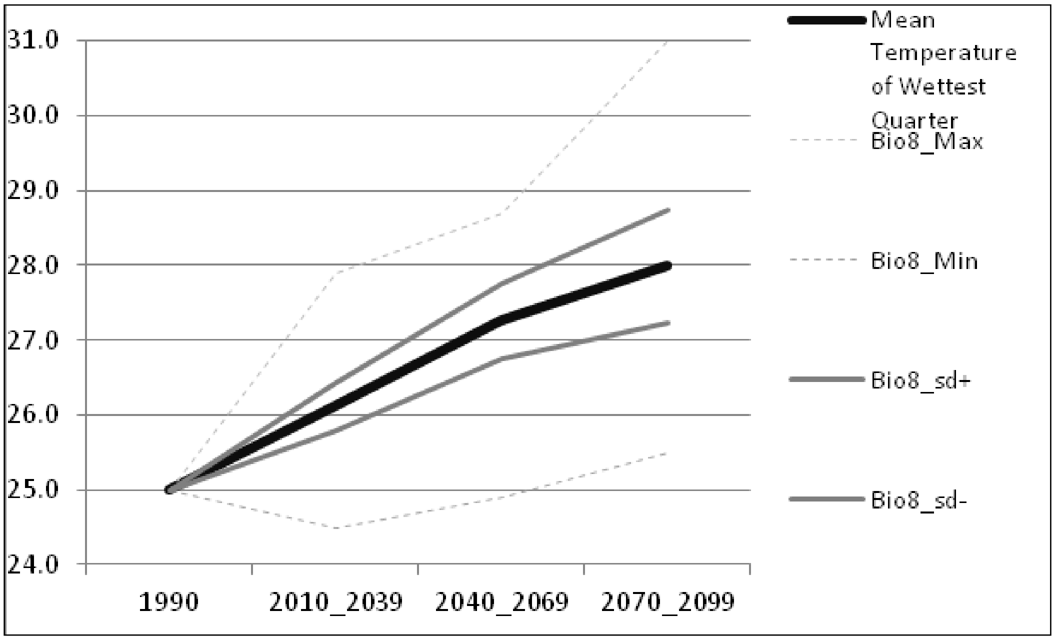

Figure A7. Fort Bragg, Bio 8 — Mean Temperature of Wettest Quarter, all GCMs and scenarios.

It is projected that the summer heat and humidity at Fort Bragg will increase steadily over the next century by about 3–4 °C. There is not much variation in the predictions on this (i.e., the lines of standard deviation in Bio 8 are close in to the average). The minimum and maximum values vary among the different models and scenarios.

Figure A8 shows that the driest quarter at Fort Bragg includes the October to December time frame. Therefore, as shown in Figure A9, the mean temperatures for that period may steadily rise from 11 to 14 °C. The late fall may become warmer as well as drier. The maximum temperatures are set by various model scenario combinations while the most significant minimums are set by the A1B/giss_model_er arrangement.

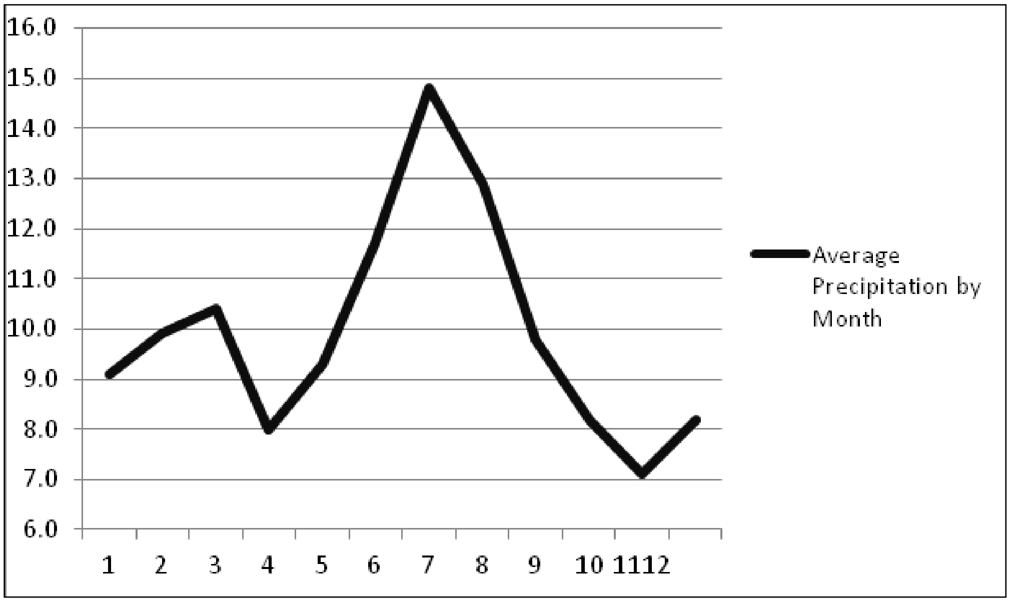

Figure A8. Fort Bragg, Precipitation by Month for 1990 (mm) existing situation.

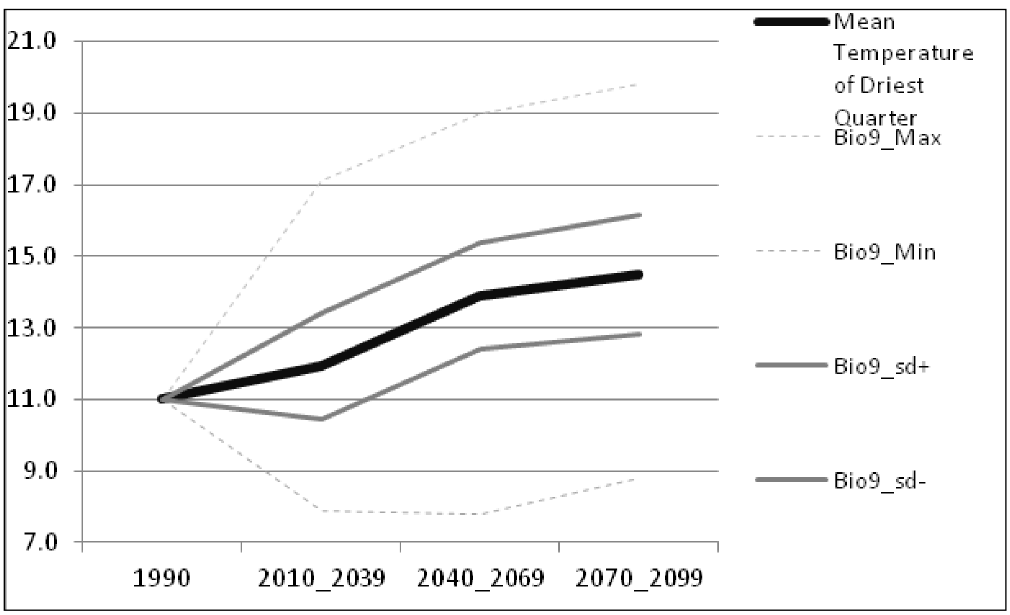

Figure A9. Fort Bragg, Bio 9 — Mean Temperature of Driest Quarter, all GCMs and scenarios.

Unlike many of the previous graphs, there is very little change in the near term, but in the long term, the temperature in this period may increase by about 3.7 °C in the long term, which is consistent with other expected increases.

Figure A10 shows that there may be a steady increase in the warmest part of the year by over 1 °C in the near term and over 3 °C in the long term. From Mean Temperature by Month for 1990 (Figure A11), the warmest quarter at Fort Bragg would include June, July, and August. One can expect the summer temperatures to increase steadily over time.

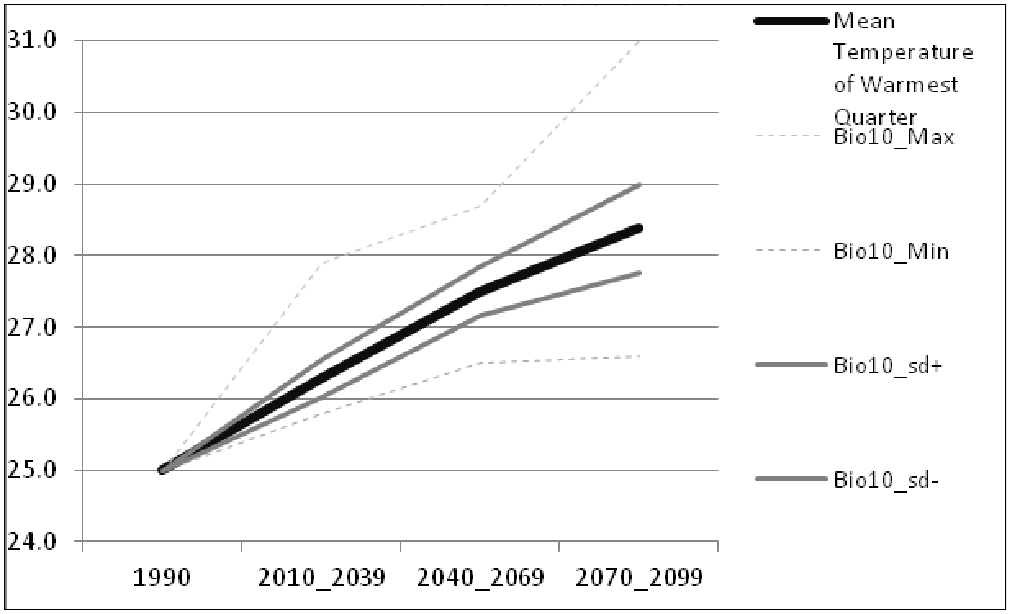

Figure A10. Fort Bragg, Bio 10 — Mean Temperature of Warmest Quarter, all GCMs and scenarios.

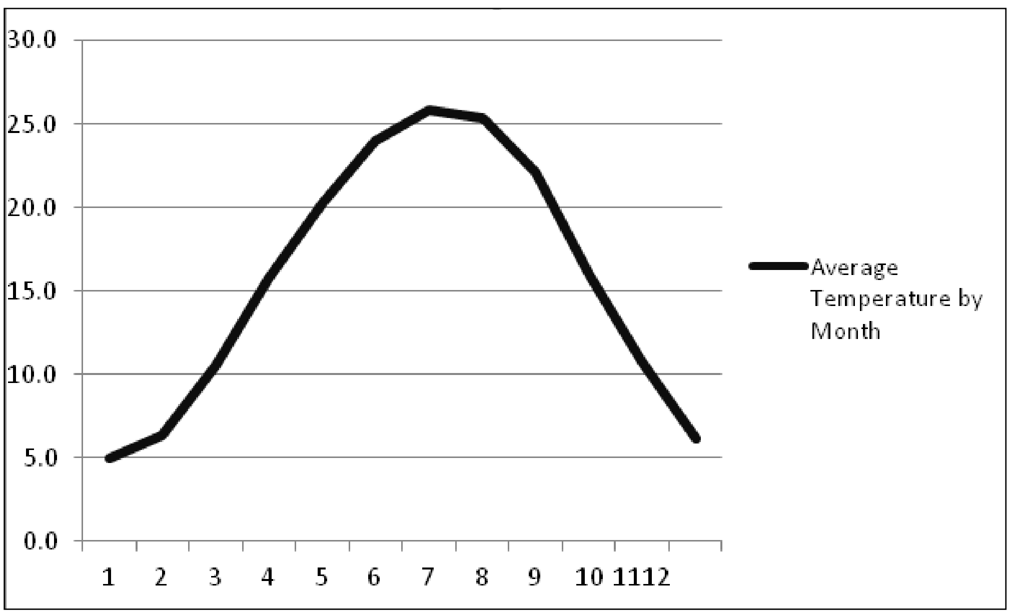

Figure A11. Mean Temperature by Month for 1990 (°C), existing situation.

