U.S. Fish and Wildlife Service

Examination of Climate-Related Threats to Water Resources in the National Wildlife Refuge System

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Cover photographs: Clockwise starting from top left corner, Bill Williams River National Wildlife Refuge, Arizona; Moosehorn National Wildlife Refuge, Maine; Chassahowiztka National Wildlife Refuge, Florida; Salton Sea National Wildlife Refuge, California. Photos by J. L. Wilkening.

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Executive Summary

Introduction

The Water Resource Inventory and Assessment (WRIA) project was initiated in 2011 based on recommendations made in 2008 from the U.S. Fish and Wildlife Service's (FWS) national Water Resources Team. The primary purpose of the WRIA project is to gather information about the National Wildlife Refuge System's (NWRS) water resources and provide assessments regarding status and water-related threats and needs. These assessments are used to identify and prioritize issues related to all aspects of water resource management in the NWRS and are the agency's most comprehensive effort to date to inform management at all levels of the organization, about these issues.

A major component of the WRIA project was the collection of water-related threats and needs data for each NWRS management unit into a WRIA National Database Application. These threats and needs assessments were developed to ensure that regional assessments were similar enough to compare across the nation. A key aspect of this effort was the use of a standard classification scheme to consistently capture these threats and needs. Threat classifications can be identified and filtered where the threat is caused by a factor that is related to a climatic driver, which offers an opportunity to understand threats to the NWRS with climate-related influences.

The FWS recently adopted the Climate Change Action Program (CCAP, USFWS 2021), which guides agency response to climate change and provides a unified approach to implement climate adaptation actions across programs and regions. The CCAP is a living framework designed to evolve over time and is comprised of seven elements. This report was created to specifically address the second element, which identifies the need to provide further information about climate change impacts on water resources and related knowledge gaps.

This report is a summary and analysis of climate related threats and needs information entered as of July 25, 2022, for 471 refuge units (national wildlife refuges and wetland management districts). The report presents a set of recommendations on next steps as informed by results regarding water resources issues and needs facing the NWRS. This 2023 updated report focuses more specifically on climate, builds upon results from the 2019 report, and includes an additional 32 NWRS units. Although results represent the first comprehensive assessment of climate change effects on NWRS water resources, there are the usual caveats associated with survey data such as potential subjectivity of staff entering the data. Key questions addressed include the following:

- What are the most common refuge threats with climate-related cause?
- Are there significant differences in threats with climate-related causes in different areas of the country?
- What are the most common needs at stations facing climate-related threats?

Analysis Summary

The WRIA project underscores the realization that there are prevalent and pervasive threats facing the NWRS' water resources. These threats jeopardize the conservation mission of individual refuges and of the NWRS in general. The most commonly identified threats to NWRS water resources involve both water quantity and water quality problems. **The top five most commonly identified threats with climate-related causes were**:

	Most Common Identified Threats	Top Severe Identified Threats
1	Insufficient Surface Water	Insufficient Surface Water
2	Altered Flow Regimes	Loss/Alteration of Wetland Habitat
3	Habitat Shifting/Alteration	Loss/Alteration of Estuarine Habitat
4	Excess Surface Water	Compromised Water Management Capability
5	Loss/Alteration of Wetland Habitat	Habitat Shifting/Alteration

Of the 471 refuge units, 264 (56.1%) had identified at least one climate-related threat serious enough to be designated as a severe threat. These severe climate-related threats were viewed as being so consequential that they potentially compromise the conservation mission of these stations.

Identifying root causes of these threats is important to understand drivers of threats, which is key to evaluate vulnerability of habitat and species management to climate change. **The most common climate-related causes of all water-related threats facing the NWRS were:**

	Most Common Climate-Related Cause	Top Severe Climate-Related Causes
1	Climate Warming	Climate Warming
2	Drought	Drought
3	Extreme Precipitation	Sea Level Rise
4	Sea Level Rise	Extreme Precipitation
5	Change in Precipitation Patterns (Non-Extreme)	Rain-Snow Regime

Patterns in climate-related threat occurrences were evaluated qualitatively for the top 5 most common climate-related threats and climate-influenced causes by visual interpretation of maps showing refuge locations where at least one occurrence of that climate-related threat was found.

The top five most common climate-related threats exhibited some geographic patterns but were highly variable. Insufficient surface water was a larger issue for units in the southern regions, but a more severe threat type for the southwestern portion of the country and Alaska. Altered flow regimes was cited as a

high severity threat type by at least one unit in most Regions. Excess surface water was more commonly cited in the eastern half of the country and Alaska. Loss or alteration of wetland habitats was most cited at coastal refuges scattered throughout the country.

The top five most common climate related causes of threats exhibited distinct geographic patterns. Drought was more frequently cited in the western half of the country while extreme precipitation was more common in the eastern regions. Both were cited equally in Alaska although extreme precipitation was cited more frequently. Non-extreme change in precipitation patterns was less commonly cited overall and primarily clustered in the midwestern region of the country. Sea level rise was cited in all regions with coastal units, including Alaska and Hawaii, Finally, climate warming was relatively well distributed throughout the nation but appeared to be slightly more common in Alaska and less common in the northeastern portion of the country.

Like threats, the frequency of need occurrences (unique combinations of refuge and need type) was tabulated at stations with climate-related threats to identify the most common refuge needs for stations impacted by climate change. **The following are the top five most common needs for all refuges that had at least one climate-related threat:**

	Most Common Climate-Influenced Need	**Most Common High Priority Climate-Influenced Needs**
1	Water Quality Baseline Monitoring	Water Supply / Quantity Monitoring
2	Water Supply / Quantity Monitoring	Water Quality Baseline Monitoring
3	Targeted Water Quality Monitoring	Build/Strengthen/Expand Watershed Partnerships
4	Water Level Monitoring	Water Level Monitoring
5	Climate Change Vulnerability Assessment	Replace or Repair Water Management Infrastructure

The top two to four observed needs identified in this national project were informational in nature: related to water quality or water quantity monitoring. Because the objectives of these monitoring needs were not further assessed, it's not yet possible to know if and how monitoring would help address climate-related threats.

Recommendations:

The following recommendations for how the NWRS can better evaluate climate-related threats and needs in the future are presented in this report.

Develop a better understanding of how water monitoring data can inform response to climate-related threats. The NWRS should further investigate the objectives of water monitoring needs (water quality and quantity) to determine how they fit into decision-making and habitat

management, preferably under existing Inventory and Monitoring Program frameworks. The NWRS should consider a strategy to support and prioritize collection of water resources data (water quantity and quality) that can effectively inform decisions on adaptation to climate change.

Support cross-regional collaboration on climate vulnerability assessments that can inform adaptation of water management and planning to climate change: Using common climate-related threats and climate-influenced causes as the basis for pilot project selection, the NWRS should support or implement climate vulnerability assessments (funding, strike teams) at selected stations with a focus on water resources issues.

Improve threats and needs data collection, and use of WRIA Database to track progress: The Water Resources Team (WRT) should decide whether to prioritize a national effort to update, improve, and expand data entry at regular intervals (i.e., 1-2 years or greater) with improved documentation on data quality to ensure consistent and complete data entry. Inclusive in this update would be refinement of climate-related attributes that define threats and needs, and an assessment of how needs address threats.

1.0 Introduction

The US Fish and Wildlife Service (FWS) has long recognized that many of our agency's conservation priorities are only achievable if water resources are properly understood and managed. In 2008, the FWS national Water Resources Team (WRT) presented recommendations to the National Wildlife Refuge System (NWRS) leadership for a system-wide assessment of water resources and the establishment of a national database to store and analyze water information. The WRT felt these assessments were necessary to identify and prioritize issues related to all aspects of water resource management in the NWRS (U.S. Fish and Wildlife Service 2012). This assessment effort would allow us to address a basic question that has challenged FWS water resource managers for decades: What is the status of water resources in the NWRS? In 2010, FWS leadership established the National Resource Program Center (NRPC) in Fort Collins, CO as an office dedicated to interdisciplinary science, including inventory and monitoring and water resources. The NRPC took the recommendations of the WRT and spearheaded the water resource assessment effort.

In 2011, with funding largely from the NRPC, this effort coalesced into a national project referred to as the Water Resource Inventory and Assessment project (WRIA;(U.S. Fish and Wildlife Service 2013). A primary purpose of the WRIA project was to provide a standardized and comprehensive national inventory and assessment of the waters of the NWRS leading to strategies that address opportunities, threats, and needs at the appropriate spatial scale. The WRIA project was also considered for the National Fish Hatchery System (NFHS), but completion has not been consistent across the nation at this time.

A major component of the WRIA project was the collection of water-related threats and needs data for each NWRS management unit into a WRIA National Database Application (U.S. Fish and Wildlife Service 2019). These Threats and Needs assessments were developed to ensure that regional assessments were similar enough to compare across the nation. A key aspect of this effort was the use of a standard classification scheme to consistently capture these threats and needs, so that when a hydrologist in one region uses threat terms like "insufficient surface water" or "nutrient pollution," hydrologists in other regions are working from a common definition.

Recognizing the transformative effects of climate change and the resulting profound management challenges, the FWS recently adopted the Climate Change Action Program (CCAP, USFWS 2021). The CCAP guides FWS response to climate change and provides a unified approach to implement climate adaptation actions across programs and regions of the agency. It utilizes the best available science and partner collaborations to address climate related challenges at landscape scales. This living framework was designed to evolve over time and is comprised of seven elements. The second element focuses on the production and interpretation of climate science to be applied by agency practitioners to address conservation needs. The second element specifically identifies the need to provide further information about climate change impacts on water resources and related knowledge gaps. This report responds to that request and was developed by a CCAP working group created to inform this effort. Elements of the CCAP provide direction at the national level and can be scaled down to smaller levels. For example, the Region 1 CCAP is conducting a similar analysis that will inform water resource management at localized scales.

This document provides an updated summary of the many water challenges facing the NWRS. **Key questions it addresses include the following:**

1.) How many stations have climate-related threats with climate-influenced causes and how many are severe?

2.) What are the most common and severe threats with climate-related cause?

3.) What are the top 5 climate related causes of any threat? What are the top 3-5 climate related causes of severe threats?

4.) Are there significant differences in threats with climate-related causes in different areas of the country?

Proposed Questions:
We addressed these questions through the following analysis steps:

1.) Compile statistical summaries of the most common and severe climate related threats, and the most common and high-priority needs at stations facing climate-related threats.
2.) Evaluate differences in regional and spatial patterns in climate related threat results.

This analysis accounts for information in the WRIA National Database as of July 25, 2022. As of that date, threats and needs information have been collected from **471** stations in the NWRS (Figure 1), representing 74% of the 592 Refuge System units. All 471 stations identified at least one water resource threat, but only 381 stations identified at least one need. TAs more information is received from refuges and hatcheries across the nation, an update to this report will be warranted. Updated analyses will add credibility to these interpretations and aid in removing bias from survey results.

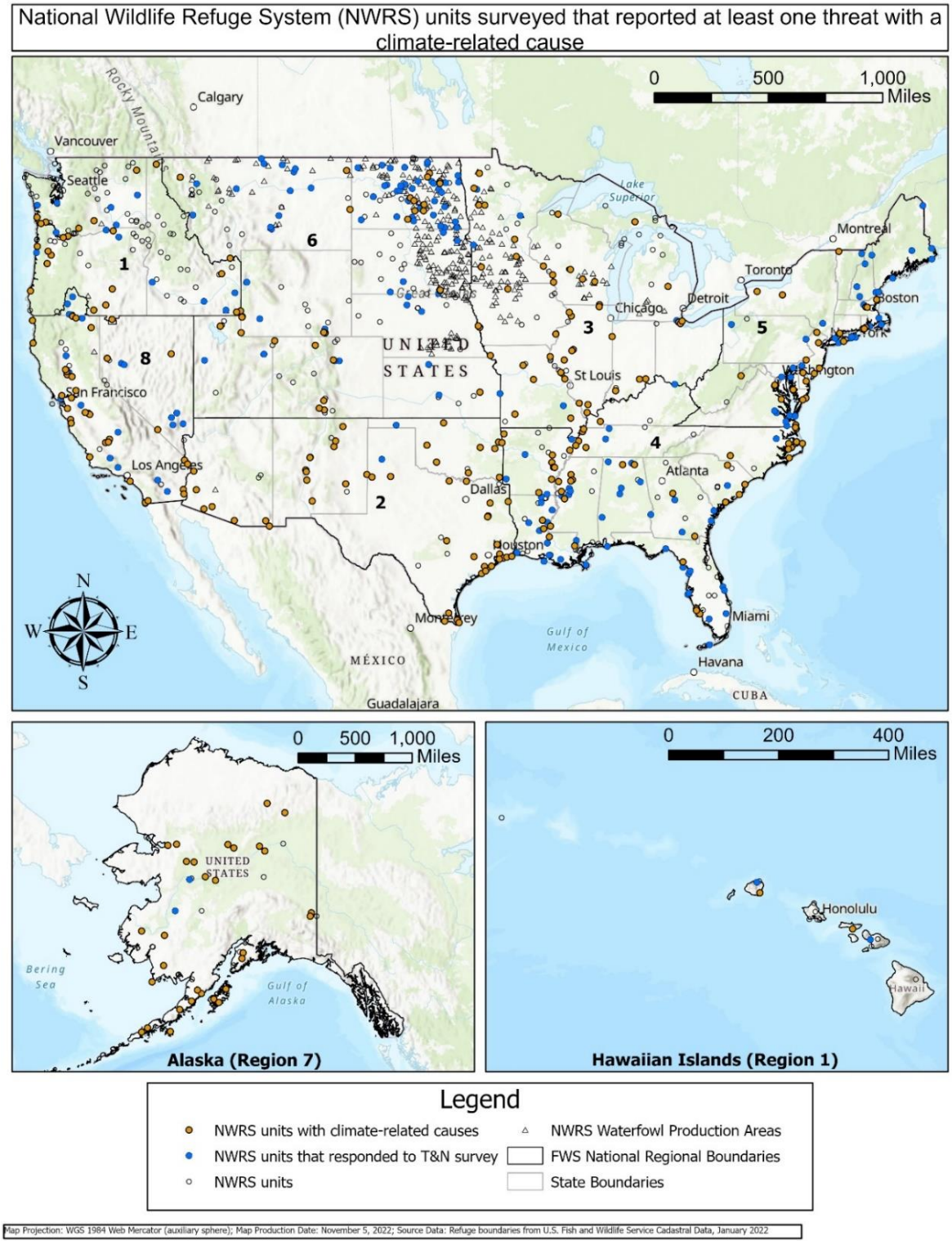

Figure 1. National Wildlife Refuges and Wetland Management Districts where at least one threat with a climate-related cause in the WRIA National Database as of July 2022. Note: the absence of an NWRS unit from any of the figures does not necessarily indicate that a particular climate change threat or cause is not occurring. Not all NWRS units responded, and no responses were received from any units in the Caribbean region.

2.0 Methods

2.1 Data Collection

2.1.1 Threats and Needs Classification

A WRIA Application (includes database and other sources of relevant water-related information) had been constructed by developers working for the Environmental Conservation Online System (ECOS) in conjunction with a user team of representatives from all FWS regions. During initial discussions about developing a database for NWRS and NFHS water-related information, it was recognized that an important component was the capture of threats and needs data for refuge and hatchery water supplies. To make this information available for querying and analysis in the database, the user team recognized the need for a classification system for threats and needs. Subsequently, a set of standardized lists of threats and needs from which all users could choose was developed.

Threats were classified into threat types and causes. After several iterations, the user team agreed upon a list of **32** threat types organized in three broad categories: Water Quality, Water Quantity, and Aquatic Habitat **(**USFWS 2019: Appendix A**)**. Threat causes were more varied; the team identified **89** potential causes, organized into six categories: Water Quality, Water Supply/Quantity, Water Management Capability, Water Rights/Legal, Landscape Alteration, and Climate (USFWS 2019: Appendix A).

The three broad categories for threat types and six categories of threat causes are for organizational purposes only. Any threat type can be associated with any cause. A threat type can have multiple causes, but each type-cause relationship is treated as a separate threat within the database. This was done because each type-cause may have a different solution, or one cause could be mitigated, but the threat remains due to other causes. For example, nutrient pollution is a threat type that may have causes tied to agricultural runoff and livestock, the remedies for which are very different, and nutrients would still be an issue if only one of these were mitigated.

Similarly, needs were classified into eight broad (Level 1) categories and 66 specific (Level 2) needs (USFWS 2019: Appendix A). Unlike the threats classification, in which any threat type could be associated with any cause, the specific Level 2 need had to be matched with the corresponding Level 1 category. For example, “Water Quality Baseline Monitoring” could only be matched with the Level 1 category “Monitoring/Measurement”. Because the Level 1 categories lack specificity, only the Level 2 need types were analyzed for this report.