It might be significant to address the issue of climatic shifts in the warmest months (i.e., the warmest months shift to the left or right). Figure A12 (similar to Figure A11) illustrates this condition by using the 2085 period predicted data (Mean Temperature by Month for 2085). The black line repeats the data in Mean Temperature by Month for 1990. The gray line in Figure A12 shows that the data for 2085 have shifted up, but not to the sides so the classical summer months may remain the hottest months of the year.

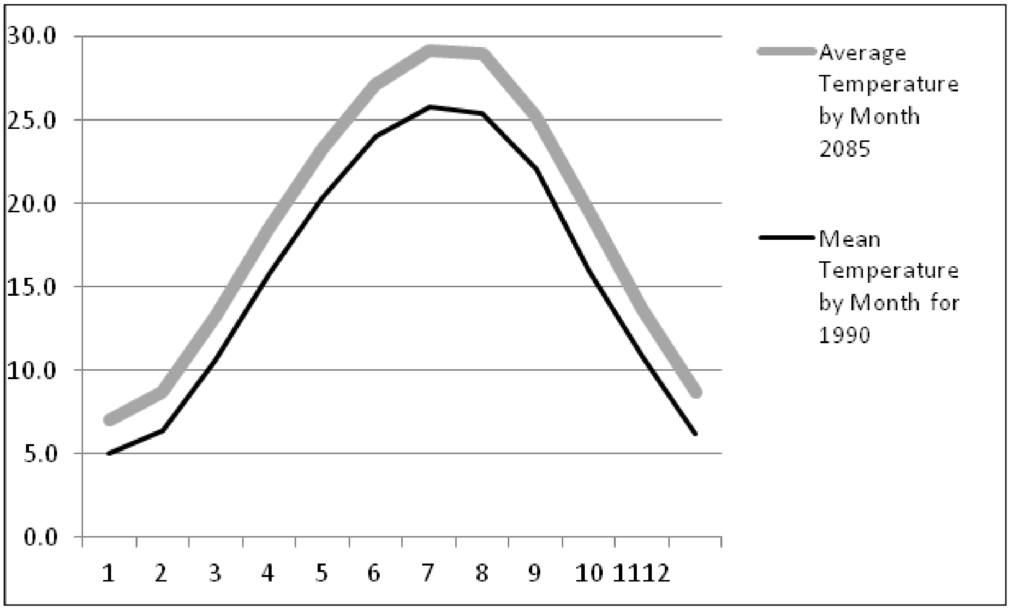

Figure A12. Mean Temperature by Month for 2085 (°C), far term predicted situation.

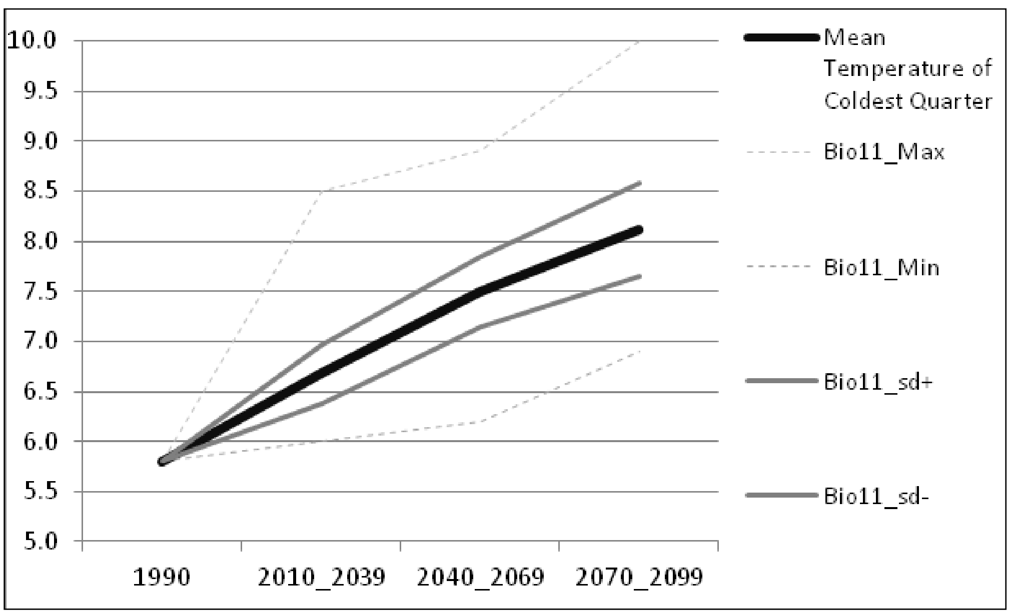

Figure A13. Fort Bragg, Bio 11 — Mean Temperature of Coldest Quarter, all GCMs and scenarios.

The mean temperature of the coldest quarter (Figure A13) shows the same slow, constantly increasing temperature trend. The winter month's coldest temperature may increase by nearly 3° C. by 2085. There is not much variation; even the extremes show the same trend. Figures A11 and A12 show that the coldest quarter centers on December, January, and February; conditions may stay that way into the long-term future. All of the maximum values come from the A1b (rapid economic growth) scenario, most are from the ukmo_hadcm3 model.

Figure A14 illustrates precipitation issues, showing the rise in annual precipitation expected per year. In the near term, there may be a jump from 120 mm to 127 mm per year. After that, the trend continues, but at an ever slower rate as time goes by. The minimum values which suggest no change are always derived from the csiro_mk3_5 model in either the A2 (regionally oriented economic growth) or B1 (global environmental sustainability) scenarios. The maximum values come from different combinations of models and scenarios.

The precipitation of the wettest month (Figure A15) shows that, in the near term, the precipitation in July at Fort Bragg may increase sharply before slowly leveling off, following the general overall yearly pattern. The maximum values are determined by the ncar_ccsm3_0 and ukmo_hadcm3 models within the B1 global environmental sustainability scenario. The minimum values come from various combinations of models and scenarios.

Figure A16 shows that the change to the precipitation in the driest month at Fort Bragg (November) is not significant; it is less than 0.5 mm. The SD is tight around the average so that there is not much disagreement among the models; even the maximum to minimum range is small (roughly 5mm). Particularly in the near term, November precipitation may barely increase.

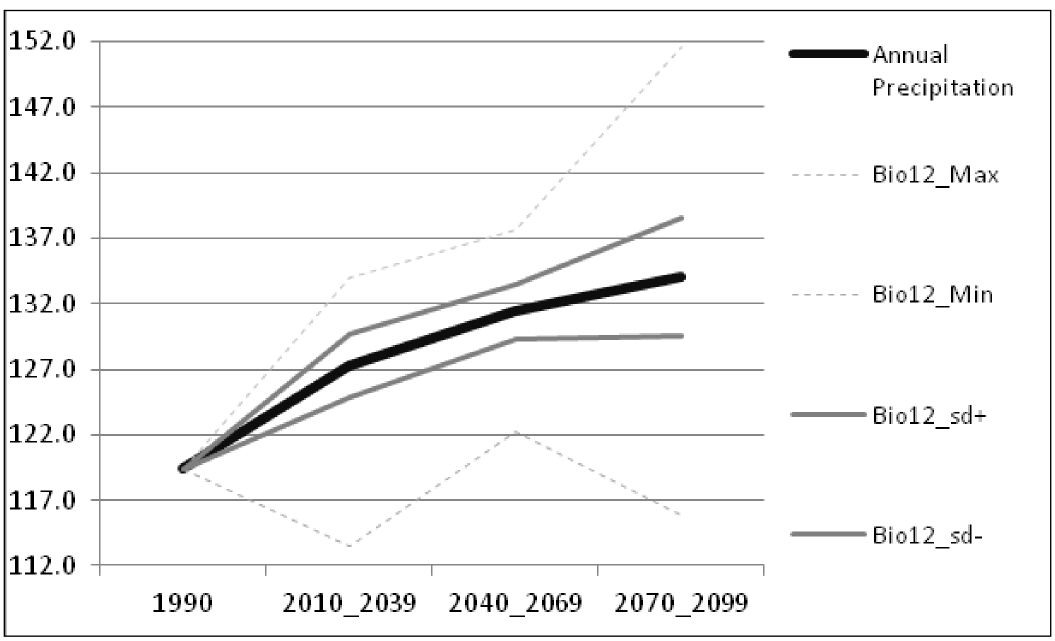

Figure A14. Fort Bragg, Bio 12 — Annual Precipitation, all GCMs and scenarios.

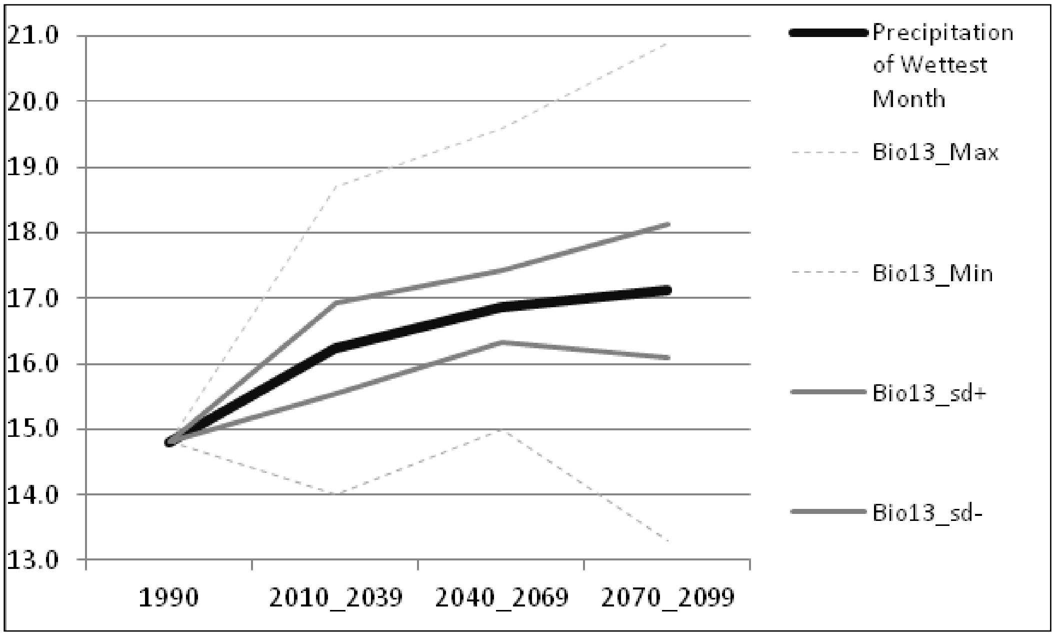

Figure A15. Fort Bragg, Bio 13 — Precipitation of Wettest Month, all GCMs and scenarios.

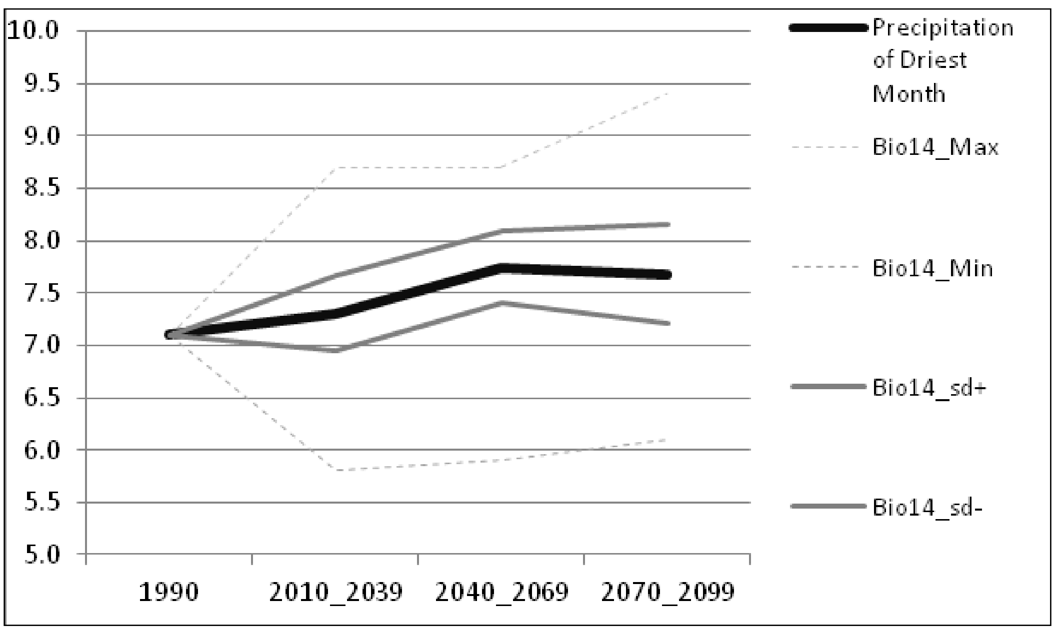

Figure A16. Fort Bragg, Bio 14 — Precipitation of Driest Month, all GCMs and scenarios.

The equation that generates Figure A17 deals with variation between seasons. At Fort Bragg it starts out at a low positive value meaning that there is a little variation between the seasons. In the short run the variation may jump from a low value to another low value and then stabilize to near 2.4. Notice that even the minimum value always stays positive; variation in seasons may remain even in the worst case.

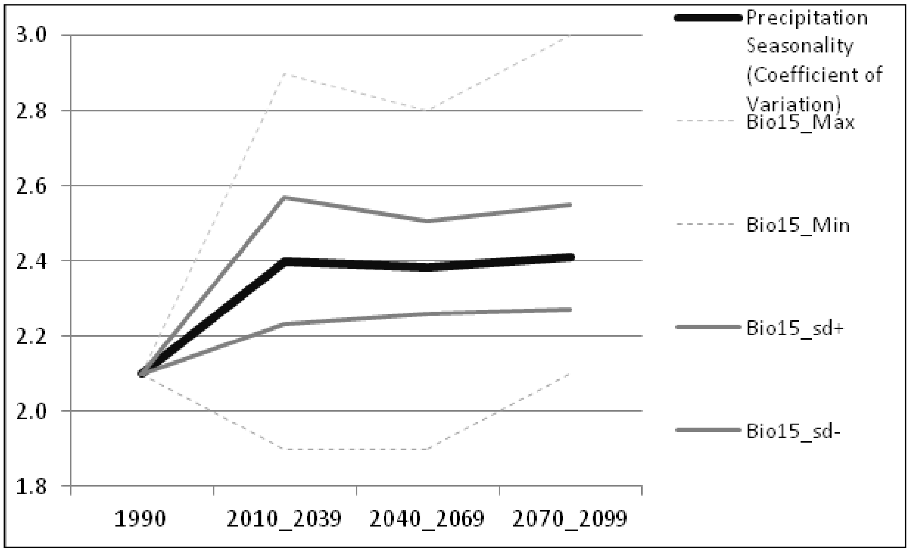

Figure A17. Fort Bragg, Bio 15 — Precipitation Seasonality (Coefficient of Variation), all GCMs and scenarios.

The equation used to generate the chart in Figure A17 deals with variation between seasons. At Fort Bragg, it starts out at a low positive value meaning that there is a little variation between the seasons. In the short run, the variation may jump from a low value to another low value and then stabilize to near 2.4. Notice that even the minimum value always stays positive; variation in seasons may remain even in the worst case.

Figure A18 shows that there may be a near term increase of 4 mm in the wettest quarter (June to August). This will cause it will be more humid in the summer, creating better conditions to grow fungus (among other items), which is an important consideration for foot soldiers. In the long term, the precipitation rises only slowly. On this concern the ranges vary on a strange manner. The maximum values come from different models, but all belong to the A1B scenario - Maximum energy requirements with a balance across sources. The minimum values vary across scenarios, but they all come from the csiro_mk3_5 model. Those minimums zigzag a good deal, which suggests they are not reliably defined.

Figure A19 shows that the Precipitation of Driest Quarter increases quickly from 23.5 mm in 1990 to 24.7 mm in 2025 then to 25.9 mm in 2055 and then levels off. Winter (October to December) is the driest quarter, so the winter may be a bit wetter, another indicator that fungus will be a bigger problem. The range on the models is wide, although the standard deviation is not greater than other concerns. The maximums are determined by a variety of model and scenarios combinations while the minimums all come from the csiro_mk3_5 model with different scenarios.

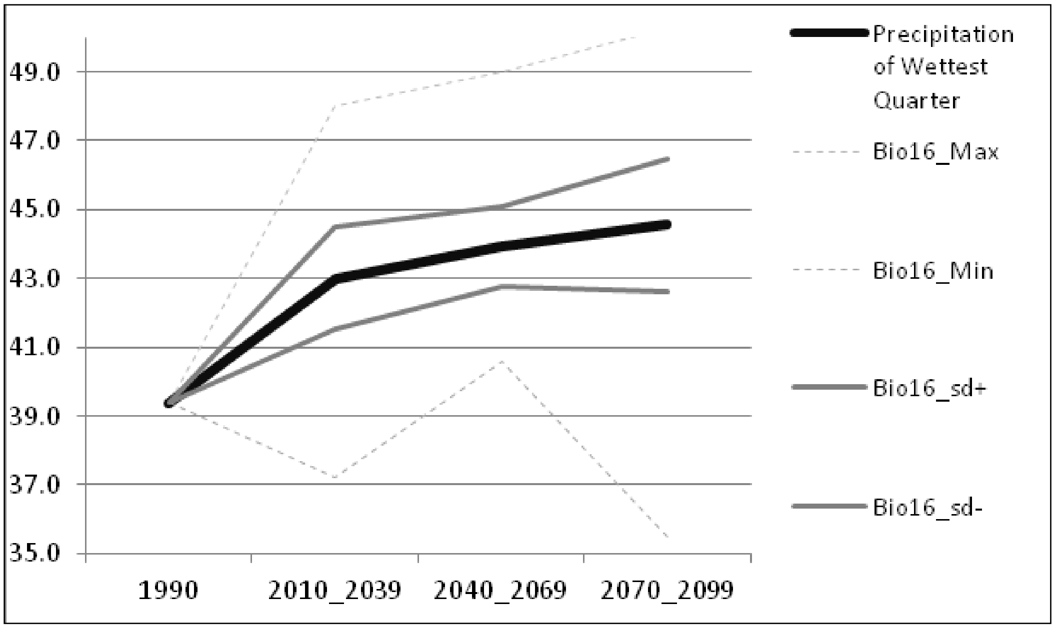

Figure A18. Fort Bragg, Bio 16 — Precipitation of Wettest Quarter, all GCMs and scenarios.

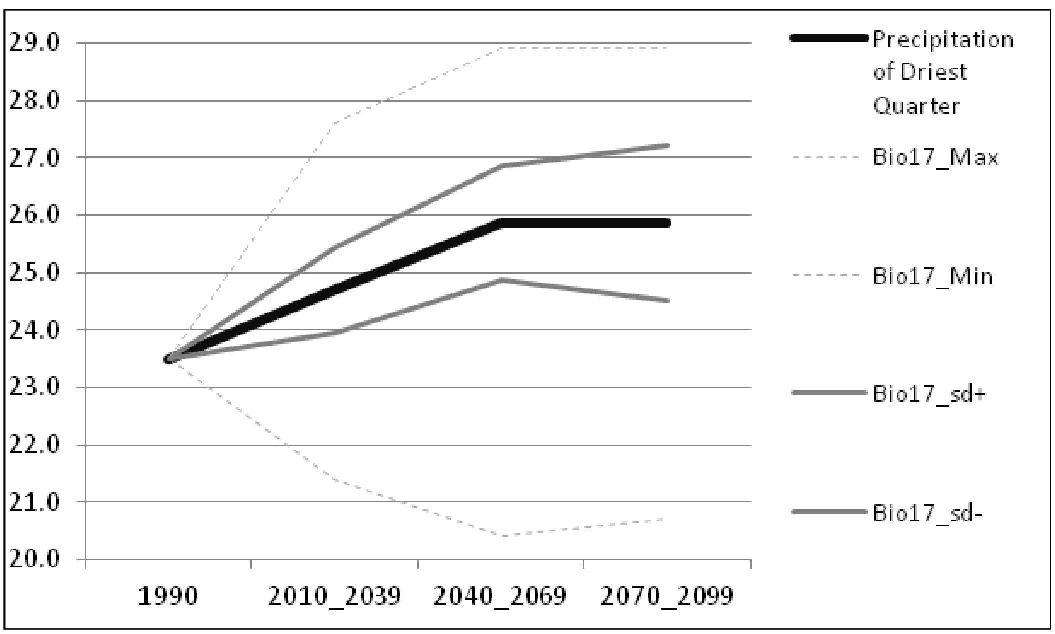

Figure A19. Fort Bragg, Bio 17 — Precipitation of Driest Quarter, all GCMs and scenarios.

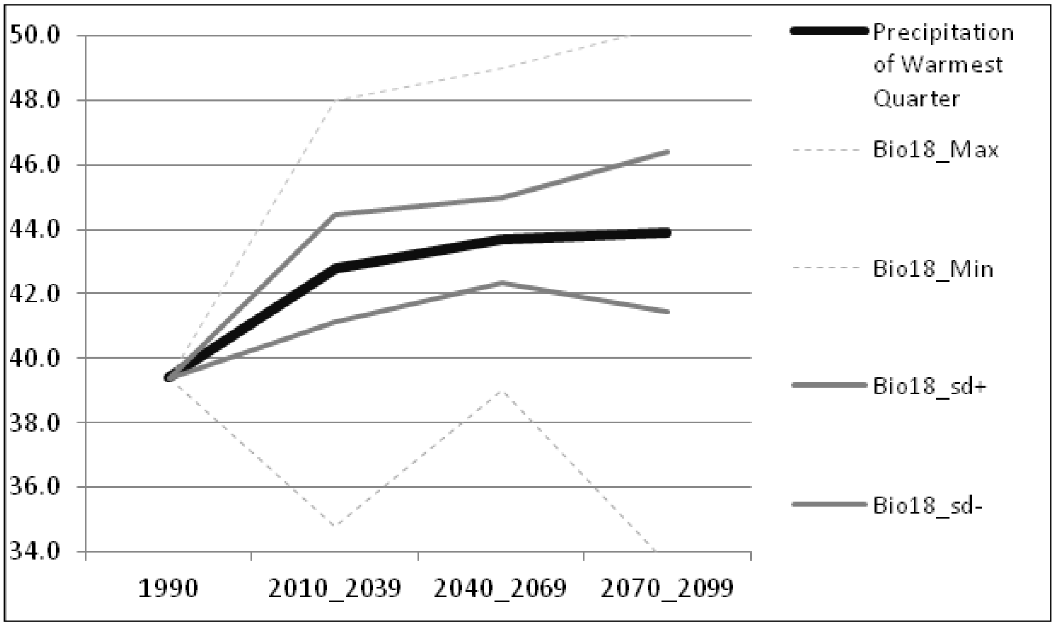

Figure A20. Fort Bragg, Bio 18 — Precipitation of Warmest Quarter, all GCMs and scenarios.