For this analysis, threat classifications were further identified and filtered where the threat is caused by a factor that is related to climate (for the remainder of this report, these are referred to as “climate-influenced causes”). Hereafter, threats with climate-influenced causes are referred to simply as “climate-related threats”.

Several similar climate-influenced cause definitions were reclassified under a new single classification. Initially, the following causes from the original classification definitions were considered (Appendix A). This lumping was based on feedback from individuals who participated in the 2018 data entry effort who indicated that there was not a distinguishable difference between cause definitions in practice where the difference was related to changes in the rate, frequency, or severity. In many cases, climate change is impacting refuges now; the change in rate, frequency, and severity may not often be cited alone, or even known. Furthermore, this reclassification helps streamline interpretation to maximize the assessment of unique climate-related causes affecting refuges.

- “Extreme Precipitation Events” and “Change in Frequency/Severity of Extreme Precipitation

Events" were reclassified to "Extreme Precipitation"
- "Rain-Snow Regimes" and "Changes in Rain Snow Regimes" were reclassified to "Rain-Snow Regime"
- "Droughts" and "Increase in Drought Frequency/Severity" were reclassified to "Drought"
- "Storm-Induced Coastal Erosion" and "Increase Rate of Storm-Induced Coastal Erosion were reclassified to "Storm-Induced Coastal Erosion"
- "Tropical Storms/Hurricanes" and "Increased Frequency/Intensity of Tropical Storms and Hurricanes" was reclassified to "Tropical Storm/Hurricane".

Threats experienced in the past with climate-influenced causes indicate a vulnerability to climatic drivers, and it is assumed that this vulnerability would continue or increase with ongoing climatic change. In terms of understanding threats and vulnerability to climate, it is assumed that many management actions to adapt from ongoing climate change would remain the same. It is also assumed that if a threat occurs because of a climate-influenced cause, then the threat is one that has been persistently or notably observed over time (i.e., extreme precipitation events), or is projected to occur more frequently in the future (i.e., change in frequency/severity of extreme precipitation events). It is also assumed that the climate-influenced causes identified above can be accurately defined as related to climate (the expectation that these types of events will occur again in the future, or a shift in the climate that will increase the likelihood that these events will occur in the future), and not related to single events resulting from variable weather.

As of the date of this analysis, the WRIA database is no longer housed on the ECOS platform because of changes to contractual priorities for database access and maintenance, and changes in user needs. However, the threats and needs dataset has been preserved in an interim excel-based format while the WRT and the NRPC decide on a long-term data storage solution for this information.

Climate-related rationale for needs were not explicitly identified in the database schema. Furthermore, needs in the database were not explicitly tied to threats even though the capability for this many-to-many data relation was an option in the original database schema (see section 2.1.4 for more information).

As an alternative, for this analysis, trends in needs were assessed for stations facing at least one threat with a climate-related cause. An assumption was made that needs identified for these stations will likely assist the refuge in addressing climate-related threats even if the relation was indirect. For example, if a station is facing insufficient surface water due to drought, and has a need for improved water use monitoring, it is likely that this information will be important for the refuge to adapt management to increase resiliency to drought. Another example may be the identification of water-related thresholds, which will be an important component of the sequential adaptation necessary for many stations.

2.1.2 Threats and Needs Data Attributes

Additional required attributes for both threats and needs were entered into the database to help with analyses and any subsequent prioritization of work. In addition to threat type and cause, attributes required for each threat include severity, timeframe, whether the FWS can address the threat independently, source of threat information, and the quality of that information. Of relevance to this assessment is threat severity. The categories of severity are defined as follows:

- **High**: Prevents fulfillment of refuge purpose(s) or NWRS mission; threatens public safety; threatens Threatened and Endangered (T&E) species; threatens adverse legal consequences; threatens infrastructure.
- **Moderate**: Hinders completion of one or more management objectives (e.g., degrades habitat for non-T&E species, inadequate infrastructure for habitat management).

- **Low**: Directly or indirectly affects refuge operations but does not hinder refuge purposes or management objectives. Potentially of concern.
- **Unknown**: Insufficient information to determine severity.

Thus, a “high severity” water-related threat with a climate-related cause represents a serious situation for a refuge. The rationale for including this attribute is to identify refuges with these high-severity threats to prioritize potential adaptation efforts. The other threat attributes can also help with this prioritization process.

Additional attributes for needs data include priority, required effort, timeline, whether the FWS can address the need independently, the source of the information, and the quality of that information. Priority is particularly emphasized in this analysis to identify the most urgent water-related needs of the NWRS. The categories for water need priority are defined as follows:

- **High**: Necessary to fulfill refuge/hatchery purpose(s) or NWRS mission; necessary to protect public safety, infrastructure or avoid serious legal consequences; necessary for survival of T&E species
- **Moderate**: Necessary to complete one or more management objectives, or protect/restore habitat for non-T&E species
- **Low / Unknown**: Would be helpful for refuge operations, but not critical to refuge functions, or is unknown

As with threats, these additional need-related attributes can help to identify urgent needs at stations facing threats related to climate change and prioritize efforts to fulfill them.

2.1.3 Threats and Needs Data Collection and Entry

The WRIA application/database is administered by NWRS-Headquarters, but the identification and entry of threats and needs information is the responsibility of the eight FWS regions. Flexibility was given to the regions in how this information is acquired. Some regions used region-wide surveys of refuges, with varying degrees of follow-up with refuge personnel. All regions used interviews with refuge personnel and completed WRIA reports, as well as other reports such as Comprehensive Conservation Plans (CCPs) and Contaminant Assessment Process (CAP) reports, to at least some degree. For data entry, WRIA developers with ECOS constructed an Excel spreadsheet that can be used to batch-load multiple threats and needs into the database. Most regions used this spreadsheet for at least a portion of their data entry. Sources of information for threats and needs data are shown in Appendix A.

2.1.4 Caveats about the Data

Information contained within the WRIA database represents the best available data on water resources in the NWRS. However, there have been differences in interpretation and intensity of data collection, reflecting variability among the eight regions and subjectivity among individuals entering data within the same region. Assignment of attributes such as threat severity and information quality were primarily based on definitions provided in the WRIA application, with some latitude for professional judgement. All these differences introduce at least some bias into the data. This issue is further discussed in USFWS 2019, but important points are discussed in this section.

Regarding data collection, there are known differences among the regions in how threats information was acquired (described above), and the intensity of data collection efforts (USFWS 2019: Figure 2a and 2b). For example, a region that followed the initial WRIA guidelines as a “reconnaissance level” survey will likely uncover fewer threats than a region that examined each refuge more intensively, such as from completion of a much more detailed WRIA report. As such, regions used variable data-entry processes

that could result in “lumping” and “splitting” of entries. To minimize this bias and increase consistency, this analysis includes counts of the number of unique threat and need occurrences at each refuge, rather than the total number of threats and needs. Additional examples of this issue are discussed in USFWS (2019).

Note that information on threats and needs remains incomplete for many refuges. Therefore, some currently existing threats or needs not identified at a refuge at the time of this report may be identified during subsequent assessments, in addition to new threats or needs that may arise over time.

The most common sources of both threats and needs data are WRIAs, threats and needs assessments (regional surveys or theme-focused station assessments), and personal communication with refuge staff (USFWS 2019). WRIA was the most common source for needs data, and threats and needs assessments were the most common source for threats data (USFWS 2019: Figure 2a and 2b).

Based on a questionnaire sent to regional representatives who entered data into the application, WRIAs and field station interviews (either as threats and needs assessments or other personal communication with staff) were the two most helpful sources of data entered into the application. Most information derived from field station interviews were either entered directly into the application or used to develop a WRIA where info was then entered into the application (82%). However, 36% of respondents indicated that field station interview information was put directly into the application with little or no interpretation from a hydrology professional. Quality codes assigned for both threats and needs were mostly made with professional judgement by a hydrology expert (45%), strictly following the quality code definitions provided by the WRIA application (27%), or both (9%).

2.2 Data Analysis

To perform the analysis of data from the WRIA database, an R-script that was developed for the previous analysis (USFWS 2019) was modified to summarize key metrics from an output of data from the WRIA database. This R-script included code to perform the filtering necessary to identify climate-related threats and climate-influenced causes, including reclassification of climate-influenced causes (see section 2.1.1 for classification definitions). The R-script also retained the same process for filtering out records from the WRIA database that were of poor or unsuitable quality for analysis, including records where the fields Quality and Source were null. This filtering process ensured that only records with verified quality and known sources were retained for analysis.

The R-script was applied to data extracted from the WRIA database as of July 25th, 2022. Updates to records in the WRIA database since the date of data extraction applied to the previous analysis (WRIA 2019, August 2018) were not analyzed, but it was assumed that minimal changes were made between these two dates because there was no request among regions to make updates to the records. It was beyond the scope of this analysis to compare changes made between August 2018 and July 2022.

The R-script was used to address the following questions, which are described in more detail below:

1.) What are the most common climate-related threats, and climate-influenced causes of threats, across the nation?
2.) Are there significant differences in climate-related threats and climate-influenced causes across the nation and among regions?
3.) What are the most common water resources needs at stations with climate-related threats across the nation?

2.2.1 What are the most common climate-related threats, and climate-influenced causes of threats, across the nation?

To identify the most common threat types associated with climate change, we tabulated the frequency of unique combinations of refuge and threat type where the threat has a climate-influenced cause. To investigate which climate-related threats pose the greatest challenges for fulfillment of refuge system mission, we further tabulated the most common climate-related threat occurrences where the threat severity was cited as “high”. We summarize these results in tabular form listing the top 5 most common climate-related threat types and top 5 most common high severity climate-related threat types and in graphical form with bar charts showing the top 10 most common climate-related threat types and high severity climate-related threat types.

Understanding inherent causes for climate-related threats is important for helping to determine the feasibility of adaptation. Causes of common climate-related threats were also investigated by identifying the top 5 and top 10 most common threats with climate-influenced causes of all threats and climate-related threats with high severity. Additional threat attributes are discussed for those climate-related threats that are among both the top 5 most common and top 5 most common with high severity.

2.2.2 Are there significant differences in climate-related threats in different areas of the country?

Patterns in climate-related threat occurrences were evaluated qualitatively for the top 5 most common climate-related threats and climate-influenced causes by visual interpretation of maps showing refuge locations where at least one occurrence of that climate-related threat was found. Color coding was used to identify the severity ranking of that threat.

Appendix figures (Appendix C) were created to identify and summarize the top 5 most common climate-related threats and climate-influenced causes for each region. The top 5 climate-related threats and climate-influenced causes by region were identified and ranked by frequency of occurrence.

Using maps, graphs, and the tables described above, qualitative analysis was performed to identify and interpret patterns in the regional breakdown or identify any other spatial similarity of common threats across the country. Unique threats only found in one region and not others were also identified.

2.2.3 What are the most common water resources needs across the nation?

Similar to threats, we tabulated the frequency of need occurrences (unique combinations of refuge and need type) at stations with climate-related threats to identify the most common refuge needs for stations impacted by climate change. For the remainder of this report, these stations are referred to as “needs at stations with climate-related threats”. To investigate which needs at stations with climate-related threats are the highest priorities for the refuge system mission, we separately tabulated the most common need occurrences where the need priority was cited as “high”. We summarize these results in tabular form listing the top 5 most common needs and top 5 most common high priority needs, and in graphical form with bar charts showing the top 10 most common needs and high priority needs.

3.0 Results

3.1 Threats

At the time of analysis, the WRIA database contained ***2,375*** refuge threat occurrences (unique combinations of refuge and threat type), and ***2,654*** unique causes of refuge threat occurrences (unique combination of refuge, threat type, and threat cause). There were 264 refuges that had at least one climate-related threat, which represents 56% of refuges with threat entries in the WRIA. The most common threat types, including the top ten most common and severe threats, are described below. Common causes of threats, as well as common causes for all threats, are also discussed.

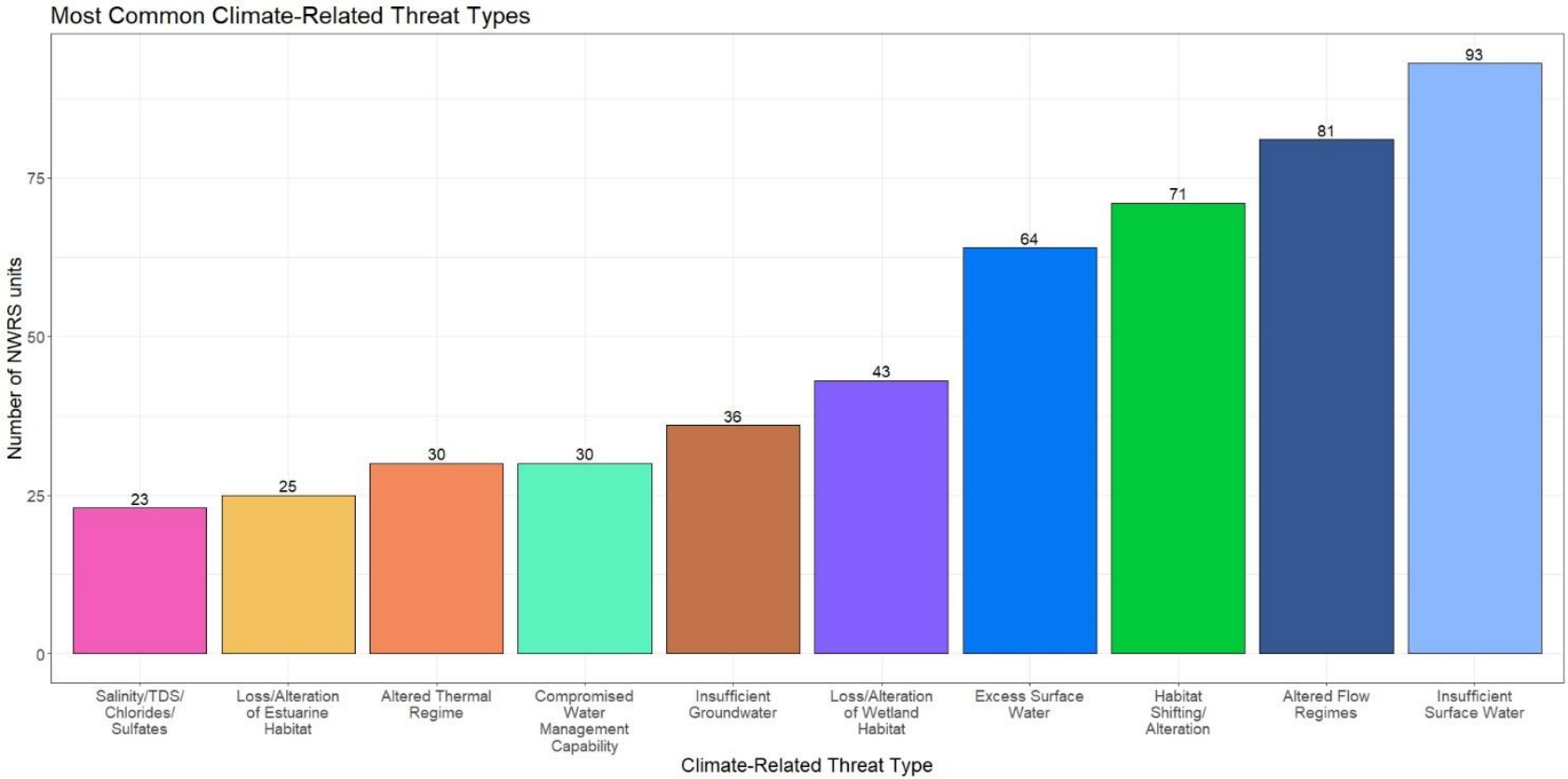

Figure 2. Top 10 most common climate-related threat types for refuges in the WRIA database as of July 2022

3.1.1 Most Common Threat Types with Climate-Related Causes

The top ten most common climate-related threat types for all refuges were (Figure 2):

1. Insufficient Surface Water
2. Altered Flow Regimes
3. Habitat Shifting/Alteration
4. Excess Surface Water
5. Loss/Alteration of Wetland Habitat
6. Insufficient Groundwater
7. Compromised Water Management Capability
8. Altered Thermal Regime
9. Loss/Alteration of Estuarine Habitat
10. Salinity/TDS/Chlorides/Sulfates

The top five most common climate-related threat types where the severity was ranked as High for all refuges were (Figure 3):

1. Insufficient Surface Water
2. Loss/Alteration of Wetland Habitat
3. Loss/Alteration of Estuarine Habitat
4. Compromised Water Management Capability
5. Habitat Shifting/Alteration

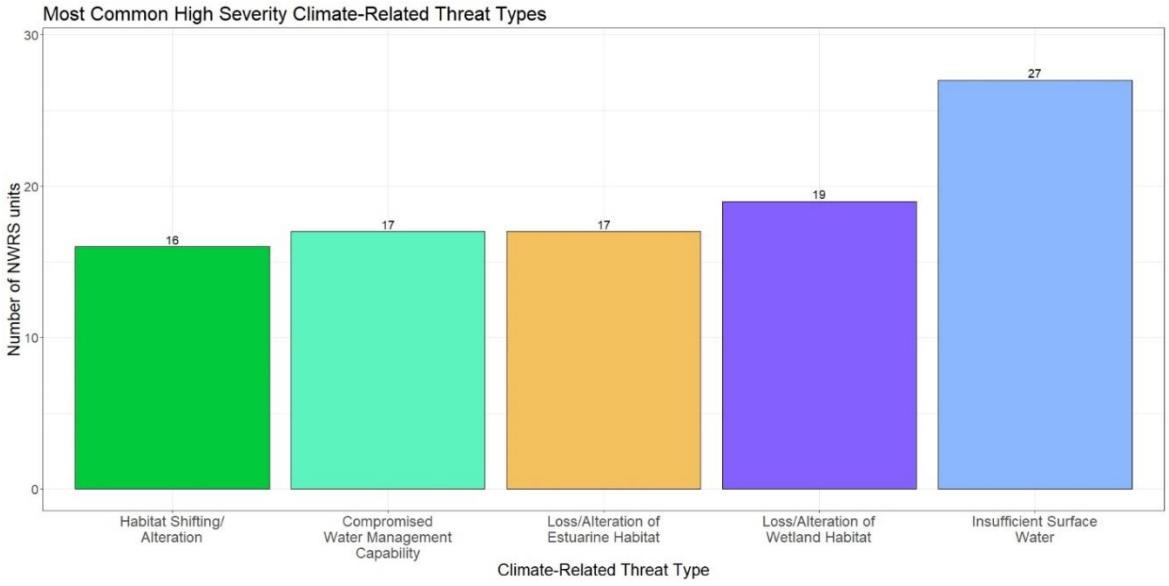

Figure 3. Top 5 most common climate-related threat types in which the severity was listed as "high"

Insufficient flow regimes, habitat shifting-alteration, and loss/alteration of wetland habitat, were not only among the most common refuge climate-related threats but were also the most common severe refuge climate-related threats.