The chart shown in Figure A20 is similar to that in Figure A19 in terms of average values, range, variation and form of maximum and minimum. In Figure A20, the models indicate that there may be a near term increase of 4 mm in the warmest quarter (June to August). This implies it may be more humid in the summer indicating a climate better suited to growing fungus among other items, an important consideration for foot soldiers. In the long term the precipitation amount rises only slowly. On this concern the ranges vary on a strange manner. The maximum values come from different models, but all belong to the A1B scenario - Maximum energy requirements with a balance across sources. The minimum values vary across scenarios and models. Those minimums zigzag a good deal, which suggests they are not reliably defined.

Figure A21 shows that there will be a slow and steady increase in the precipitation of the winter months by about 3mm. The standard deviations indicate that the trend is well defined. The maximum values vary between models and scenarios, and the minimums are all from the csiro_mk3_5 model, but from different scenarios. So, winters at Fort Bragg may be a little bit warmer.

(Note that the issue of Bio20 Consecutive Dry Months has already been discussed in the body of the report.)

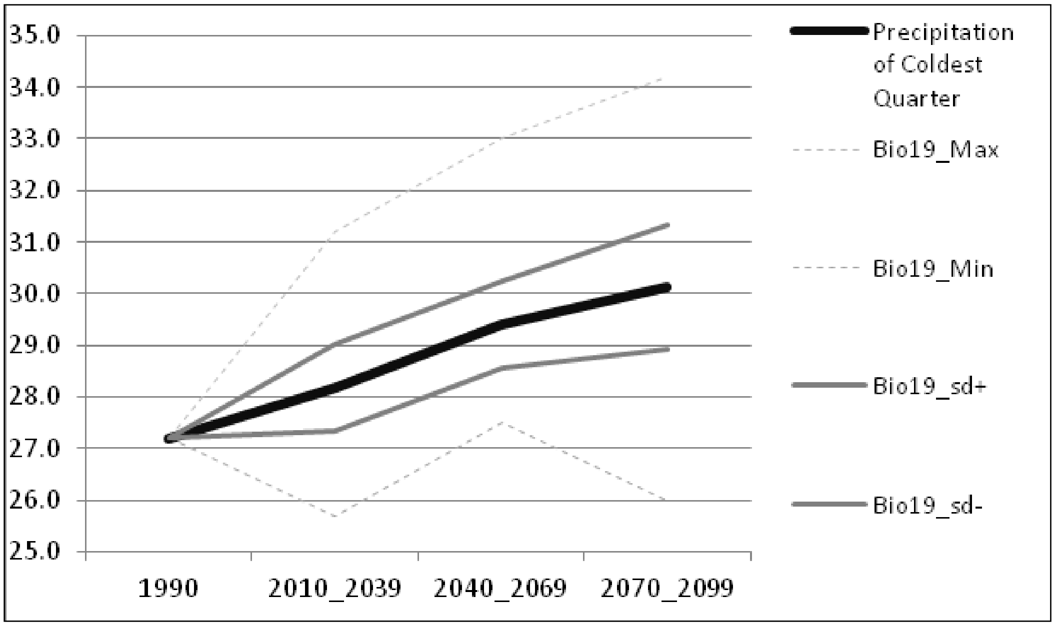

Figure A21. Fort Bragg, Bio 19 — Precipitation of Coldest Quarter, all GCMs and scenarios.

General observations about many of the previous graphs.

The BioClim projected data at Fort Bragg show that the temperature may rise across most concerns by about 3 °C while rainfall may in the short term dramatically rise and stay high. The outliers on one side (maximum or minimum depending on the concern) are often defined by the ncar_ccsm3_0 B1 scenario and at the opposite extreme often by the Canadian cccma_cgcm3_1_t47 model A2 combination.

Appendix B: Less Significant Tree Species Migrations

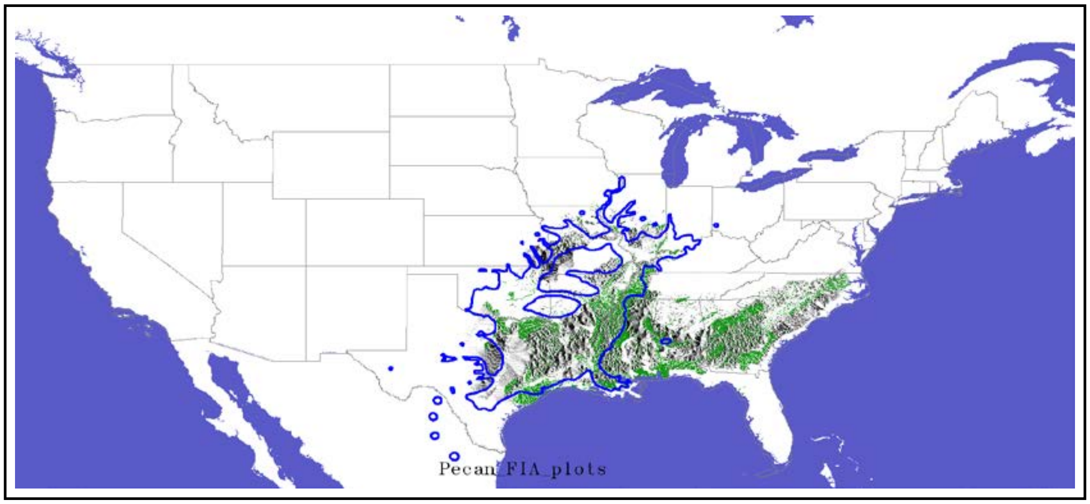

Figure B1. Pecan (*Carya illinoinensis*) may expand into the Fort Bragg area where it is currently very rarely found.

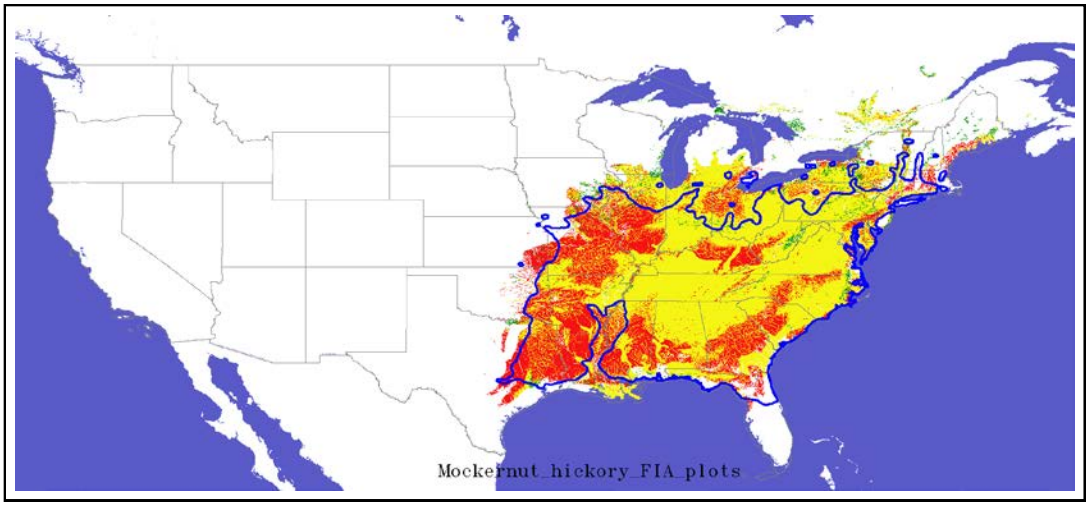

Figure B2. Mockernut hickory (*Carya tomentosa*) may stay a healthy resident in the Fort Bragg area.

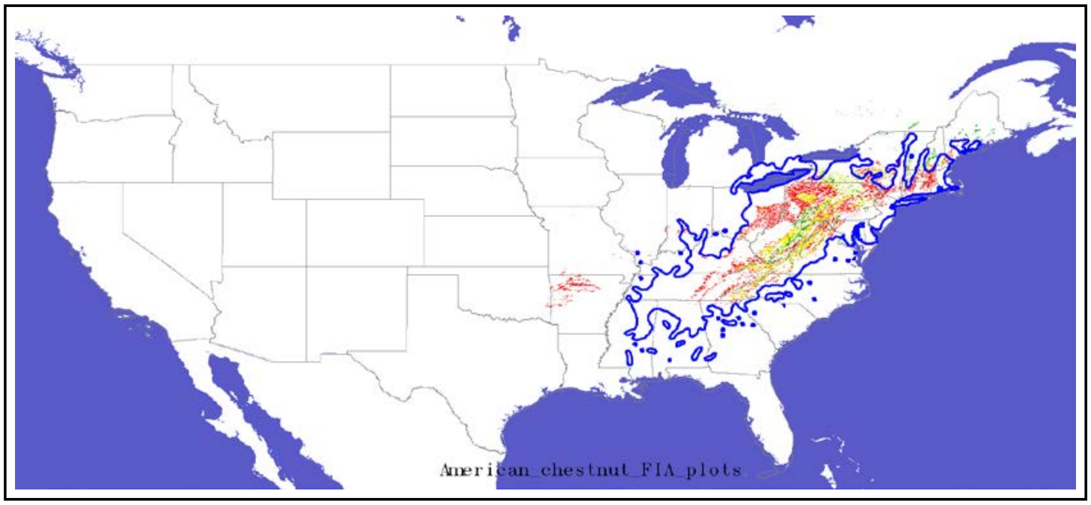

Figure B3. Near Fort Bragg the American chestnut (*Castanea dentata*) is at the edge of its range. By 2050 that range may shrink away from the installation.

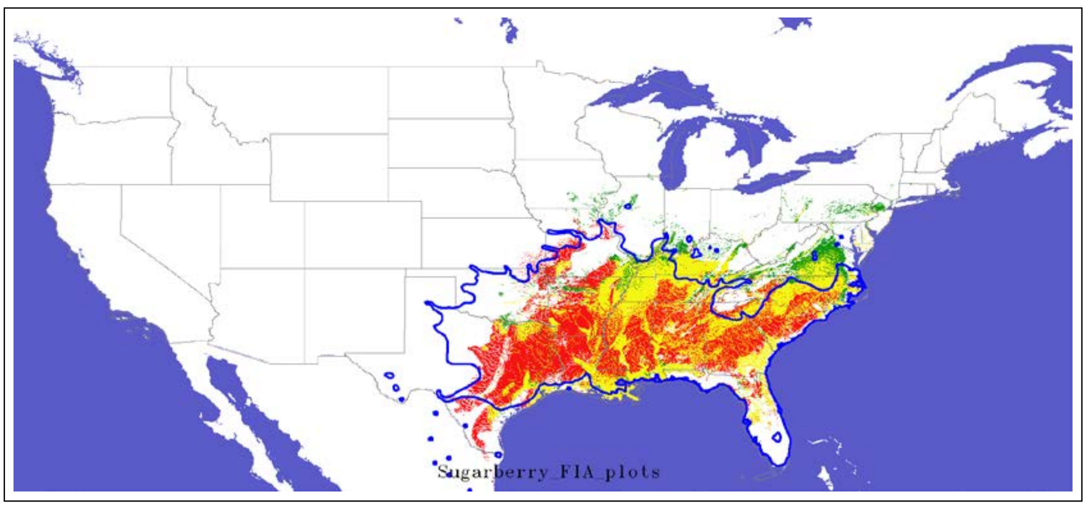

Figure B4. Sugarberry (*Celtis laevigata*) may stay healthy near Fort Bragg.

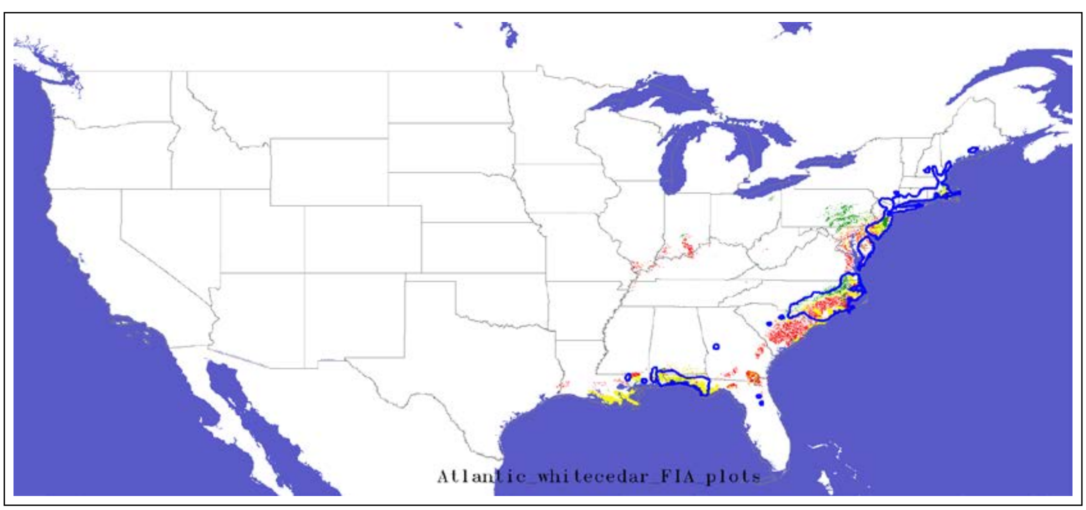

Figure B5. Atlantic white cedar's (*Chamaecyparis thyoides*) range is near Fort Bragg. The edge of its range may remain near Fort Bragg.

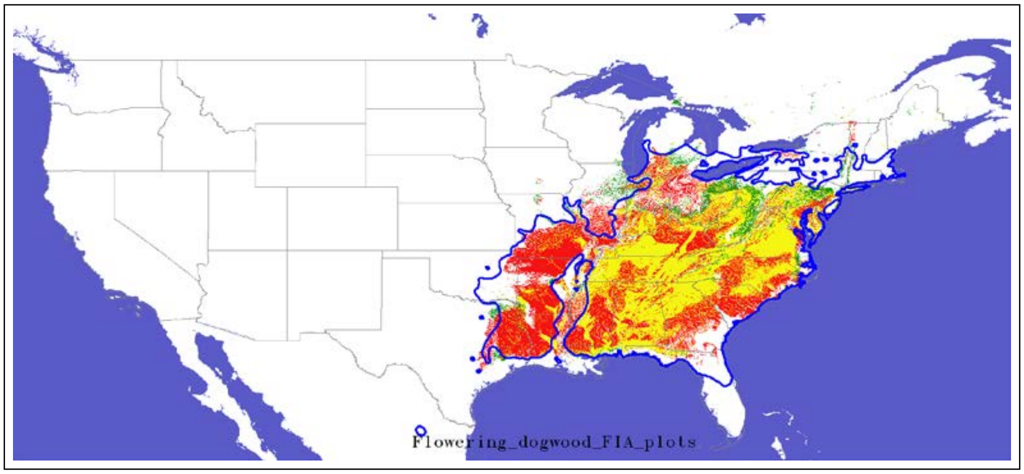

Figure B6. Flowering dogwood (*Cornus florida*) may remain a healthy resident around Fort Bragg.

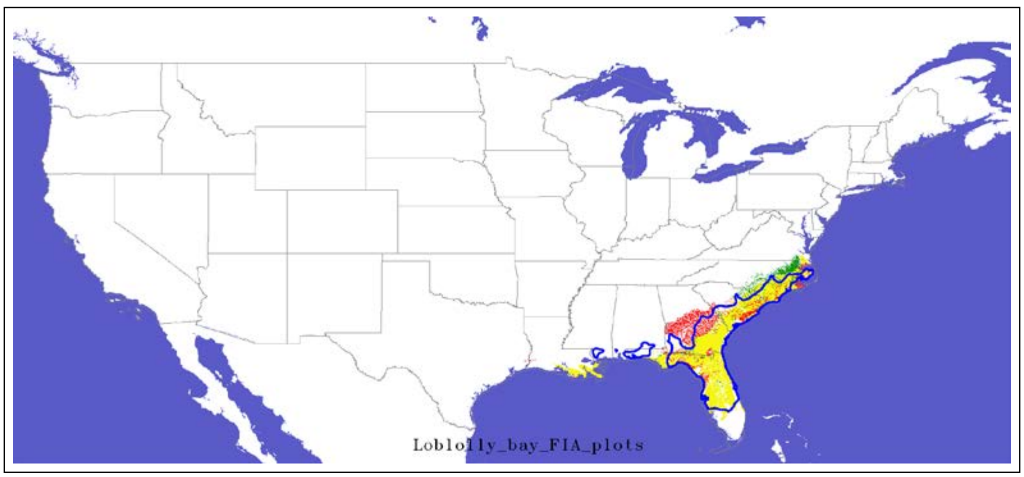

Figure B7. Loblolly Bay's (*Gardonia lasianthus*) range edge is near Fort Bragg. By 2050 the range of the loblolly bay may expand to include Fort Bragg. Therefore its existence at the installation may become more common.

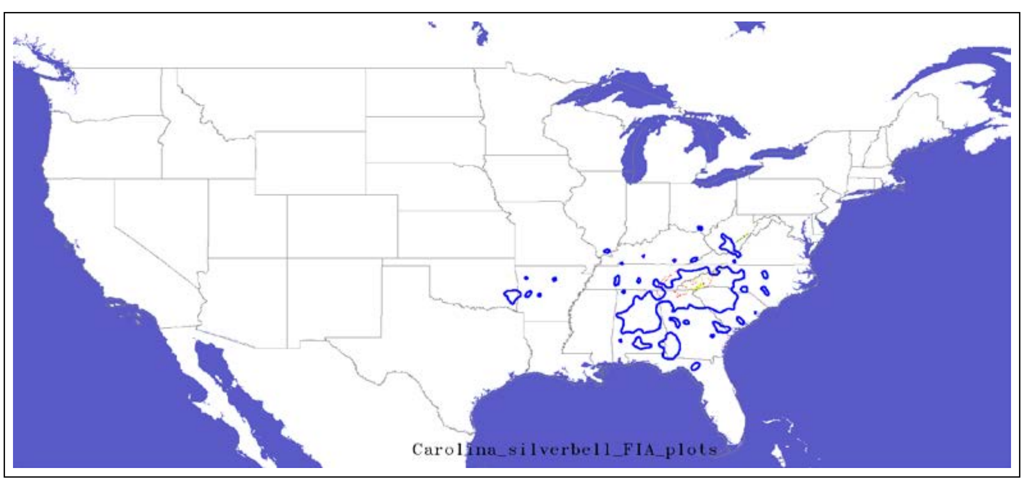

Figure B8. Carolina silverbell's range (*Halesia carolina*) currently includes Fort Bragg. Within a few decades it may become rare or disappear altogether from the installation.

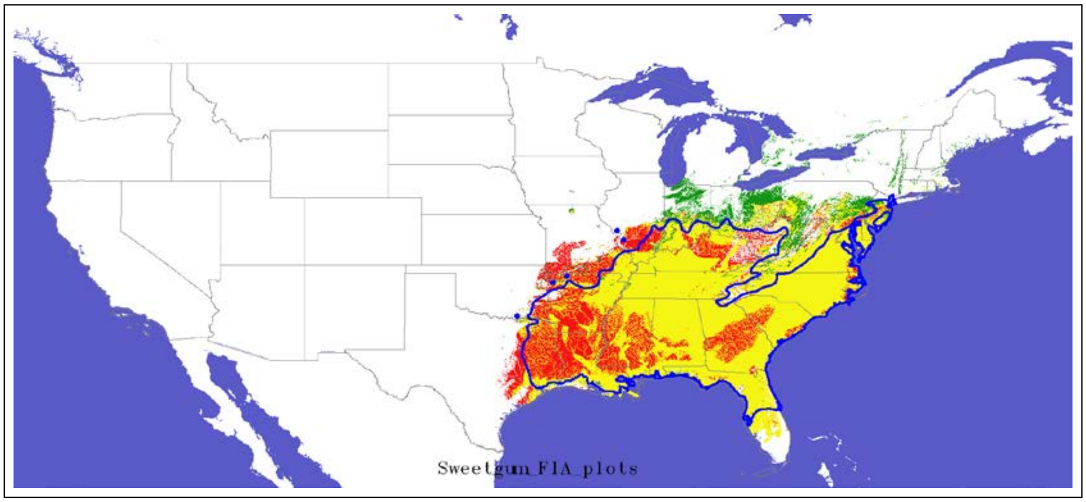

Figure B9. Sweetgum (*Liquidambar styraciflua*) may remain a common resident at Fort Bragg.

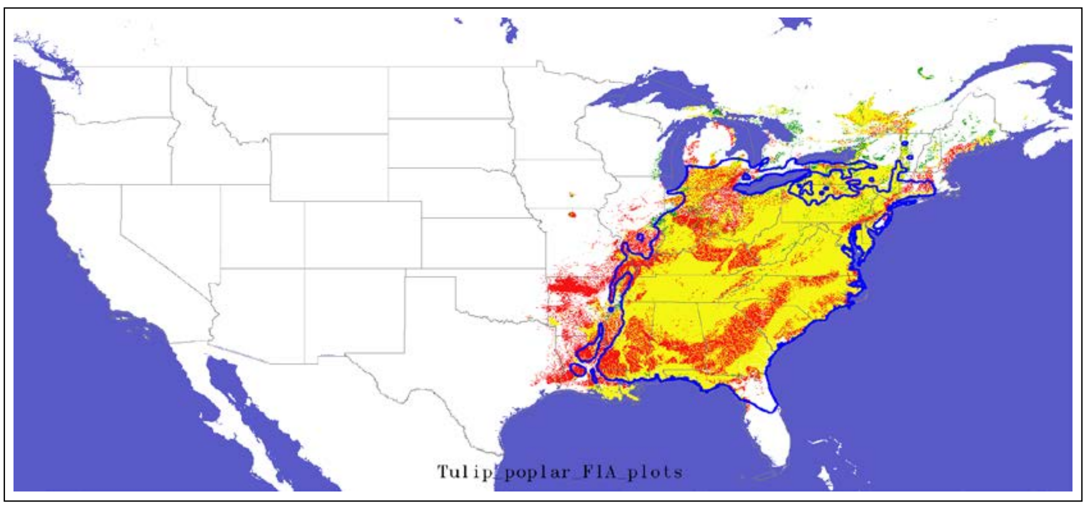

Figure B10. Tulip poplar (*Liriodendron tulipifera*) may remain a common resident at Fort Bragg.

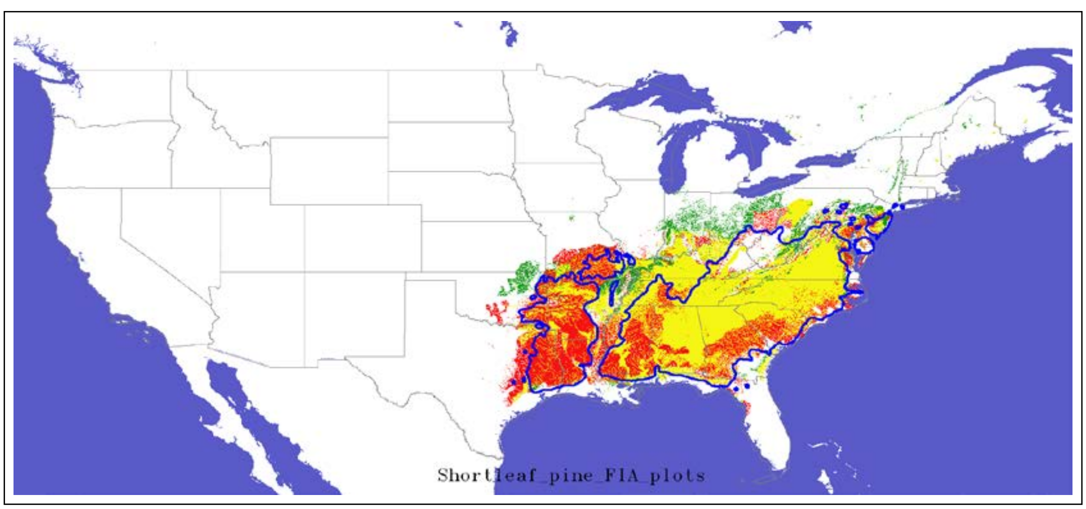

Figure B11. Shortleaf pine (*Pinus echinata*) may remain a common resident at Fort Bragg.