Compromised water management capability and loss/alteration of estuarine habitat were among the top

five most common severe climate-related threats, but these threats weren't as common overall. Both threat types with a climate-influenced cause each represented just 3.6% of all refuges with threat entries in the WRIA, and 6.4% of refuges with at least one climate-related threat entry.

Altered flow regimes and excess surface water were among the most cited climate-related threats but were not often cited as being severe compared with other climate-related threats. Altered flow regimes with climate-influenced cause represented 17% of all refuges with threat entries in the WRIA, and 31% of refuges with at least one climate-related threat entry. Excess surface water with climate-influenced cause represented 14% of all refuges with threat entries in the WRIA, and 24% of all refuges with at least one climate-related threat entry. This observation indicates that while altered flow regimes and excess surface water with climate-influenced causes are widespread, the impact of this threat on refuges is either unknown or less severe than other threats.

Threat Type Ranked by Occurrence	1st- Insufficient Surface Water		2nd- Altered Flow Regimes		3rd- Habitat Shifting/Alteration		4th- Excess Surface Water		5th- Loss/Alteration of Wetland Habitat	
1st Most Common Cause	Drought	72	Climate Warming	37	Climate Warming	40	Extreme Precipitation	36	Climate Warming	17
2nd Most Common Cause	Climate Warming	23	Extreme Precipitation	25	Sea Level Rise	16	Change in Precipitation Patterns (Non-Extreme)	19	Sea Level Rise	16
3rd Most Common Cause	Rain-Snow Regime	19	Change in Precipitation Patterns (Non-Extreme)	18	Change in Precipitation Patterns (Non-Extreme)	9	Climate Warming	14	Drought	7
4th Most Common Cause	Change in Precipitation Patterns (Non-Extreme)	8	Drought	9	Drought	7	Rain-Snow Regime	9	Extreme Precipitation	5
5th Most Common Cause	Glacier Retreat	5	Rain-Snow Regime	9	Tropical Storm/Hurricane	7	Sea Level Rise	8	Storm-Induced Coastal Erosion	5

Table 1. Top 5 threat types with climate-related causes, and the top 5 climate-influenced causes associated with those threats, for threats entered for refuges in the WRIA database (with number of NWRS occurrences).

3.1.2 Common Climate-Influenced Causes of Refuge Threats

The top 10 most common climate-influenced causes of all threats, regardless of severity (Figure 4) were:

1. Climate Warming
2. Drought
3. Extreme Precipitation
4. Sea Level Rise
5. Change in Precipitation (Non-Extreme)
6. Rain-Snow Regime
7. Storm Induced Coastal Erosion
8. Tropical Storms/Hurricane
9. Temperature Extremes
10. Glacier Retreat

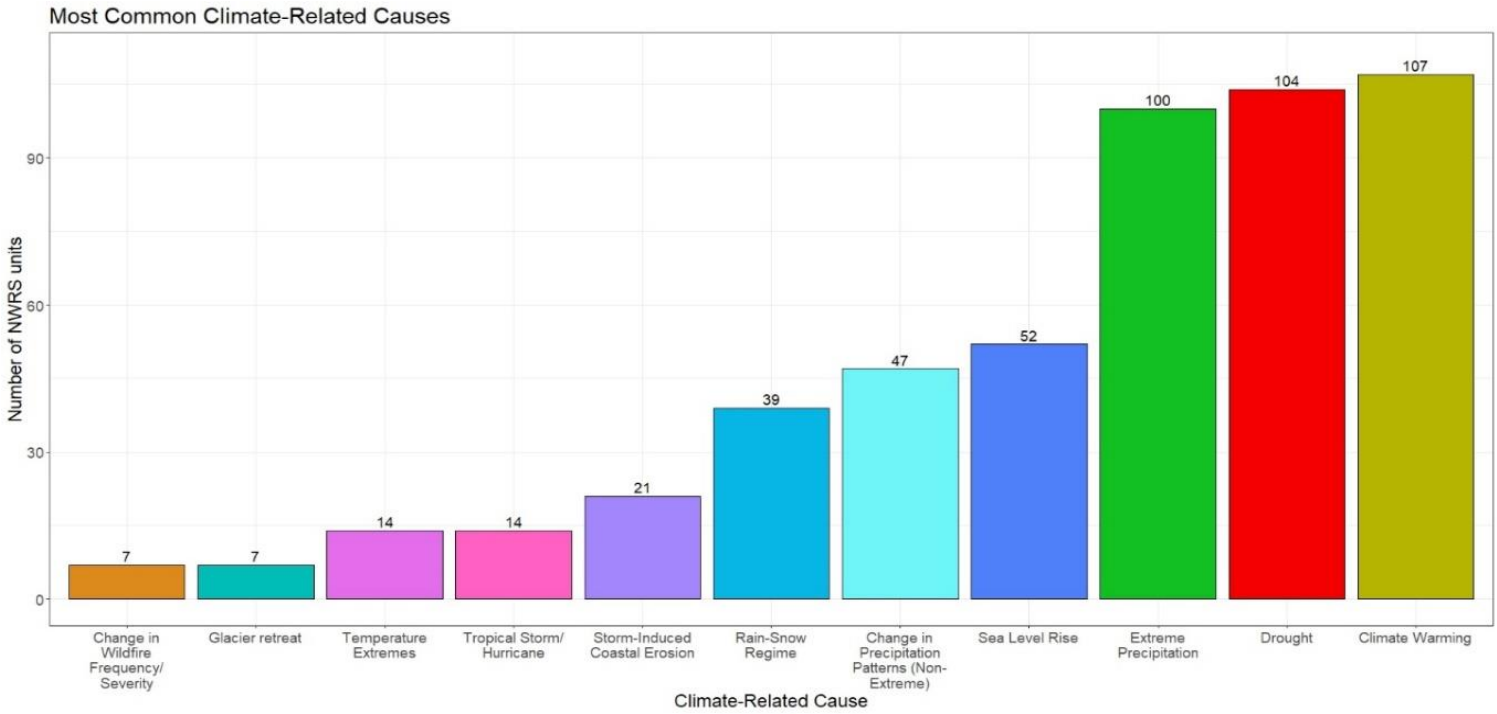

Figure 4. Top 10 most common climate-related causes of threats entered for refuges into the WRIA database as of July 2022

The top 5 most common climate-influenced causes where the severity of the threat with the climate-influenced cause was ranked as High were (Figure 5):

1. Climate Warming
2. Drought
3. Sea Level Rise
4. Extreme Precipitation
5. Rain-Snow Regime

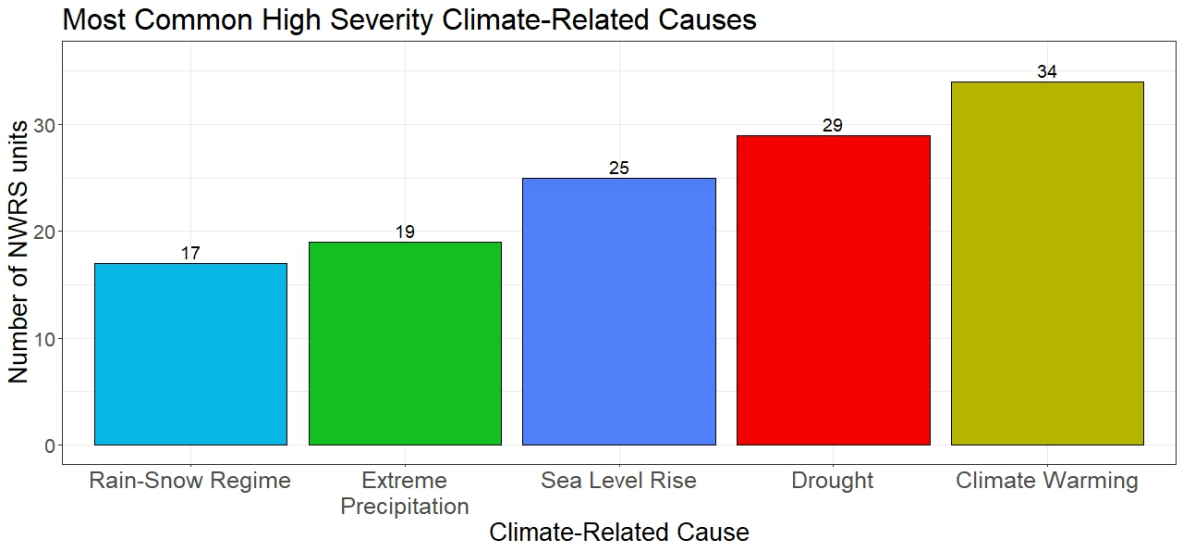

Figure 5. Top 5 most common climate-related causes of threat types where the severity of the threat was listed as "high", for refuges with data in the WRIA database as of July 2022

The climate-influenced cause climate warming, drought, extreme precipitation, and sea level rise were the most often cited climate-influenced cause of refuge threats and were also commonly cited as causing threats with high severity. Changes in precipitation (non-extreme) was commonly cited, but not often causing a threat with high severity. Rain-snow regimes was cited as a climate-influenced cause of refuge threats with high severity but wasn't often cited overall.

Insufficient surface water was the most cited climate-influenced threat both overall and with high severity, with drought as the most common climate-influenced cause. Other common climate-influenced causes of insufficient surface water were climate warming, rain-snow regime, changes in precipitation patterns, and glacier retreat.

Altered flow regimes were the second most cited climate-related threat, with climate warming cited as the most common climate-influenced cause, followed by extreme precipitation, changes in precipitation patterns, drought, and changes in rain-snow regime.

Habitat shift/alteration was the third most cited climate-related threat, which was also often cited as severe. The most common climate-influenced cause of this treat was also climate warming, followed by sea level rise, changes in precipitation, drought, and tropical storms/hurricanes.

Excess surface water was the fourth most cited climate-related threat, though it wasn't often cited as severe. The most common climate-influenced cause of this threat was extreme precipitation, followed by changes in precipitation patterns, climate warming, changes in rain-snow regime, and sea level rise.

Loss/alteration of habitat was the fifth most cited climate related threat and was often cited as severe. The most common climate-influenced cause of this threat was climate warming, followed by sea level rise, drought, extreme precipitation, and storm-induced coastal erosion.

The generic climate-influenced cause of "climate warming" was the most cited climate-influenced cause, and top cause for altered flow regimes, habitat/shifting alteration, and loss/alteration of wetland habitat. However, this cause lacks specificity in the driver of the threat, which suggests that either the categories of climate-influenced causes that were available were insufficient to describe the driver, or that the

climate-influenced cause is complex or multi-faceted.

3.1.3 Spatial and Regional Patterns in Climate-Related Threats and Climate-Influenced Causes

Spatial patterns in distribution of climate-related threats and climate-influenced causes were qualitatively assessed using maps in Appendix B and are summarized in Figures 6 and 7. Differences across FWS regions were also qualitatively assessed by assessing the top 5 climate-related threats and climate influenced causes by region and qualitatively comparing similarities and differences across regions (figures in Appendix C).

3.1.3.1 Climate-related threats

Insufficient surface water was a larger issue for units in the southern regions, but a more severe threat type for the southwestern portion of the country (Appendix B Figure B1). Numerous units in the Alaska region also cited this threat type as high severity. Overall, insufficient surface water was more frequently cited as high or moderate for units in the Pacific, Southwest, and Pacific Southwest regions and in the southern portions of the Midwest, Southeast, Mountain Prairie, and Alaska regions.

Altered flow regimes was cited as a high severity threat type by at least one unit in most Regions (Southwest, Midwest, Southeast, Mountain Prairie, Alaska) but was more commonly cited as a moderate threat type in the Midwest and Alaska Regions and New Mexico (Appendix B Figure B2). This threat type was relatively scattered throughout the country and the severity was equally variable with different units in the same state or region citing this threat type as high, moderate, or low.

No regional pattern could be observed for threat types from habitat shifting or alteration, although this was cited as a high severity threat type in several coastal units in the Southeast and Alaska regions (Appendix B Figure B3).

Similar to extreme precipitation, excess surface water was more commonly cited in the eastern half of the country and Alaska (Appendix B Figure B4). At least one unit cited extreme precipitation as high severity in the Midwestern, Eastern, Mountain Prairie and Alaska regions. Extreme precipitation was also cited as a moderate threat type for coastal units in the Pacific, Southwest, Southeast, Northeast and Pacific Southwest regions.

Loss or alteration of wetland habitats was most commonly cited at coastal refuges scattered throughout the country (Appendix B Figure B5). A cluster of units cited this threat type as high or moderate along the Texas coast in the Southwest region, with similar clusters along the Atlantic coast in the Southeast and Northeast regions.

Geographic patterns were also exhibited for the top five most common climate related threat types (altered flow regimes, excess surface water, habitat shifting or alteration, insufficient surface water, loss or alteration of wetland habitat, Figure 6). Altered flow regimes was evenly distributed throughout the lower 48 states and Alaska. Excess surface water was more common in the eastern half of the country while habitat shifting, or alteration, was primarily clustered in the southern or western regions and Alaska. Insufficient surface water was equally cited in the western and southern portions of the nation. Loss or alteration of wetland habitat was less commonly cited overall and primarily clustered along the Atlantic coast.