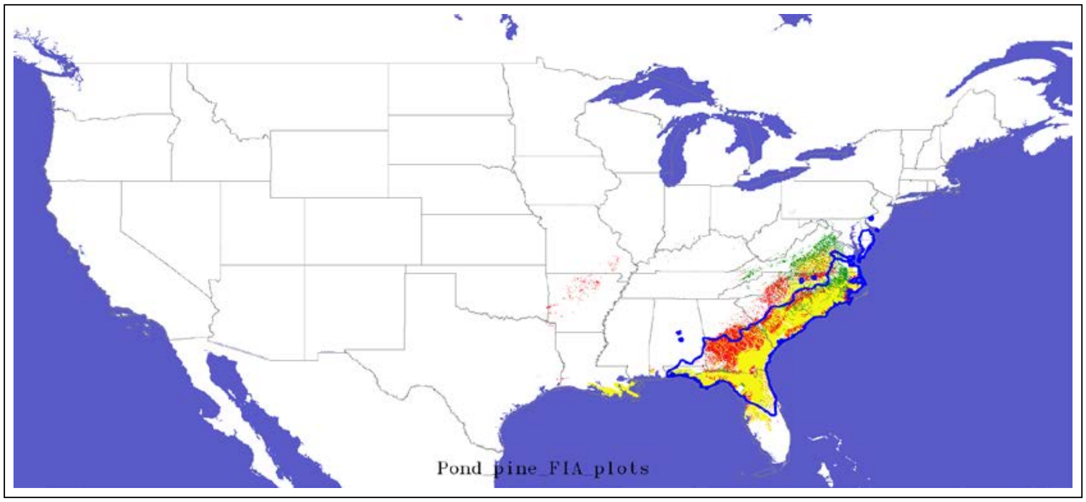

Figure B12. Fort Bragg is currently on the edge of the range of the Pond pine (*Pinus serotina*). In the near future, the range may expand to include the installation completely.

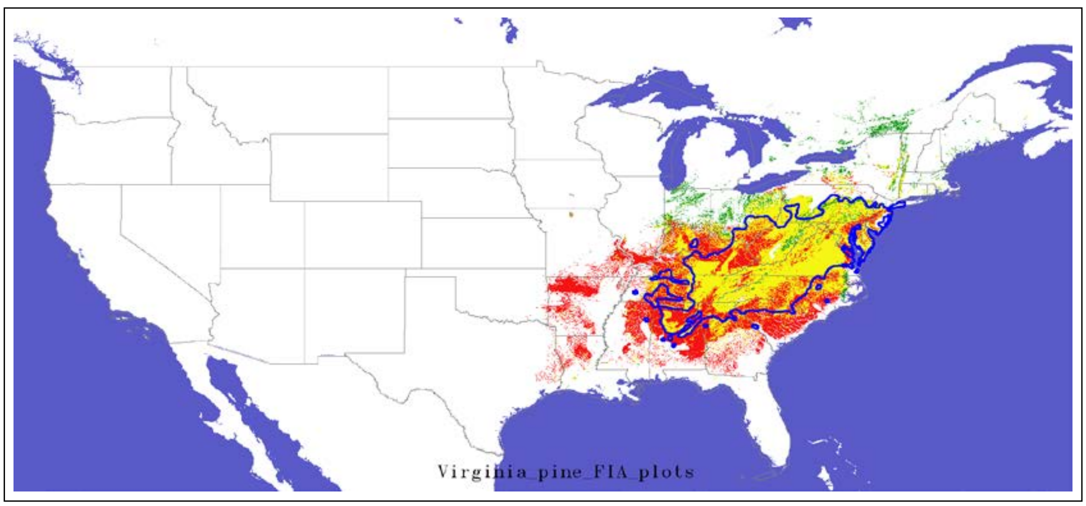

Figure B13. Virginia pine (*Pinus virginiana*) may remain a healthy resident at Fort Bragg.

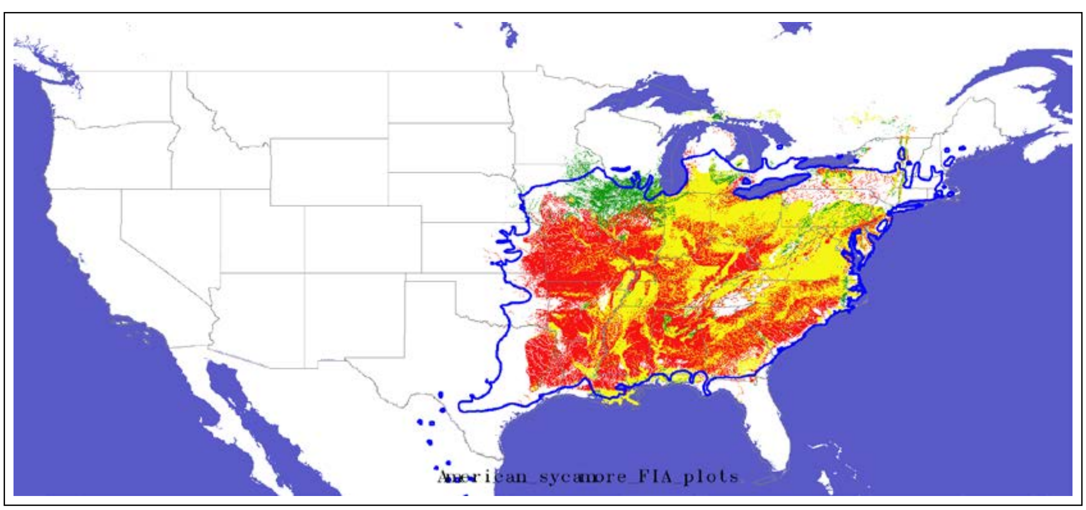

Figure B14. American sycamore (*Platanus occidentalis*) may remain a healthy resident at Fort Bragg.

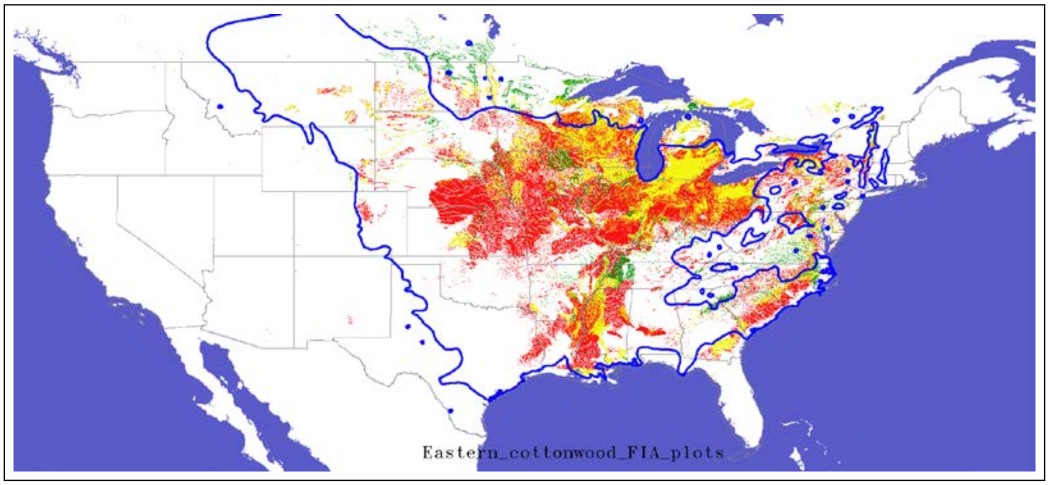

Figure B15. Fort Bragg is currently within the range of the Eastern cottonwood (*Populus deltoides*) although at the edge. However, in time, it may become a little less common.

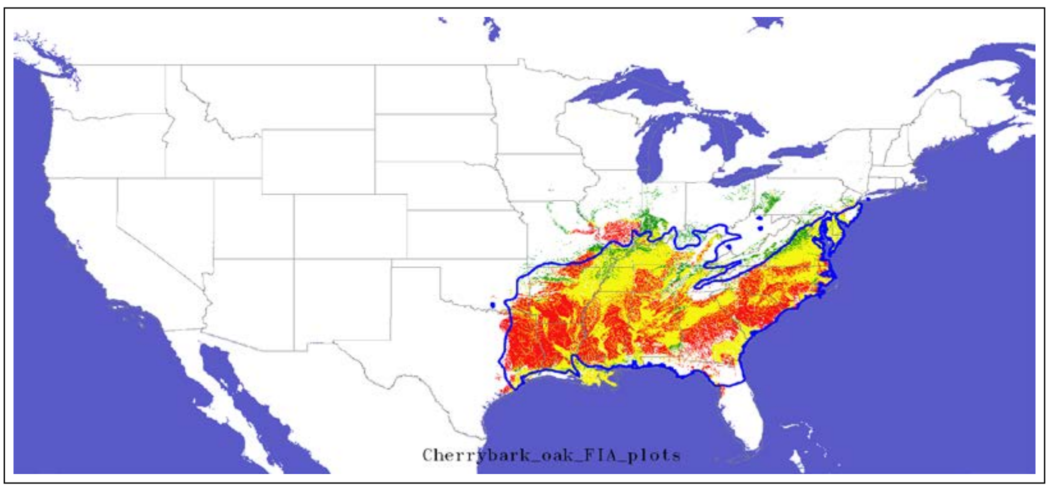

Figure B16. Cherrybark oak (*Quercus pagoda*) may remain a common resident tree around Fort Bragg.

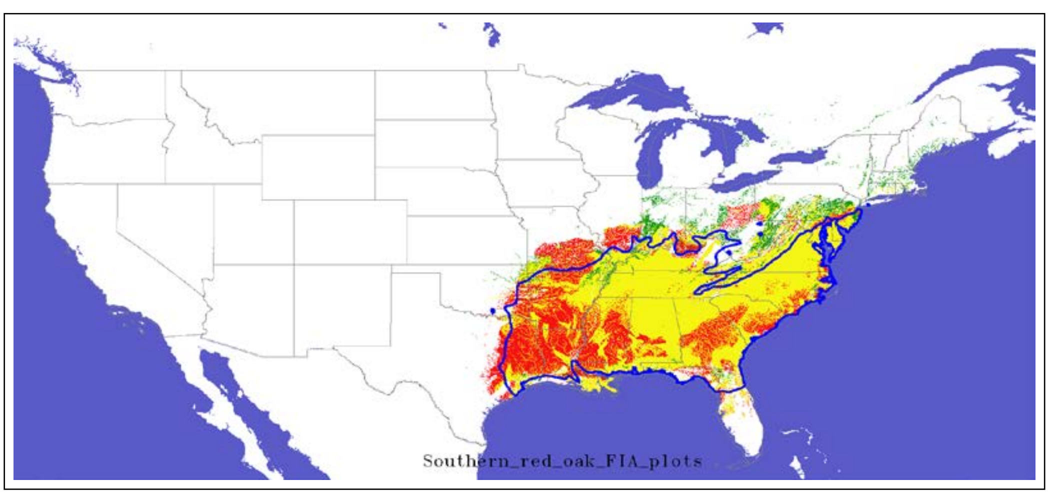

Figure B17. Southern red oak (*Quercus falcata*) may remain a common resident tree around Fort Bragg.