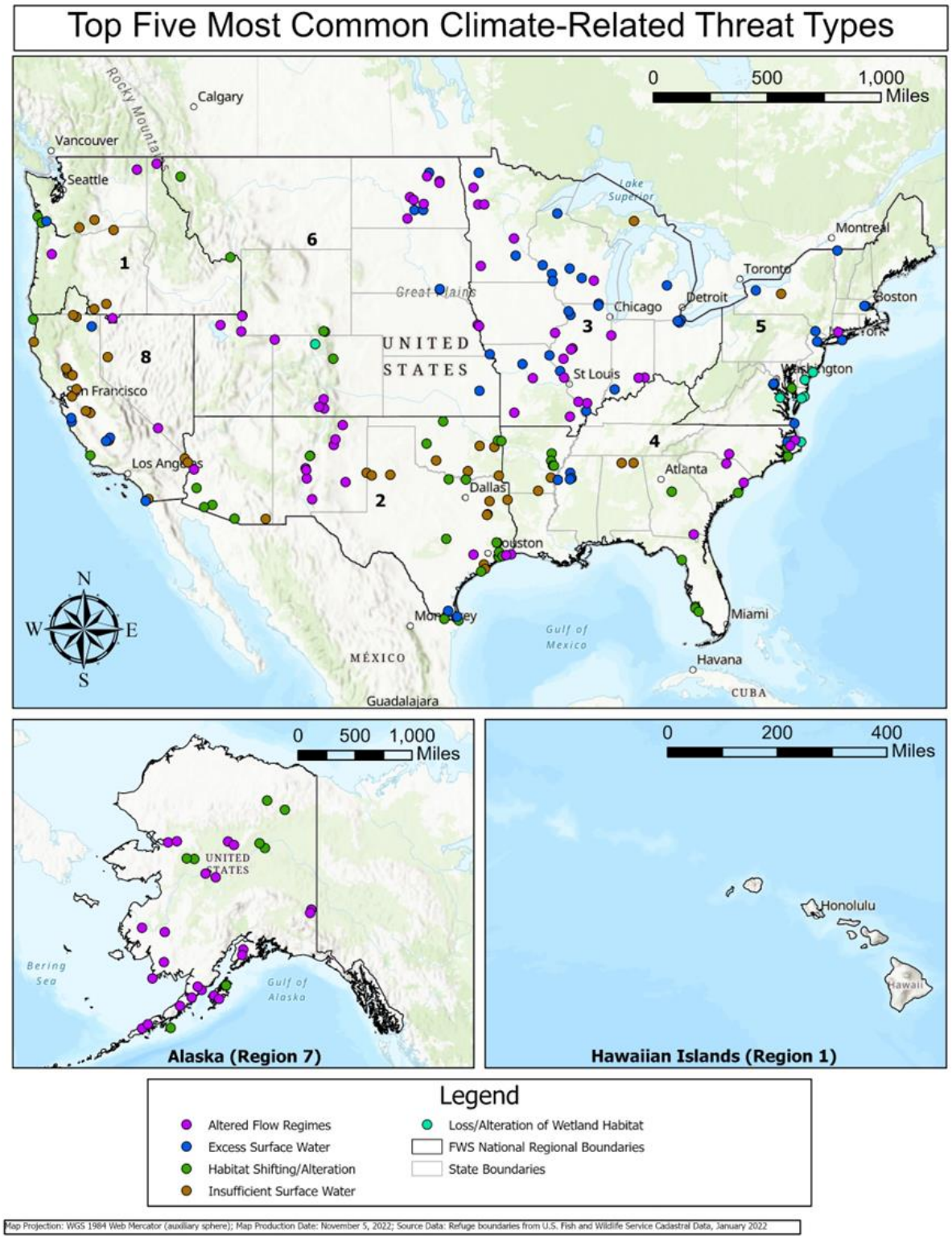

Figure 6. Spatial patterns in distribution of climate related threats across National Wildlife Refuges and Wetland Management Districts.

3.1.3.2 Climate-influenced causes

Climate warming as a threat cause was evenly distributed throughout the United States. (Appendix B Figure B6). Climate warming was most frequently cited as a severe issue at NWRS units in the western United States and Alaska. All regions had at least one unit that listed climate warming as a severe threat cause.

Drought was cited as a severe threat cause predominantly in two regions, the Southwest, and the Pacific Southwest, although there was one unit in both the Southeast and Mountain Prairie regions that also listed drought as severe (Appendix B Figure B7). Additionally, all regions had at least one unit that listed drought as a moderate threat cause with the majority of units characterizing drought as moderate in the Pacific, Midwest, and Southeast regions.

Extreme precipitation appeared to be a larger issue predominantly east of the Mississippi River, as it was cited as a severe threat cause by units located in 5 regions including the Midwest, Southeast, Northeast, Mountain Prairie and Alaska regions (Appendix B Figure B8). At least one unit in every region listed extreme precipitation as a moderate threat cause.

Not surprisingly, sea level rise was cited as a severe threat cause for many coastal units in 5 regions including the Southwest, Southeast, Northeast, Alaska and Pacific Southwest (Appendix B Figure B9). Sea level rise was cited only as a low threat cause or unknown for the Pacific region, however, which aligns with research showing sea level rise is at a slower pace on the west coast than the national average because the land is rising from shifting tectonic plates. This threat cause was not cited for any units in the Midwest or Mountain Prairie regions.

Similar to extreme precipitation, a non-extreme change in precipitation patterns was more of a prominent issue east of the Mississippi River and Alaska, with numerous units in the Midwest and Alaska regions citing this as a high severity threat cause (Appendix B Figure B10). This did not appear to be a threat cause for the southern part of the United States, as it was not cited for any units in the Southwest nor the Southeast.

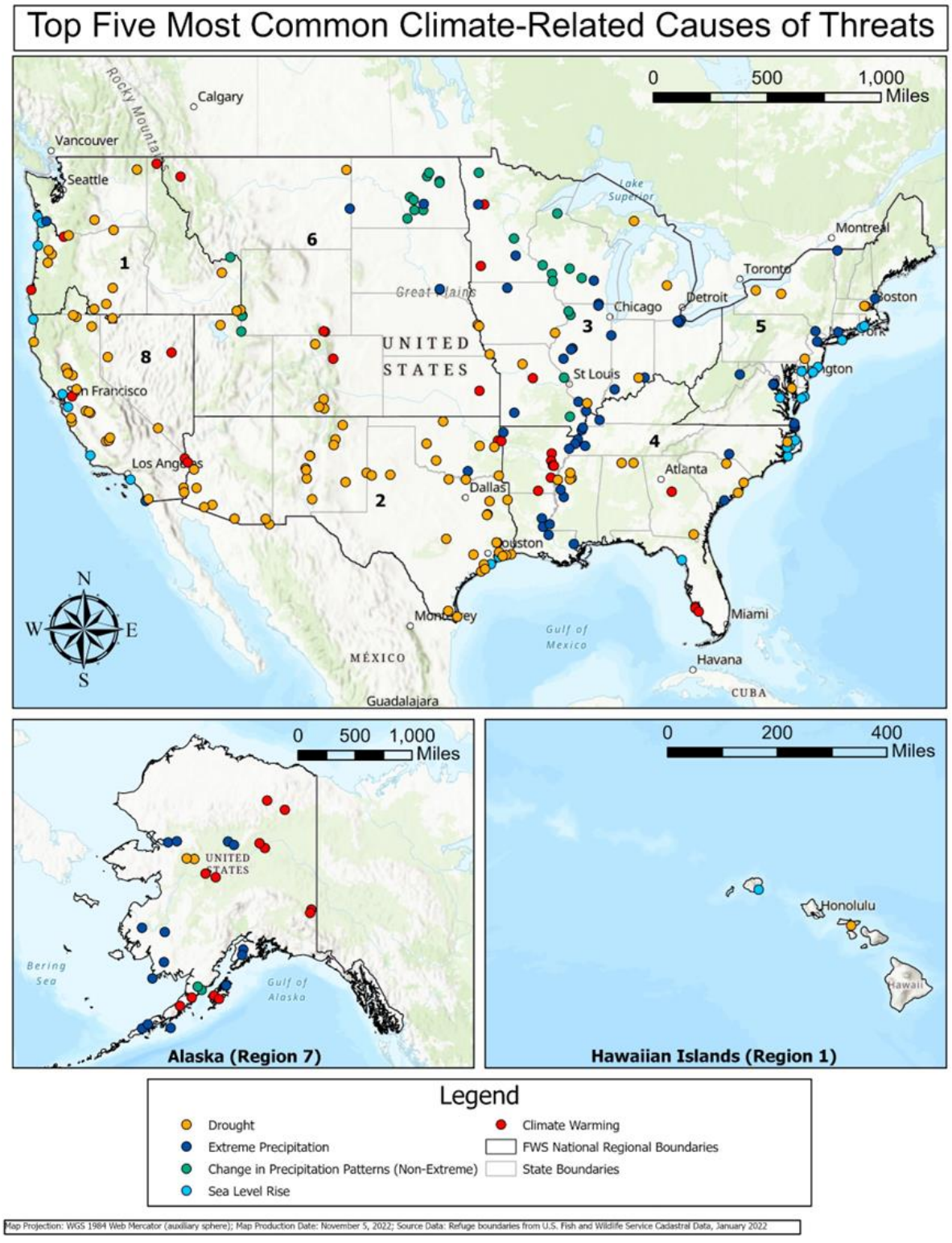

Figure 7. Spatial patterns in distribution of climate-influenced causes across National Wildlife Refuges and Wetland Management Districts.

3.2 Needs

Because refuge needs were not directly associated with threats, it is not possible at this time to summarize needs that are directly related to climate. However, it is assumed that stations experiencing or anticipated to experience climate-related threats have needs that would help to address multiple threats, including those influenced by climate drivers. Therefore, the needs analysis in this section is limited to summarizing needs at stations with at least one climate-related threat. Spatial analysis was not performed for needs at stations with climate-related threats under the assumption that this would not be as meaningful for the report objectives given the disconnect between needs and climate-related threats, but USFWS 2019 includes a more comprehensive analysis of needs across the refuge system.

Collectively, the WRIA database contains ***2,981*** refuge need occurrences (unique combinations of refuge and need type). The number of unique refuge need occurrences that were noted for refuges with at least one climate-related threat was **1908**. The most common need types at stations with at least one climate-related threat, including high priority needs, are described below. The most common need type categories are also discussed below.

3.2.1 Most common need types at stations with climate-related threats

The following are the top five most common need types (Level 2) for all refuges that had at least one climate-related threat (Figure 8):

1. Water Quality Baseline Monitoring
2. Water Supply / Quantity Monitoring
3. Targeted Water Quality Monitoring
4. Water Level Monitoring
5. Climate Change Vulnerability Assessment

The following are the top five most common high priority need types (Level 2) for all refuges that had at least one climate-related threat (Figure 9):

1. Water Supply / Quantity Monitoring
2. Water Quality Baseline Monitoring
3. Build / Strengthen / Expand Watershed Partnerships
4. Water Level Monitoring
5. Replace or Repair Water Management Infrastructure

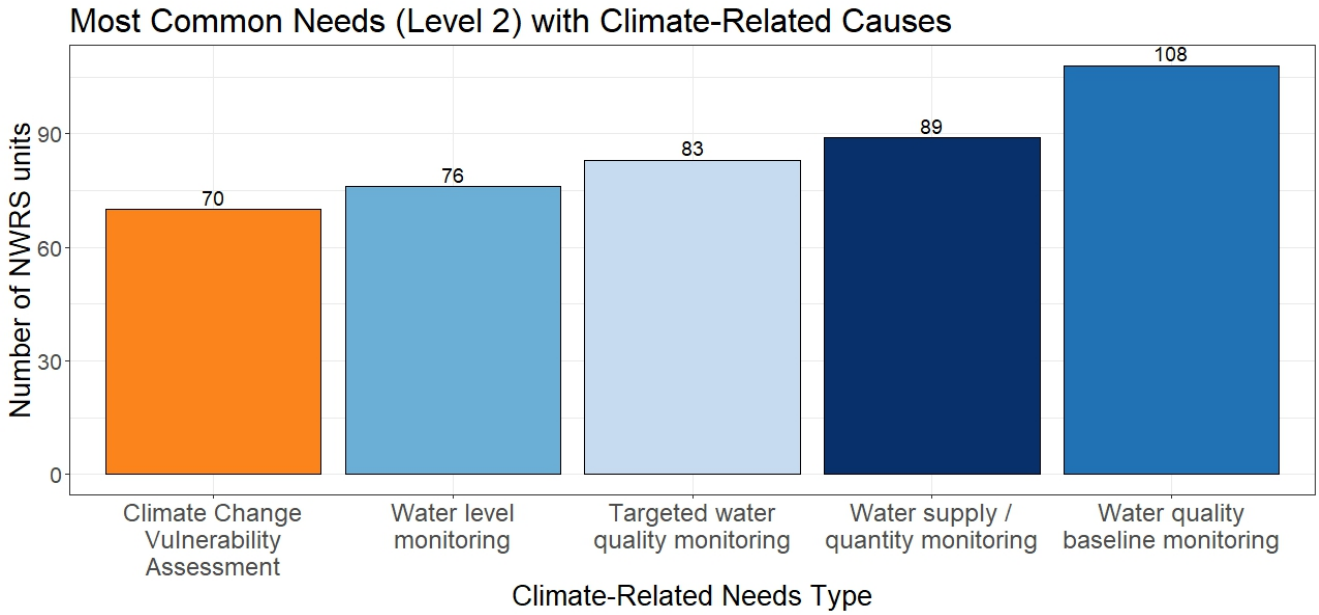

Figure 8. Top 5 most common need types for stations with threats with climate-related causes entered for refuges in the WRIA database as of July 2022

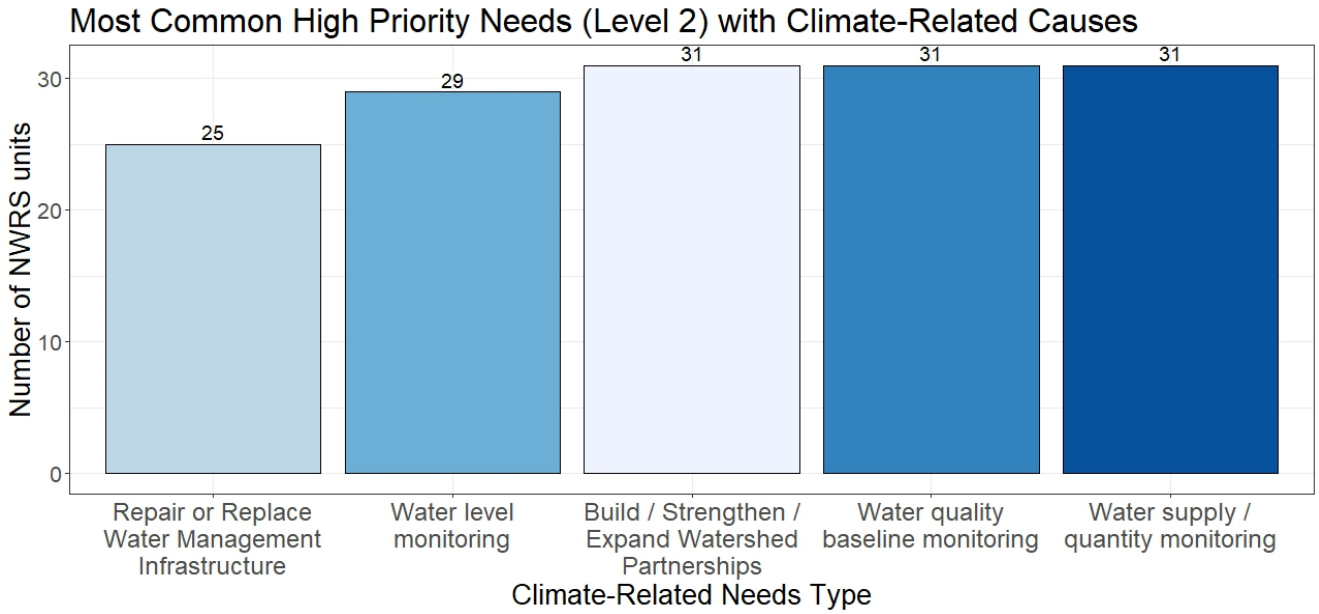

Figure 9. Top 5 most common need types for stations with threats with climate-related causes in which the priority of the need was listed as "high", for refuges in the WRIA database as of July 2022

Water monitoring (targeted and baseline water quality; water supply and water level) is both a common and high priority need for stations with climate-related causes. Climate change vulnerability assessments are a common need at stations with climate-related threats. Stations with climate-related threats also cited a need to strengthen watershed partnerships. Infrastructure improvements were a common high priority need at stations with climate-related threats.

3.2.2 Discussion of needs at stations with climate-related threats

The top two to four observed needs identified in this national project were informational in nature: related to water quality or water quantity monitoring. Because the objectives of these monitoring needs were not included in the database, it's not possible to know if and how monitoring would help address climate-related threats. Filling these particular needs will likely not directly alleviate the most commonly identified climate-related threats but could represent a necessary pre-requisite or foundational need for adaptation to threats. For example, monitoring represents the acquisition of data that are necessary to adaptively manage biological resources if properly incorporated into decision-making or represent necessary water use information that is required to protect water assets in the face of drought and/or extreme precipitation.

This finding is similar across all refuges in the previous analysis of all refuges (USFWS 2019). As discussed in that assessment, because refuges that identified water quality and quantity monitoring needs represented such a diverse set of threats, it would be challenging to address this need at the national level without further investigation into what is driving these needs at the regional or local level. For example, there might not be a consistent set of parameters to monitor across refuges or regions.

Climate change vulnerability assessments are a common need at stations with climate-related threats. This finding indicates that more information is needed to determine specific actions (including adaptation strategies) related to addressing climate-related threats. These assessments aren't always identified as a high priority now, but the priority could change in future years as climate-related threats become exacerbated with warming global temperatures.

Stations with climate-related threats also cited a need to strengthen watershed partnerships, indicating the multijurisdictional nature and geographic complexity of water resource management issues. This finding underscores similar efforts suggesting that threats (including climate-related threats) might be heavily influenced by external forces or landscape level issues that require partnerships to address.

Infrastructure improvements were a common high priority need at stations with climate-related threats. Although it is not known how climate influences are driving the need for infrastructure replacement, not being able to manage water effectively because of aging or inadequate infrastructure may decrease resiliency to climate-related threats. For example, there may be a need in the future for deeper wells, bigger well pumps, larger culverts, or the ability to lower a reservoir past dead pool.