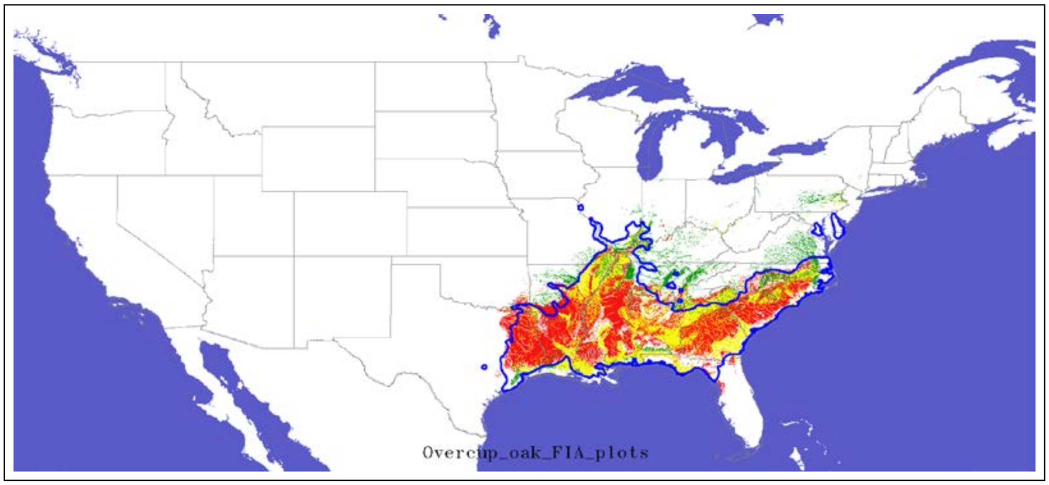

Figure B18. Although the Overcup oak (*Quercus lyrata*) is near the edge of its range around Fort Bragg it may remain at about the same level of occurrence in years to come.

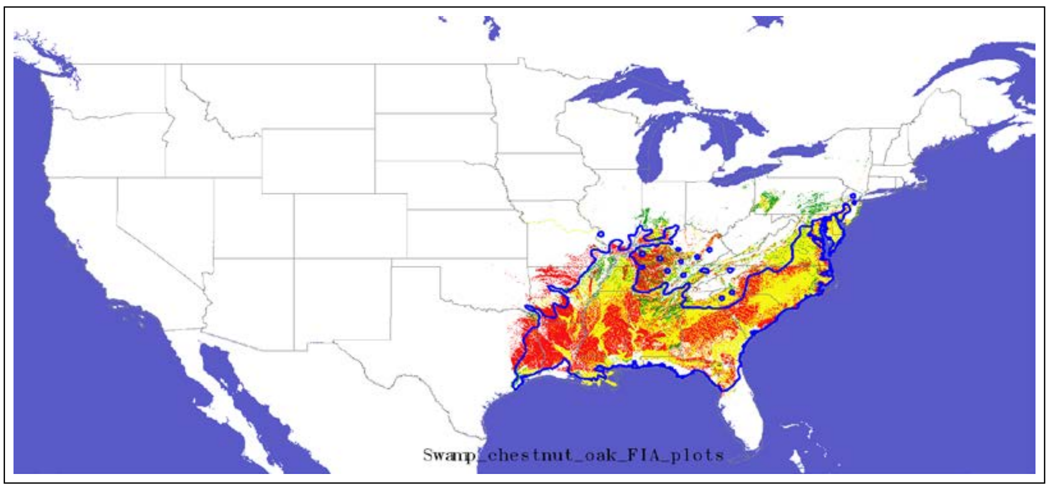

Figure B19. Fort Bragg is currently near the edge of range of the Swamp chestnut (*Quercus michauxii*) however it may expand its range slightly to more fully include the installation.

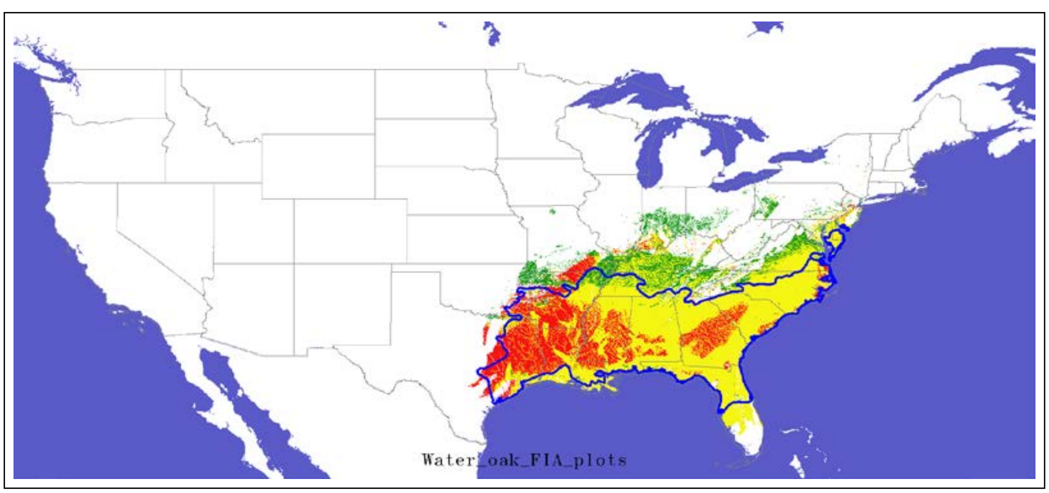

Figure B20. Fort Bragg is currently near the edge of range of the Water oak (*Quercus nigra*) however it might expand its range slightly to more fully include the installation.

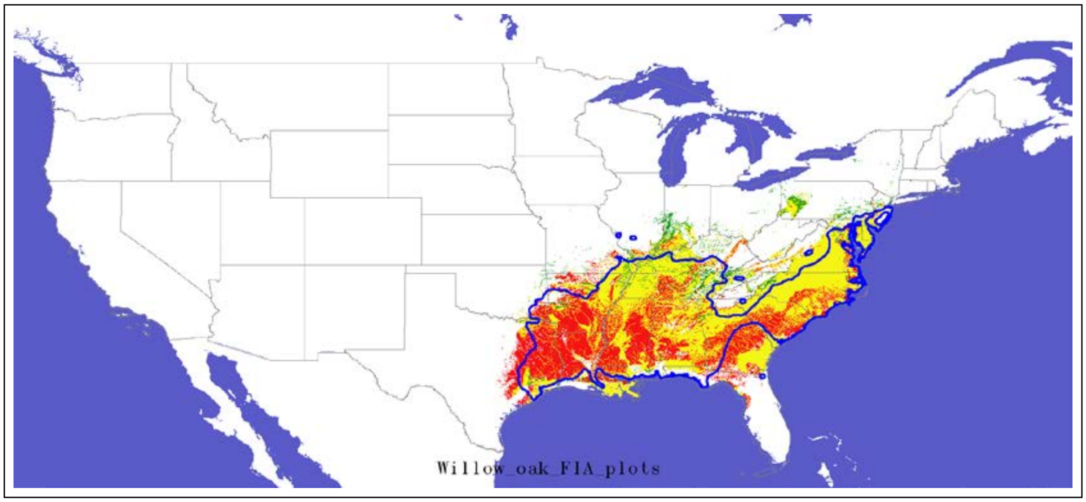

Figure B21. Willow oak (*Quercus phellos*) may remain a common resident on the installation.

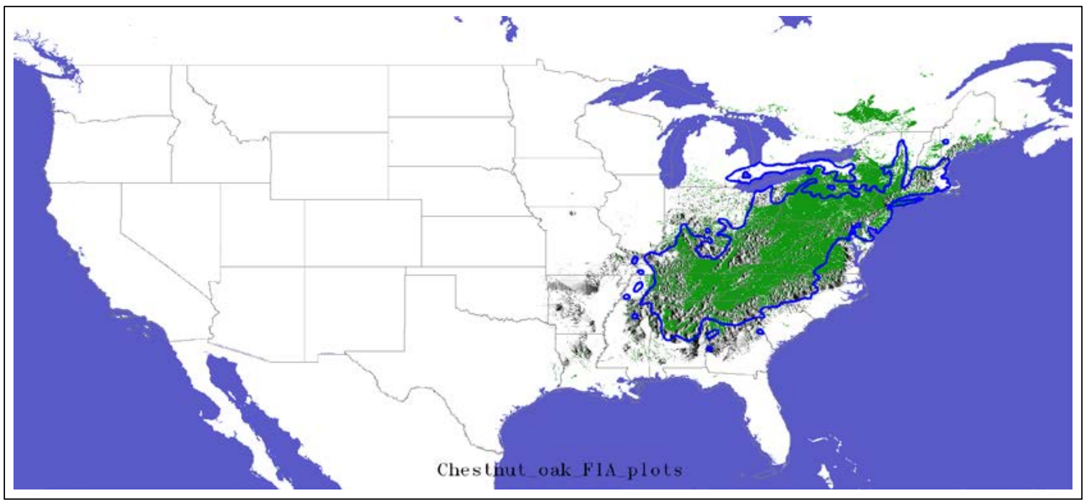

Figure B22. Chestnut oak (*Quercus priuos*) will likely remain a common resident at the installation.

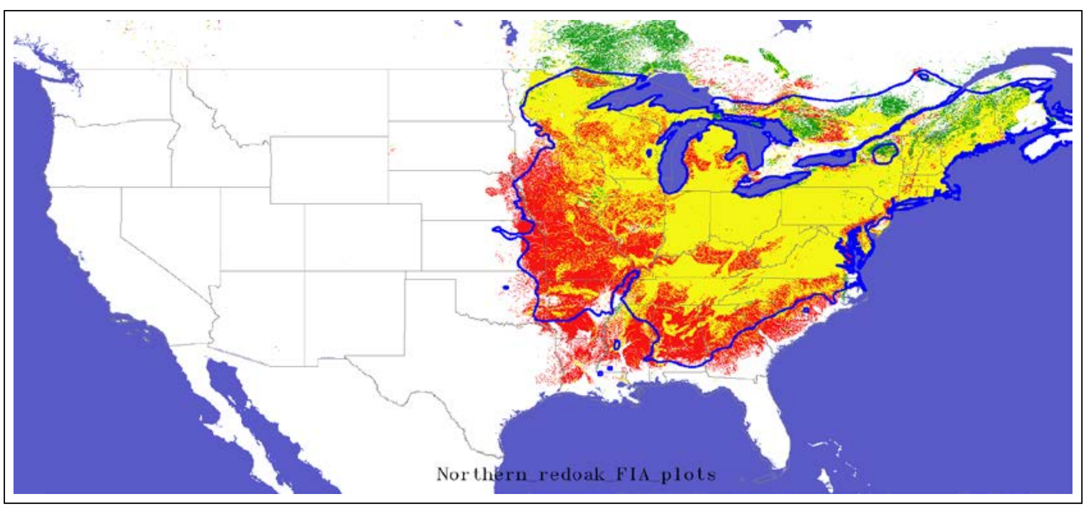

Figure B23. Currently Fort Bragg is near the edge of the range for Northern red oak (*Quercus rubra*). In the future that range may expand to more fully include the installation.