4.0 Conclusions and Recommendations:

This report was focused on a national-level analysis of data in the WRIA database to evaluate climate-related threats in the NWRS, climate-influenced causes of those threats, and needs at refuges where these threats were observed. The NWRS faces many ongoing challenges to mission achievement that are rooted in water issues. The WRIA Project is the agency's most comprehensive effort to date to supply FWS leadership with detailed assessment information to support resource allocation decisions. In

general, the recognition of water as a critical and manageable resource to the NWRS is increasing as a direct result of the WRIA project. We can now begin to answer the question: **What is the status of climate-related threats and needs for the NWRS?**

Several recommended actions for NWRS leadership (Natural Resources Leadership Team, Refuge Chiefs), CCAP, NRPC, (including the Inventory and Monitoring Coordination Team, IMCT), and the WRT are presented based on the findings of the water resources threats and needs analysis:

1. Develop a better understanding of how water monitoring data can inform response to climate-related threats:

- The NWRS should further investigate the objectives of water monitoring needs (water quality and quantity) to determine how they fit into decision-making and habitat management, preferably under existing Inventory and Monitoring Program frameworks.
- The NWRS should consider a strategy to support and prioritize collection of water resources data (water quantity and quality) that can effectively inform decisions on adaptation to climate change.
- Such a strategy should further evaluate common barriers to monitoring (such as staffing, funding, or technological limitations), and consider operational, biological, and adaptive management value to help prioritize best use of limited resources at a regional and national scale.
- Such a strategy should include collaboration from other entities that have an interest or stake in water monitoring, including NWRS leadership and IMCT.

Rationale: Most water resources issues facing refuges require additional information to address. This is highlighted by the key finding that monitoring and measurement of water (water quality, water supply, water levels) were the most common need types across the NWRS at refuges facing climate-related threats, which was a similar finding among all refuges in USFWS 2019. Monitoring is an essential component for the identification of key thresholds where current management strategies or infrastructure will no longer be viable, which informs climate change adaptation efforts.

Given these findings, there is an opportunity for the NWRS to allocate resources to help stations fulfill these needs. However, there is not currently a clear path to identify which elements of water monitoring need the most support and how this information might address high priority threats, including climate-related threats. A separate evaluation process and implementation plan at a regional or national scale would help target and identify on-the-ground short and long-term needs for water monitoring to inform climate adaptation.

2. Support cross-regional collaboration on pilot climate change vulnerability assessments that can inform adaptation of water management and planning:

- Using common climate-related threats and climate-influenced causes as the basis for pilot project selection, the NWRS should support or implement climate change vulnerability assessments (funding, strike teams) at selected stations with a focus on water resources.
- These assessments should include focus on additional monitoring or other data needs that address uncertainty in selection of adaptation scenarios, which can inform recommendation 1.
- A synthesis of outcomes of these pilot vulnerability assessments (including assessments that have already been completed) could be used to identify common adaptation strategies, which can aid in the identification of national resources (funding, staff) that can be used to implement similar strategies in other areas. Partnerships at a watershed or landscape level scale should be encouraged, as effective adaptation is often dependent upon actions off the refuge.

Rationale: Common climate-related threats facing the NWRS include insufficient and excessive surface water, altered flow regimes, compromised water management, and habitat loss. Common climate-influenced causes of these threats include extreme weather events (droughts, excessive precipitation), sea level rise, and changes in precipitation dynamics (rain-snow regimes and precipitation patterns). Climate change vulnerability assessments were cited as a common need for stations with climate-related threats. There is regional and spatial variability in where and how these threats are observed. Adaptation strategies will likely be local in nature and specific to a station and their water resources situation.

Identification of pilot refuges in need of climate change vulnerability assessments where strike teams can use shared skills to better characterize water resource vulnerability and identify viable adaptation strategies may have transferability to other locales in the NWRS. Additionally, the process used to develop such strategies should be transparent and widely applicable, to support NWRS decision making that allows for meaningful incorporation of climate change considerations into management and planning processes.

3. Improved threats and needs data collection, and use of WRIA Database to track progress:

- The WRT should decide whether to prioritize a national effort to update, improve, and expand data entry at regular intervals (i.e., 1-2 years or greater) with improved documentation on data quality and resources to ensure consistent and complete data entry.
- Inclusive in this update would be refinement of climate-related attributes that define threats and needs. This update should include retirement of the “climate warming” cause that is not explicit enough to understand drivers of threats. This update should also include improvement of data classification to better identify persistent long-term climate drivers at local and regional scales.
- Inclusive of this update would be to assess how needs relate to addressing threats, so that needs related to climate can be more directly assessed.
- If a WRIA update is made a national priority, the WRT should consider using the status of threats and needs in the WRIA Database as a metric or indicator of the status of water resources issues for the entire NWRS. This should be done in collaboration or consultation with NWRS leadership, NRPC, and IMCT. For example, the WRT could consider setting national SMART objectives for the health of water resources based on counts of refuges with threats or needs in the WRIA database and use the results from a national assessment to inform and communicate how well we are meeting those objectives. Over time, the threats and needs will become more accurate with more water monitoring data.

Rationale: Alignment analysis between threats and needs is lacking information because there are many more refuges with recorded threats than with recorded needs. Once a target for WRIA data entry completeness is identified, it will be more relevant to review previous assessments to determine the progress of addressing threats and meeting priority needs. This type of assessment could provide a measurement tool to communicate the progress of the WRT and FWS water programs in improving the conditions of the refuge system, as a result of WRT-supported programs and initiatives identified in the WRT Strategic Plan.

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Appendix A. Threats and Needs Classification in WRIA Application

THREAT TYPES

Water Quality Related Threats
Nutrient Pollution
Pathogens
Pesticides
Mercury
Metals (other than Mercury)
PCBs
Altered Thermal Regime
Salinity/TDS/Chlorides/Sulfates
Altered pH
Low Dissolved Oxygen
Endocrine Disruptors/Emerging Contaminants
Other Contaminants/ Altered Water Chemistry
Hydrocarbons
Turbidity
Harmful Algal Blooms

Water Quantity Related Threats
Insufficient Surface Water
Insufficient Groundwater
Excess Surface Water/Flooding
Excess Groundwater/High Water Table
Altered Flow Regime
Compromised Water Management Capability
Legal Challenges or Fines for Non-compliance with water policy, law, or regulation

Aquatic Habitat Threats
Impaired Stream Connectivity
Bank Erosion/Channel Incision
Sedimentation
Habitat Shifting/Alteration
Loss/Alteration of Stream Channel Habitat
Loss/Alteration of Floodplain Habitat
Loss/Alteration of Wetland Habitat
Loss/Alteration of Lake or Pond Habitat
Loss/Alteration of Estuarine Habitat
Tundra/Permafrost Thawing

THREAT CAUSES

Water Quality Causes
Agricultural Runoff
Cropland drainage/Tiling
Urban Runoff
Urban Sewage
Wastewater Treatment Facilities
Failing Septic
Livestock
Concentrated Animal Feeding Operations
Wildlife Sources
Industrial Effluent
Oil and Gas Development
Oil and Gas Exploration
Hydraulic Fracturing
Garbage/Solid Waste
Airborne Pollutants
Irrigation
Fire and Fire Suppression
Naturally-Occurring Contaminants

Water Supply/Quantity Causes
Surface Water Diversion: Agriculture
Surface Water Diversion: Municipal
Surface Water Diversion: Industrial
Groundwater Pumping: Agriculture
Groundwater Pumping: Municipal
Groundwater Pumping: Industrial
Dams
Locks
Canals
Levees/Dikes
Drainage Ditches
Channelization
Impervious Surfaces
Pumping Stations
Irrigation Return Flows
Inter-Basin Transfers
Invasive Species

(Threat Causes continued…)

Water Management Capability Causes
Non-FWS Management of Water Infrastructure
Lack of Water Management Infrastructure
Inefficient, Inadequate, or Damaged Water Management Infrastructure
Off-Refuge Water Management Infrastructure
Other Legal/Political Constraints
No Active Monitoring
Insufficient Staff/Capacity
Existing Rights Insufficient Quantity/Timing to Meet Refuge Purposes

Water Rights / Legal Causes
FWS Does Not Have Permit / Right for Refuge Water Use
Existing Permit / Right for Non-Wildlife Beneficial Use
Existing Rights Junior Priority
Existing Rights Insufficient Quantity/Timing to Meet Refuge Purposes
State Regulations Not Enforced
Refuge Water Rights Challenged by others
FWS Not Participating in Basin Adjudication
FWS Not Quantifying Water Use
Loss Due to Non-Use
No Proof of Beneficial Use
ESA Compliance /Threats to Listed Species
Interstate Compact Agreements
International Treaties
Augmentation/Replacement Requirements
Restrictions in Establishing Legislation
Other Legal Disputes/Issues

Landscape Alteration Causes
Altered Riparian Vegetation
Agriculture
Urban Development
Roads/Culverts
Road Construction/Maintenance
Road Maintenace
Pipelines and Utility Corridors
Grazing/Ranching
Logging/Forestry
Mining/Quarrying
Wetland Filling
Public Use/Recreation

Climate-Related Causes
Climate Warming
Extreme Precipitation Events
Change in Frequency/Severity of Extreme Precipitation Events
Change in Precipitation Patterns (Non-Extreme)
Rain-Snow Regimes
Changes in Rain-Snow Regimes
Droughts
Increase in Drought Frequency/Severity
Desertification
Temperature Extremes
Change in Wildfire Frequency/Severity
Sea Level Rise
Storm-Induced Coastal Erosion
Increased Rate of Storm-Induced Coastal Erosion
Tropical Storms/Hurricanes
Increased Frequency /Intensity of Tropical Storms and Hurricanes
Glacier Retreat
Tundra/Permafrost Thawing

Needs Classification

Water-Related Infrastructure

- Repair or Replace Water Supply Infrastructure
- Repair or Replace Water Management Infrastructure
- Repair or Replace Recreational Infrastructure
- New Water Supply Infrastructure
- New Water Management Infrastructure
- New Recreational Infrastructure
- Remove Infrastructure
- Inventory of Water Infrastructure

Monitoring/Measurement

- Create/Update Water Monitoring Plan
- Water Quality Baseline Monitoring
- Targeted Water Quality Monitoring
- Water Supply/Quantity Monitoring
- Suspended sediment monitoring/measurement
- Bedload monitoring/measurement
- Water Level Monitoring
- Pump test/Aquifer Yield
- Habitat Monitoring
- Species Monitoring
- New Monitoring Infrastructure

Water Supply/Management

- Acquire New Water
- Relinquish/Transfer Excess Water
- Reduce Flooding Impacts
- Create/Update Water Management Plan
- Determine Water Use Requirements

Modeling/Research/Assessment

- Water Resources Inventory and Assessment
- Hydrologic Modeling
- Instream Flows Assessment (IFIM/ELOHA)
- Hydraulic and Sediment Transport Modeling
- Groundwater Modeling
- Geomorphic Modeling
- Fluvial Geomorphic Assessment (form and function)
- Sediment transport validation
- Bank erosion modeling and validation
- Water Quality Concentration/Loading Assessment
- Climate Change Vulnerability Assessment
- Functional Assessment
- Data Gap Analysis/Water Monitoring Network Design

Mapping and Geospatial Data/Analysis

- Geographic Survey Points/Area
- Water System Mapping
- Water Rights Mapping
- LiDAR Survey
- Aquatic Habitat Mapping
- Wetland/Vegetation Mapping
- Bathymetry/Storage

Water Rights/Water Entitlements

- Water Rights/Entitlements Litigation
- Water Rights Perfection
- Water Rights/Entitlements Resolution of Disputes (non-litigious)
- Water Rights/Entitlements Interpretation
- Water Rights/Entitlements Enhancement of Reporting
- Exercise Water Rights
- Acquire New/Additional Water Rights/Entitlements
- Assert/Quantify Federal Reserve Water Right

Coordination/Support

- Build/Strengthen/Expand Watershed Partnerships
- Improve Communication/Education/Outreach with Stakeholders
- Seek Legislative Relief/Assistance
- Additional Staff/Capacity

Water Quality Mitigation/Habitat Improvement

- Reduce Non-Point Source Pollution
- Reduce Point-Source Pollution
- Develop or Promote Adoption of Best Mgt. Practices
- Restore Habitat
- Restore/Protect Beneficial Environmental Flows
- Spill Clean-up
- Protect Habitat from Invasive Species
- Land Acquisition
- Restore floodplain function
- Restore native aquatic species

Appendix B: Maps of climate-related threats and climate-influenced causes

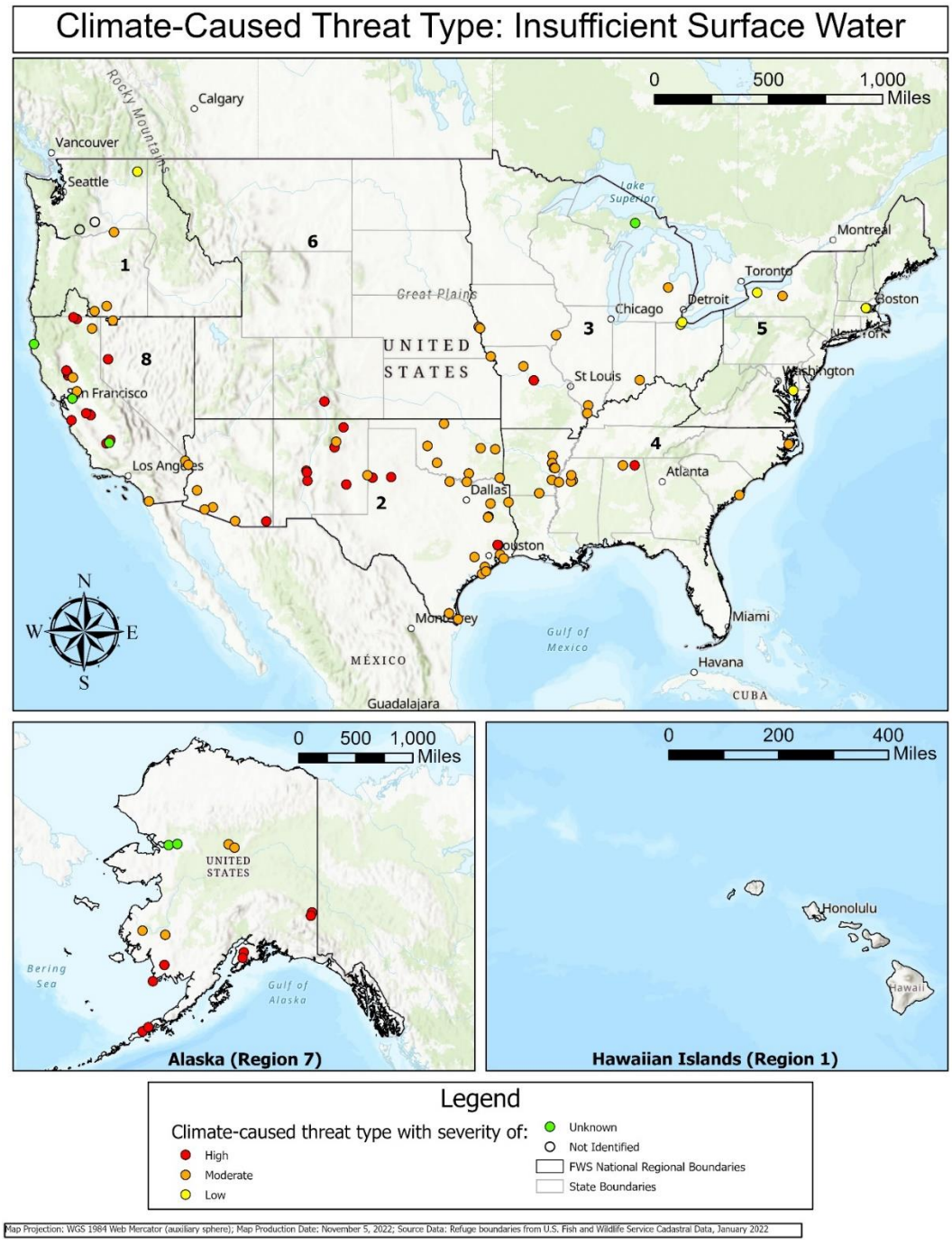


Figure B1: Threat Type: Insufficient Surface Water. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