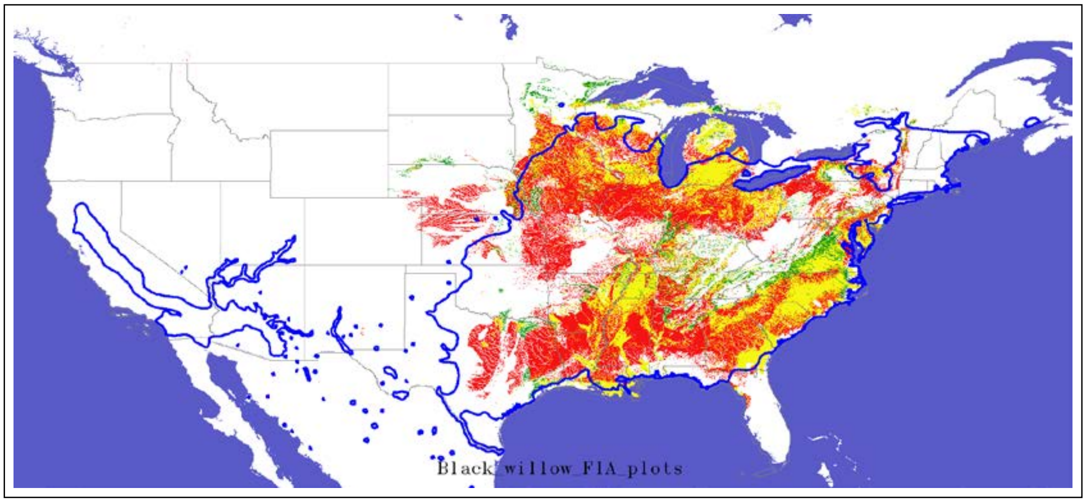

Figure B24. Black willow (*Salix nigra*) may remain a common resident at Fort Bragg.

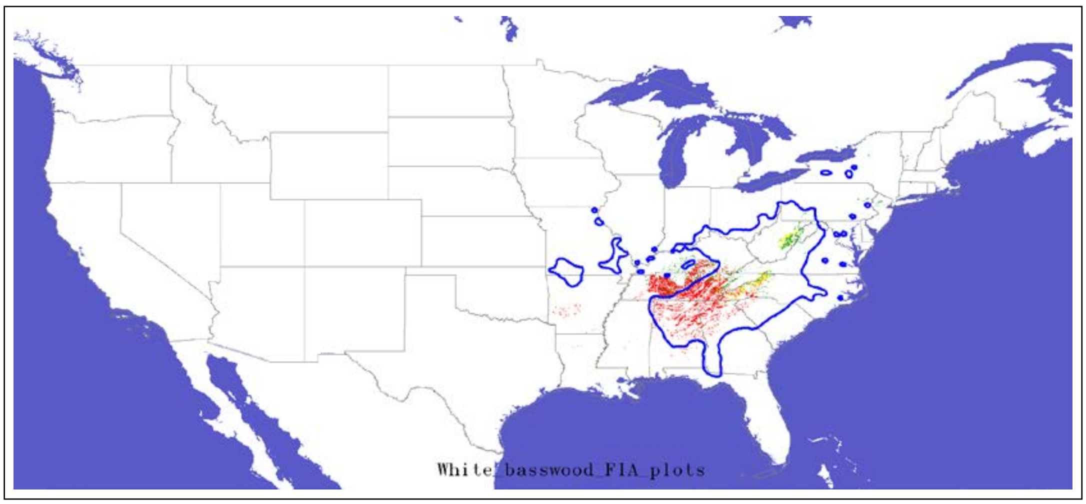

Figure B25. Currently within the range of the White Basswood (*Tilia heterophylla*), climate change may remove this species from the area of Fort Bragg.

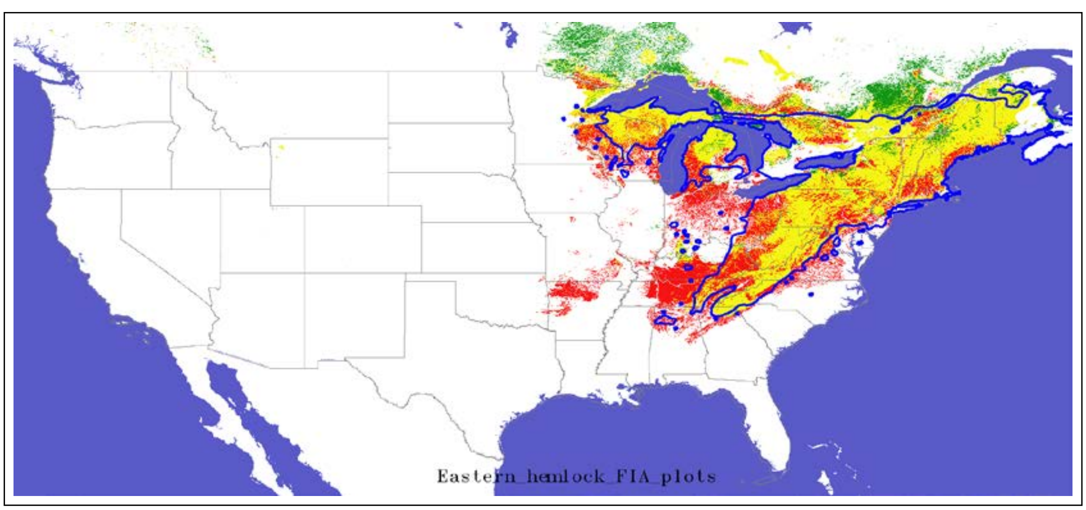

Figure B26. Currently the range of the Eastern hemlock (*Tsuga canadensis*) is near the installation. By 2050 that range may not reach Fort Bragg, but it may come closer.

Appendix C: Abridged List of Non-Native Invasive Plant Species Known To Occur on Fort Bragg

Table C1. Non-native invasive plant species known to occur on Fort Bragg.

Species	Common Name	Record*	Invasiveness Ranking†
*Record source: 1 = Hohmann and Frank 2004; 2 = LCTA; 3 = OBS; 4 = TNC; 5 = INRMP			
Species on Fort Bragg			
Trees			
Ailanthus altissima	*Tree-of-Heaven*	*1,2,3,4,5*	*High*
Albizia julibrissin	*Mimosa*	*1,2,3,4,5*	*Moderate*
Melia azedarach	*Chinaberry*	*1,2,3,4,5*	*High*
Morus alba	*White Mullberry*	*1,5*	*Moderate*
Populus alba	*White Poplar*	*1,2,4,5*	*Moderate*
Pyrus calleryana	*Bradford Pear*	*1,2,5*	*High*
Quercus acutissima	*Sawtooth Oak*	*1,2,5*	*Moderate*
Sapium sebiferum	*Chinese Tallowtree*	*1,2,5*	*High*
Vines			
Ampelopsis brevipedunculata	*Porceleinberry*	*1*	*High*
Dioscorea batatas	*Chinese Yam*	*1*	*High*
Euonymus fortunei	*Wintercreeper*	*1*	*Moderate*
Hedera helix	*English Ivy*	*1*	*Moderate*
Ipomoea spp.	*Morning-Glory*	*1,2,3,4,5*	*Moderate*
Lonicera japonica	*Japanese Honeysuckle*	*1,2,3,4,5*	*High*
Lygodium japonica	*Japanese Climbing Fern*	*1,2,3,4,5*	*High*
Pueraria lobata	*Kudzu Vine*	*1,2,3,4,5*	*High*
Veronica hederaefolia	*Ivy-Leaved Speedwell*	*2,5*	*Moderate*
Vinca major	*Periwinkle*	*2,3,4,5*	*Moderate*
Wisteria spp	*Wisteria*	*1,2,4,5*	*Moderate*
Shrubs			
Berberis thunbergii	*Japanese Barberry*	*1*	*Moderate*
Elaegnus pungens	*Thorny Olive*	*1,2,4,5*	*Moderate*
Elaegnus umbellata	*Autumn Olive*	*2,3,4,5*	*High*
Euonymus alatus	*Winged Burning Bush*	*1*	*High*
Lespedeza bicolor	*Shrubby Bushclover*	*1,2,3,4,5*	*Moderate*
Ligustrum sinense	*Chinese Privet*	*1,2,3,4,5*	*High*
Ligustrum japonica	*Japanese Privet*	*1,2,3,4,5*	*High*
Nandina domestica	*Sacred Bamboo*	*1*	
Rosa multiflora	*Multiflora Rose*	*1,2,3,4,5*	*High*

Species	Common Name	Record*	Invasiveness Ranking†
*Record source: 1 = Hohmann and Frank 2004; 2 = LCTA; 3 = OBS; 4 = TNC; 5 = INRMP			
Grasses			
Agropyron repens	*Quackgrass*	*1*	*Moderate*
Arthraxon hispidus	*Jointed Grass*	*4,5*	*Moderate*
Arundo donax	*Giant Reed*	*1,2,3,4,5*	*Moderate*
Eragrostis curvula	*Weeping Lovegrass*	*1,2,3,4,5*	*High*
Festuca elatior	*Tall Fescue*	*2,3,4,5*	*Moderate*
Microstegium vimineum	*Japanese Stiltgrass*	*1,2,4,5*	*High*
Poa compressa	*Canada Bluegrass*	*2,5*	*Moderate*
Setaria faberi	*Giant Foxtail*	*2,4,5*	*Moderate*
Sorghum halepense	*Johnsongrass*	*1,2,3,4,5*	*High*
Aquatic			
Alternanthera philoxeroides	*Alligatorweed*	*1,2,4,5*	*High*
Egeria densa	*Brazilian Water-Weed*	*5*	*Moderate*
Murdannia keisak aneilima		*1*	*High*
Myriophyllum aquaticum	*Parrot's Feather*	*1,4,5*	*High*
Herbaceous Plants			
Allium vineale	*Wild Garlic*	*1,2,3,4,5*	*Moderate*
Artemisia vulgaris	*Mugwort*	*4,5*	*Moderate*
Cassia obtusifolia	*Sickle Pod*	*1,2,4,5*	*Moderate*
Celastrus orbiculatus	*Oriental Bittersweet*	*1*	*High*
Cirsium vulgare	*Bull Thistle*	*4,5*	*Moderate*
Coronilla varia	*Crown Vetch*	*1*	*Moderate*
Glechoma hederacea	*Creeping Charlie*	*1*	*Moderate*
Lespedeza cuneata	*Chinese Lespedeza*	*1,2,3,4,5*	*High*
Melilotus spp.	*Sweet Clover*	*1,2,4,5*	*High = white and yellow*
Polygonum caespitosum	*Bristled Knotweed*	*1,2,4,5*	*Moderate*
Raphanus raphanistrum	*Jointed Charlock*	*2,3,4,5*	*Moderate*
Rumex crispus	*Curled Dock*	*1,2,4,5*	*Moderate*
Stellaria media	*Common Chickweed*	*2,4,5*	*Moderate*
Species not on Fort Bragg, but within the vicinity			
	Golden Bamboo		
	Giant Knotweed		

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14. ABSTRACT
Current guidance requires that climatic change must be considered in the Army's Integrated Natural Resources Management Plan (INRMP), the goal of which is to ensure good stewardship of natural resources that is compatible with the military mission, and that prevents the net loss of the lands required to complete that mission. Military land managers deal with their lands in the context of the local ecosystem in which they reside. If that ecosystem changes, the land manager must determine how to care for those changing lands while still supporting the installations military mission. Consideration of local consequences of climate change must begin with a review of the local manifestations and implications of climate change. This document uses an installation-specific evaluation and analysis of climate change forecasts for Fort Bragg, NC using currently available climate change data to provide a forecasting approach suitable for land-locked terrestrial Army installations.

15. SUBJECT TERMS
climate change, Ft. Bragg, NC, natural resource management, land use planning, modeling

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