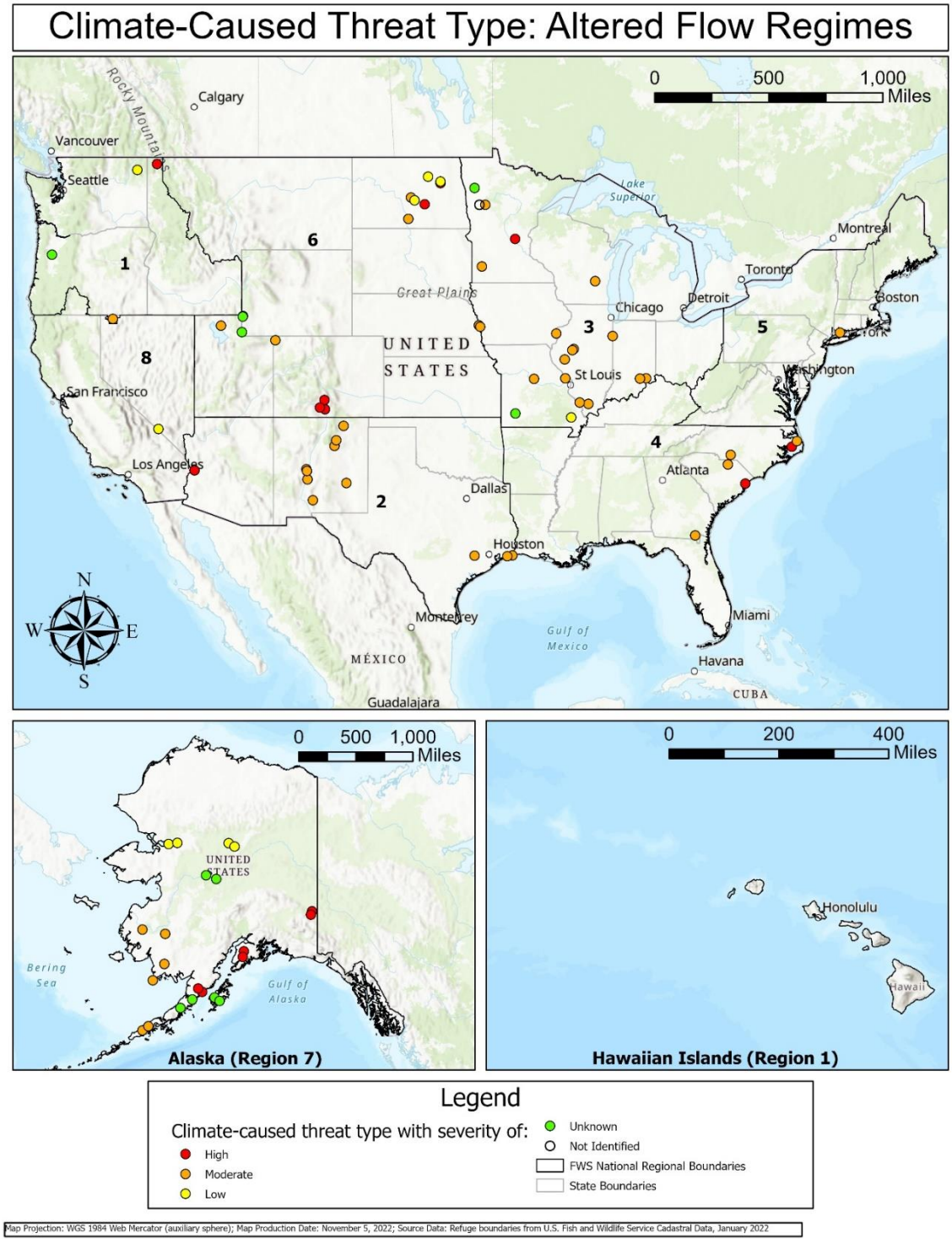


Figure B2: Threat Type: Altered Flow Regimes. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

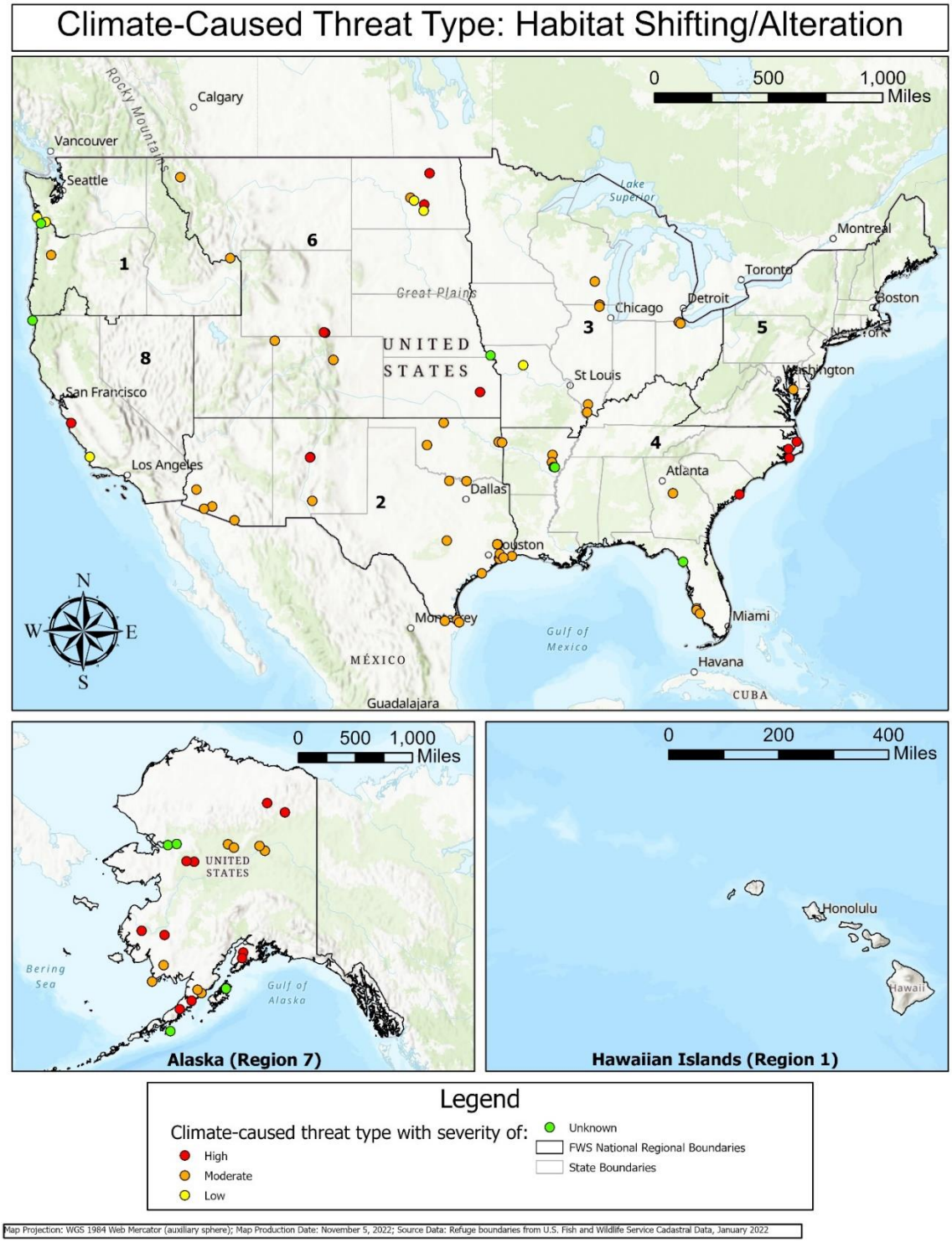


Figure B3: Threat Type: Habitat Shifting/Alteration. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

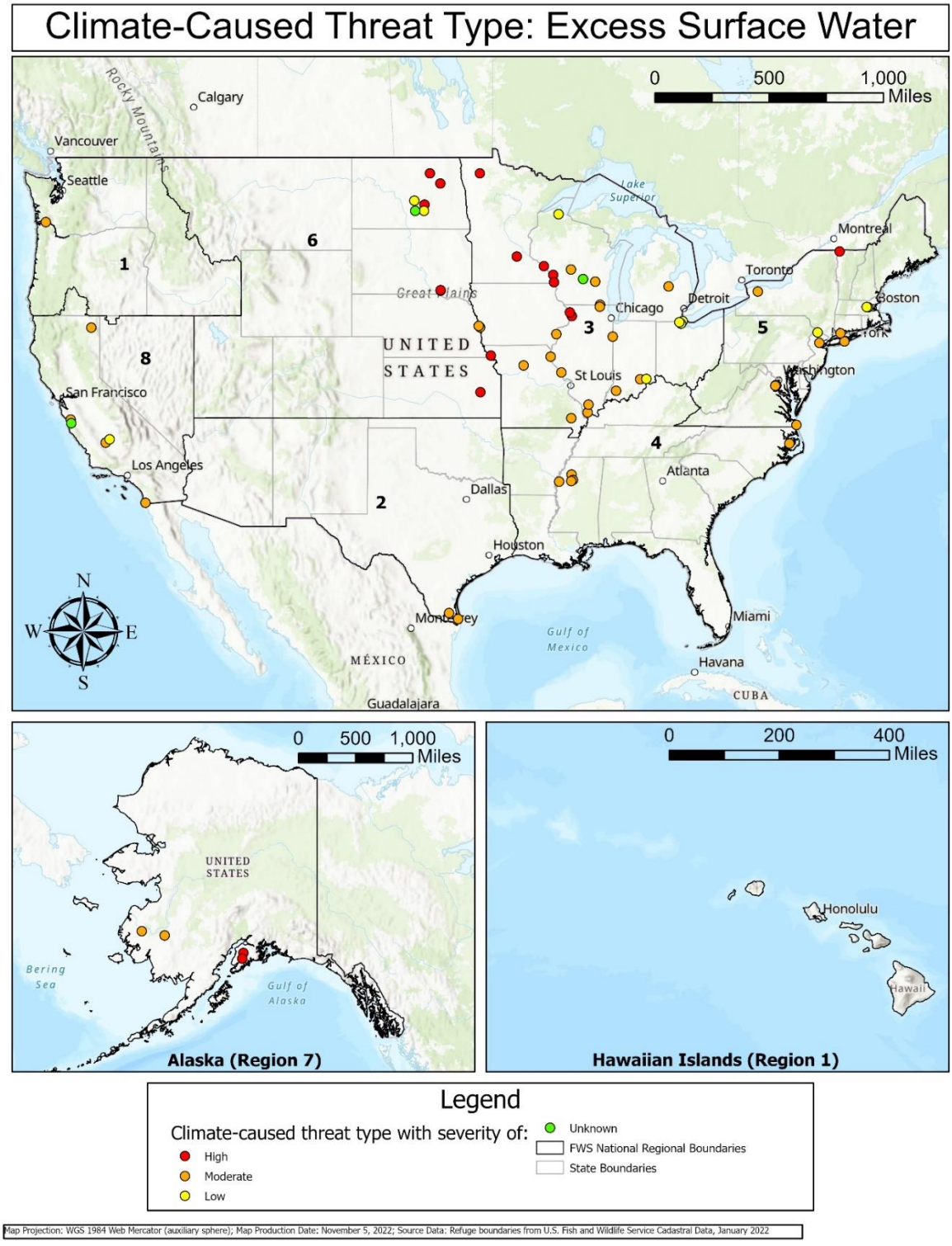


Figure B4: Threat Type: Excess Surface Water. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

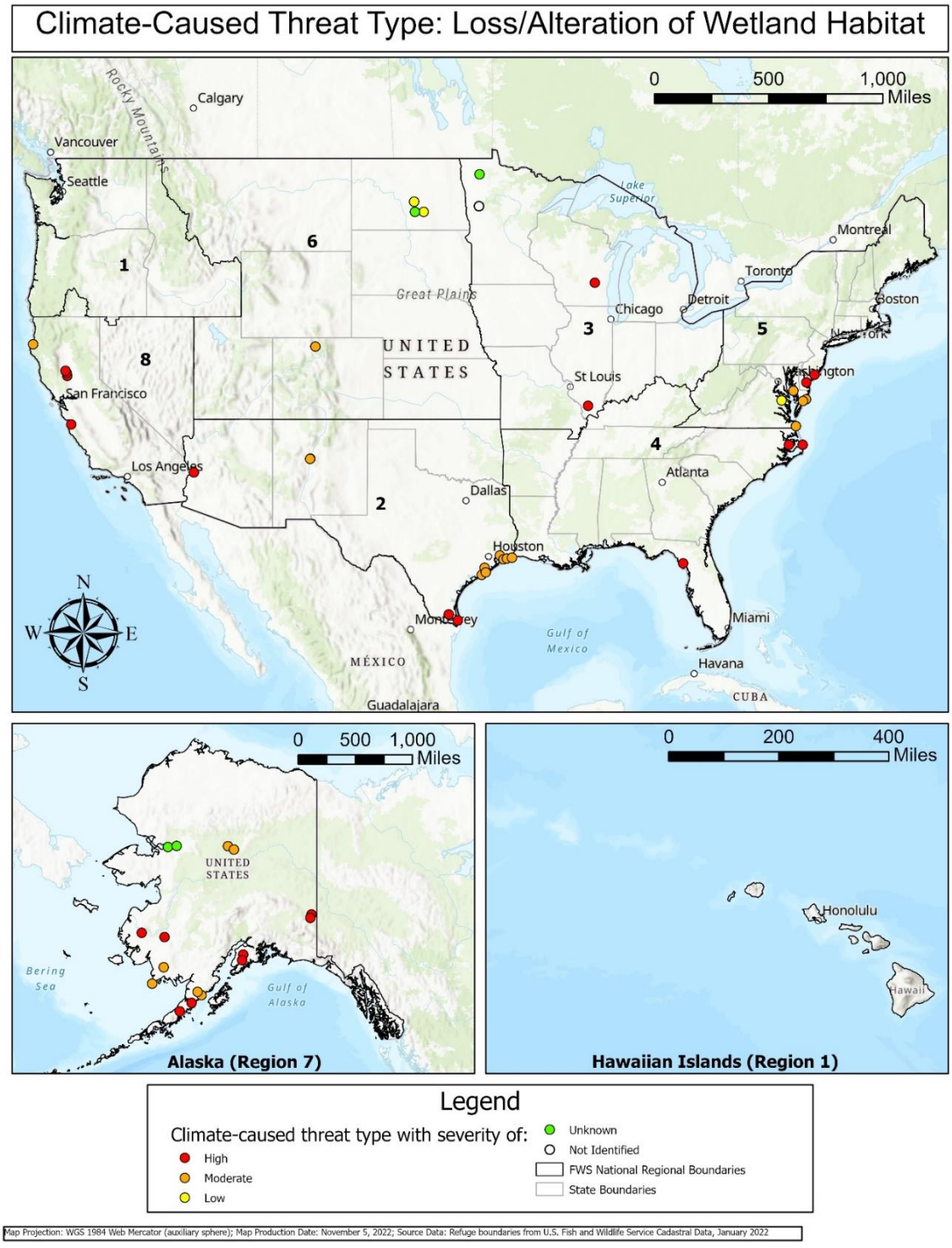


Figure B5: Threat Type: Loss/Alteration of Wetland Habitat. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

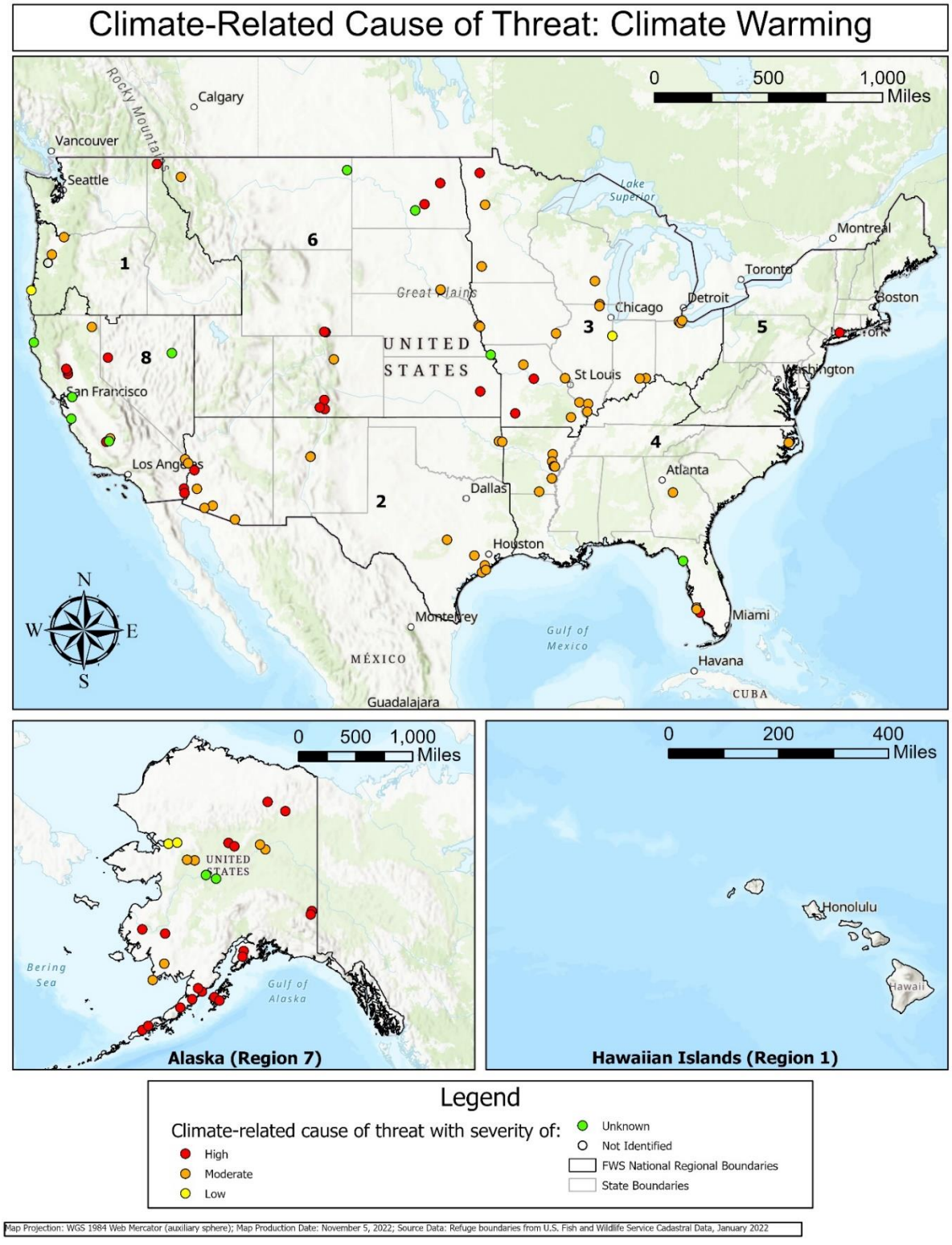


Figure B6: Cause Type: Climate Warming. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

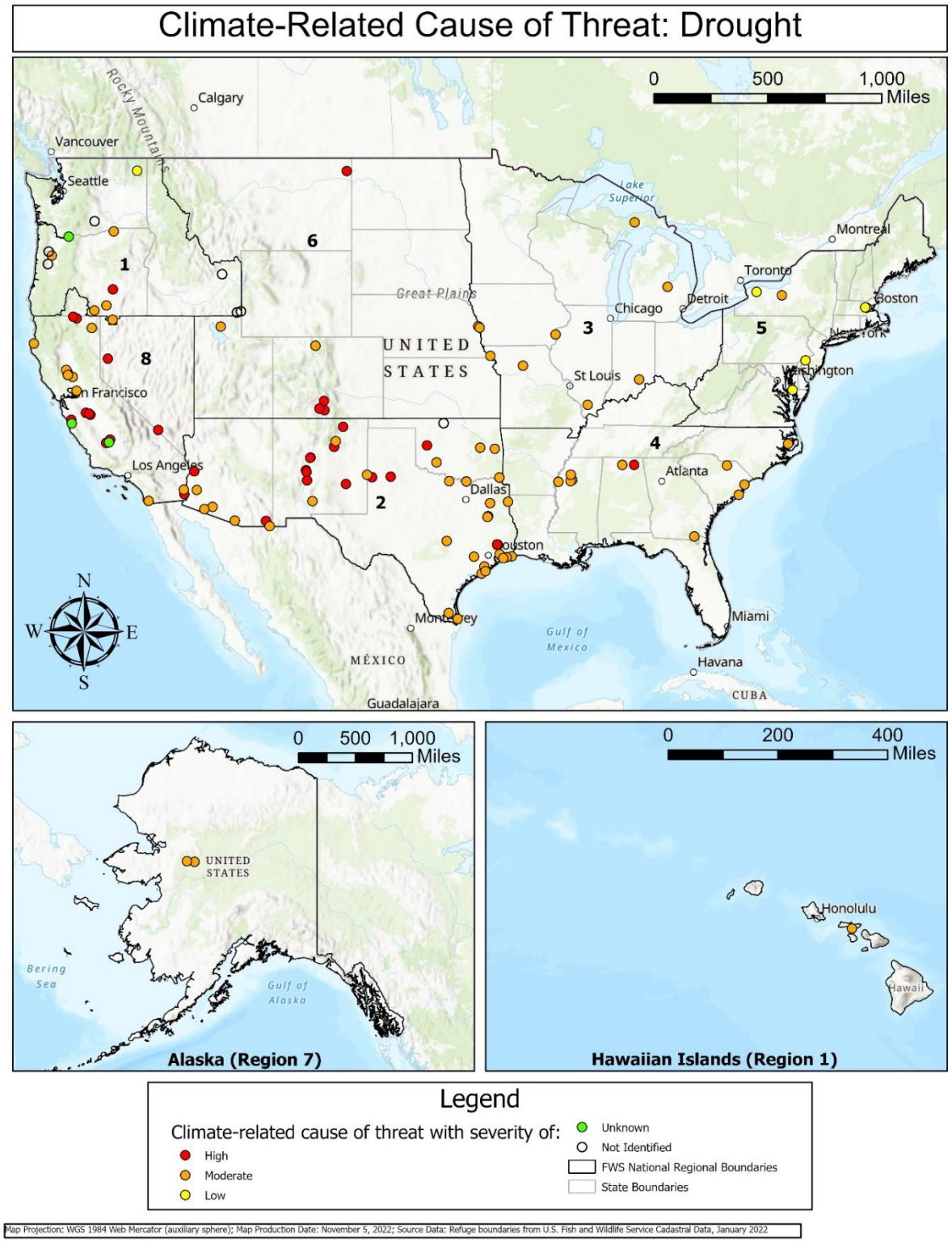


Figure B7: Cause Type: Drought. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

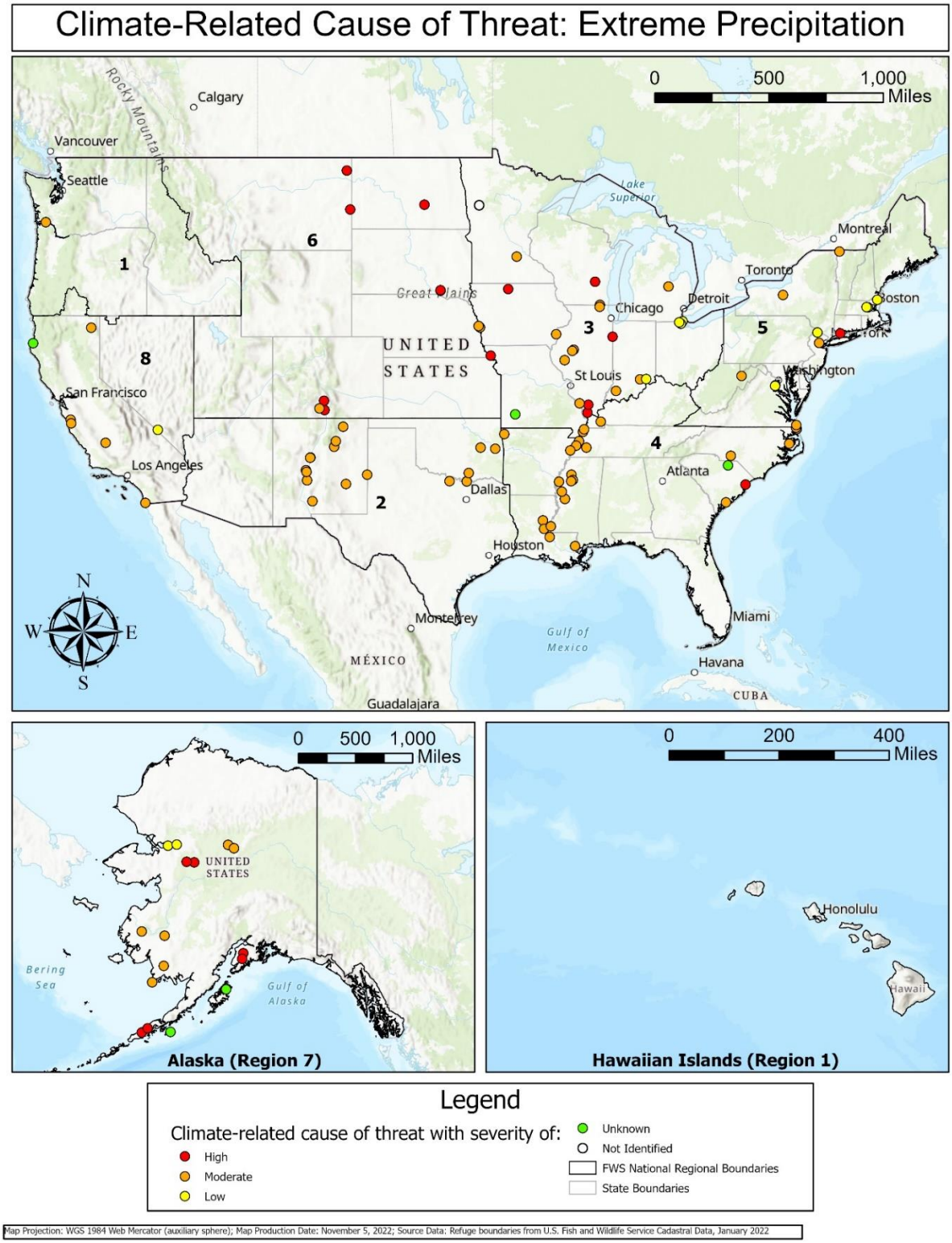


Figure B8: Cause Type: Extreme Precipitation. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

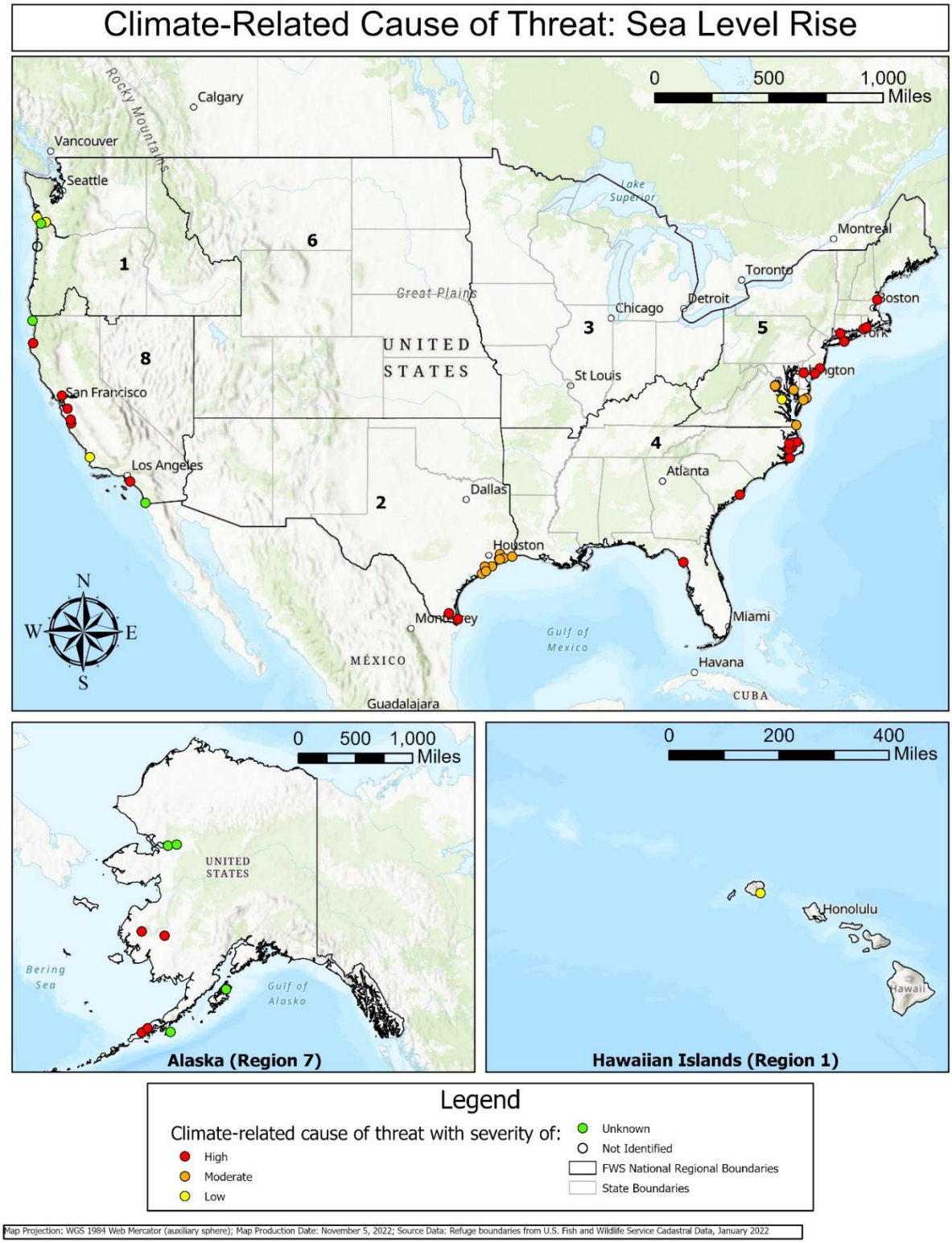


Figure B9: Cause Type: Sea Level Rise. FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

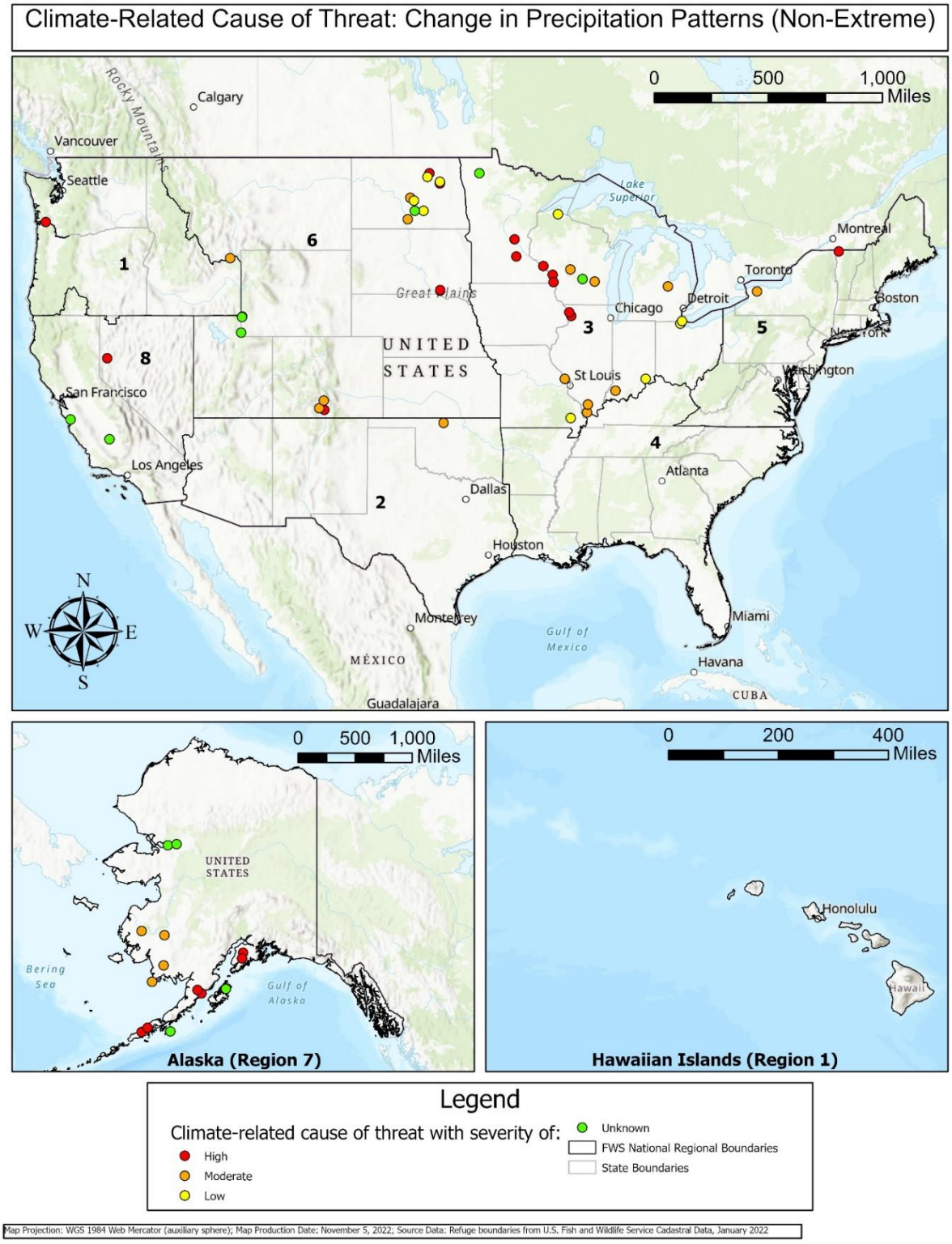
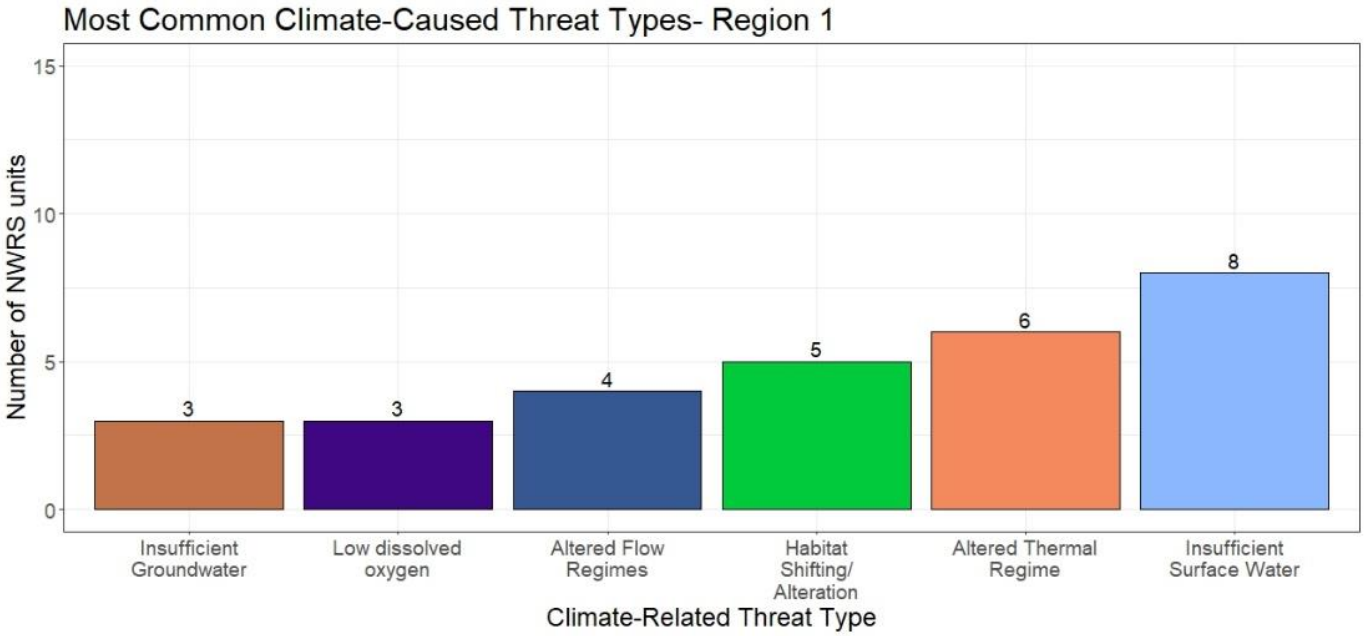
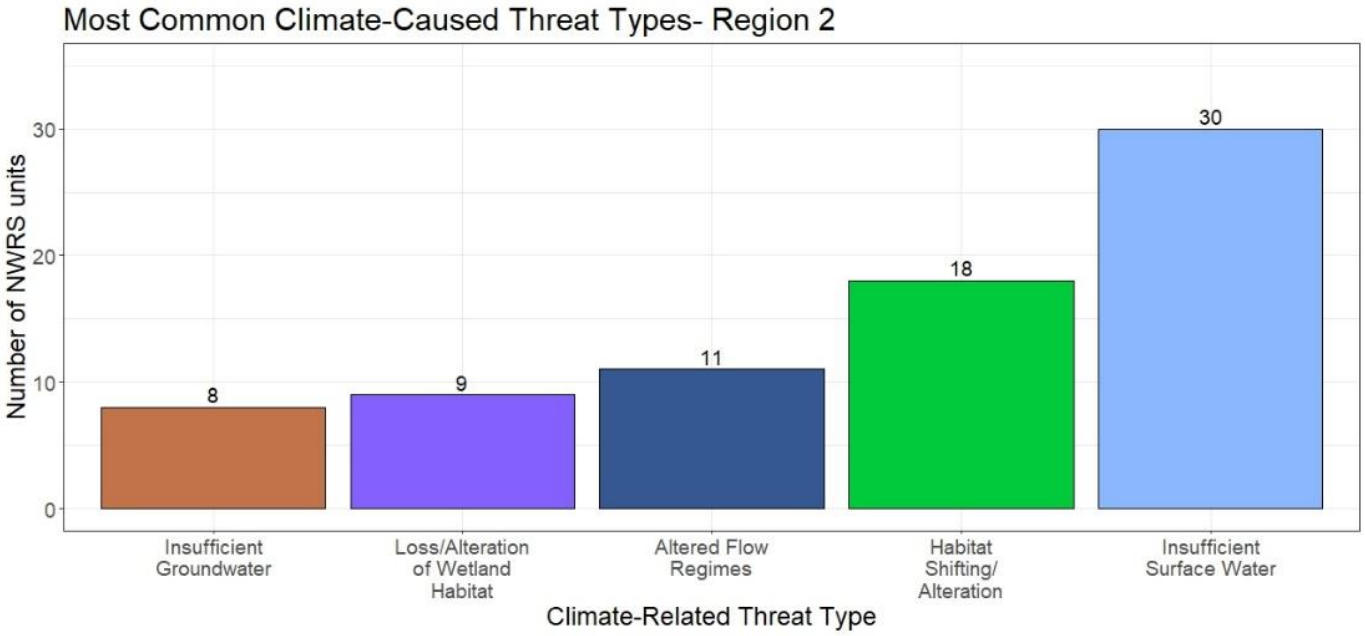


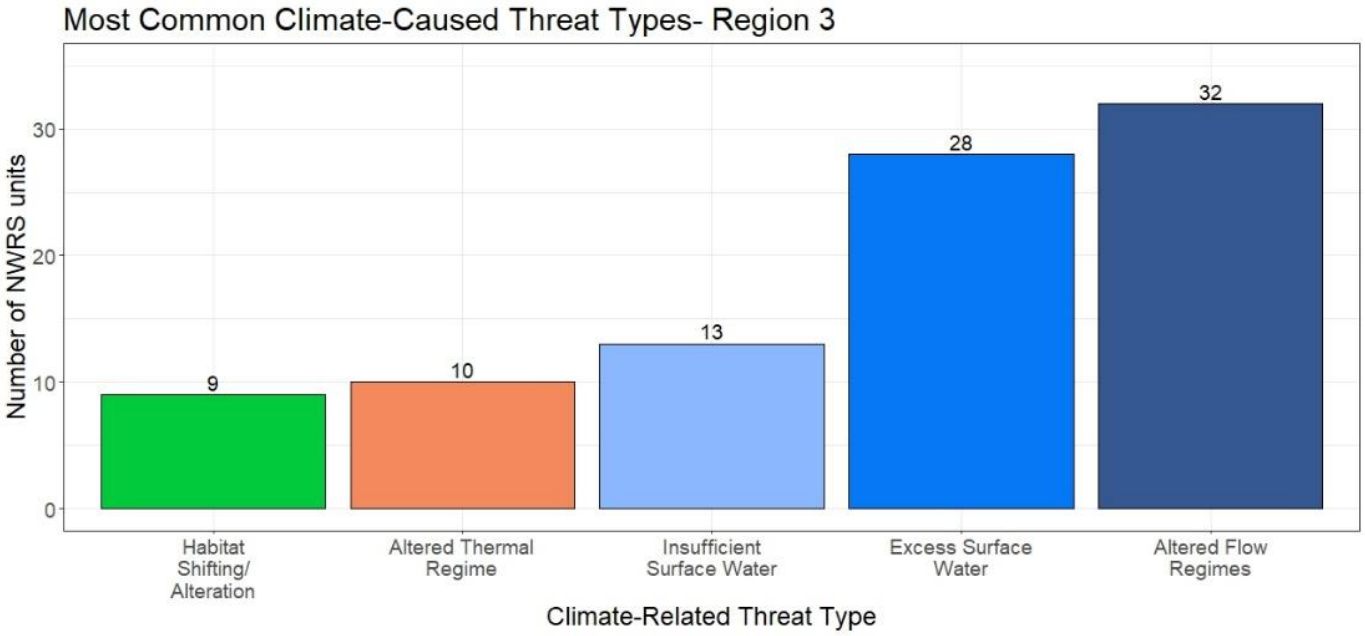
Figure B10: Cause Type: Change in Precipitation Patterns (Non-Extreme). FWS Regional Boundaries are coded as follows: 1 = Pacific, 2 = Southwest, 3 = Midwest, 4 = Southeast, 5 = Northeast, 6 = Mountain/Prairie, 7 = Alaska, 8 = Pacific Southwest.

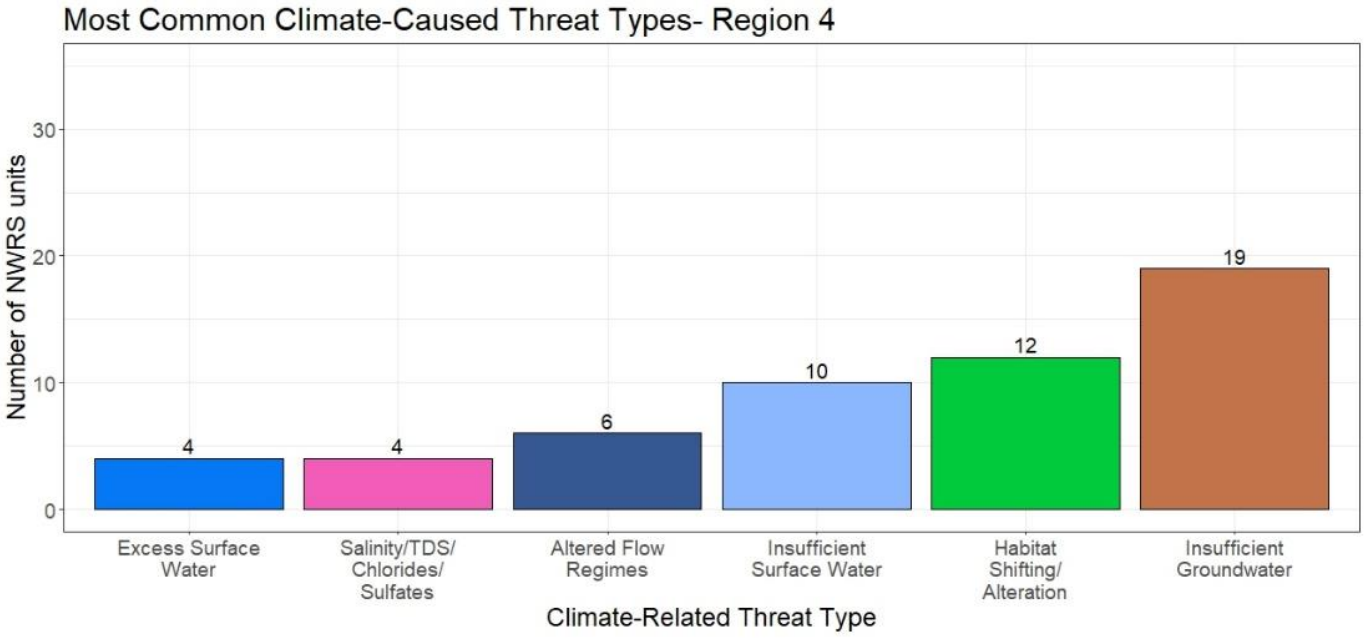
Appendix C: Figures of climate-related types of threats and climate-influenced causes across FWS regions

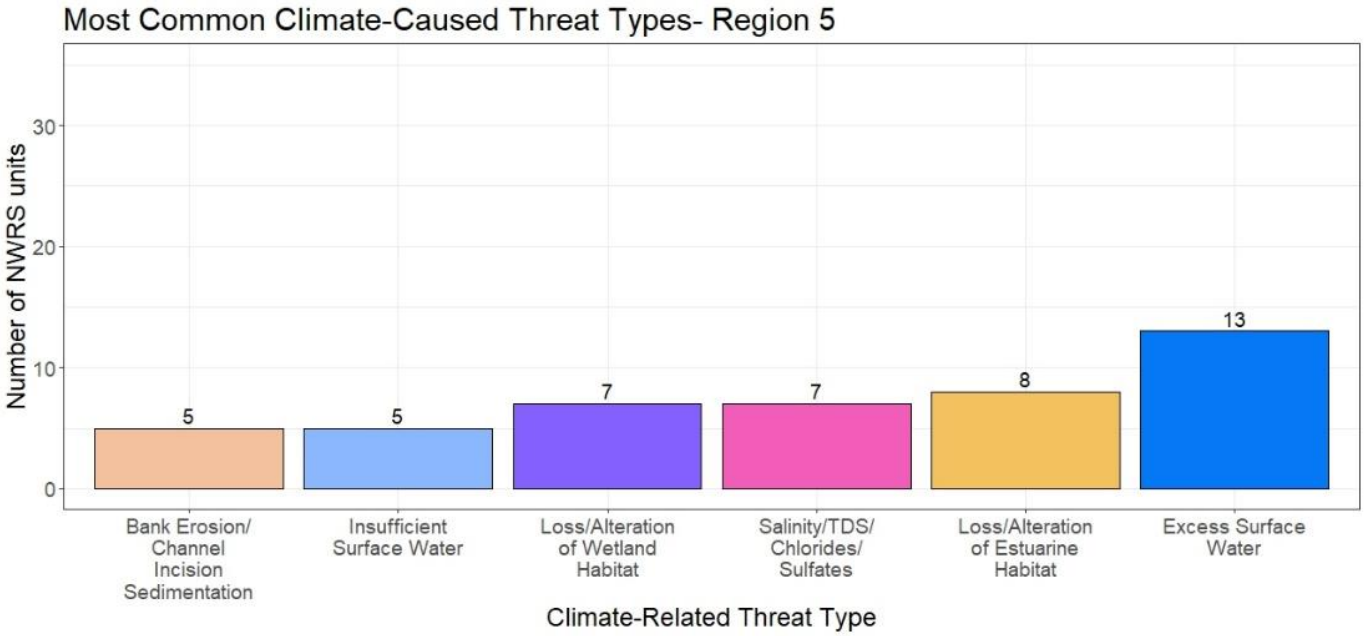
Regional trends in climate-related types of threats

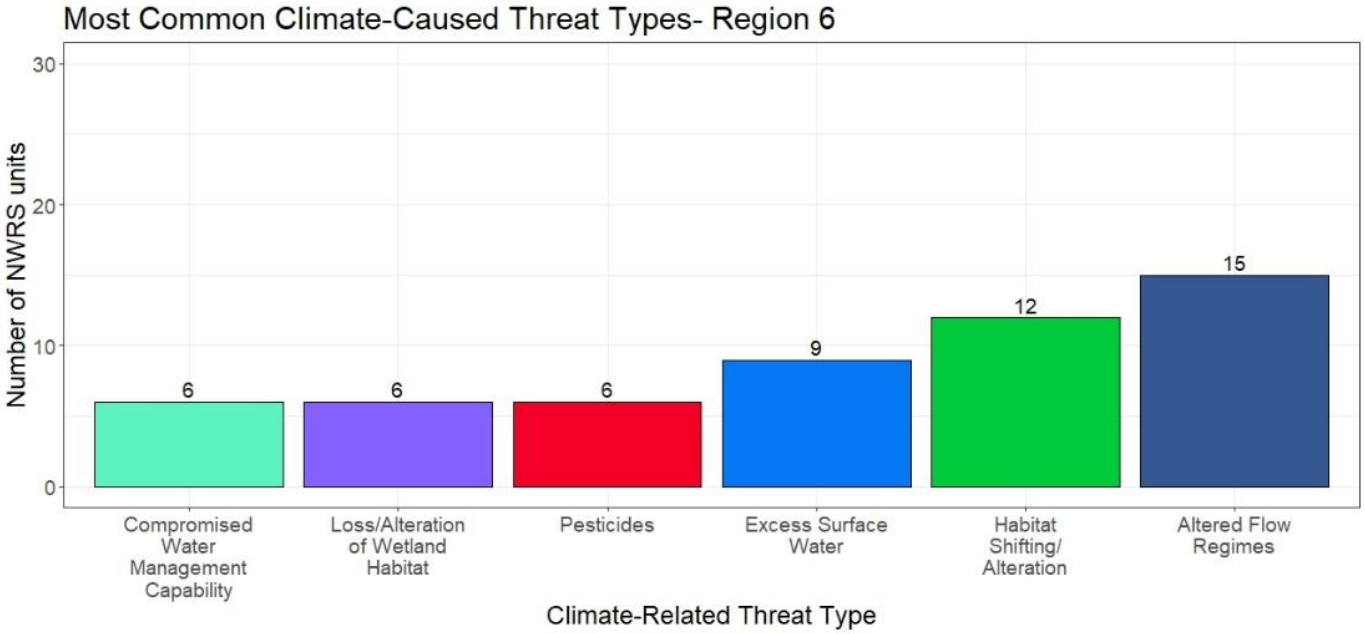


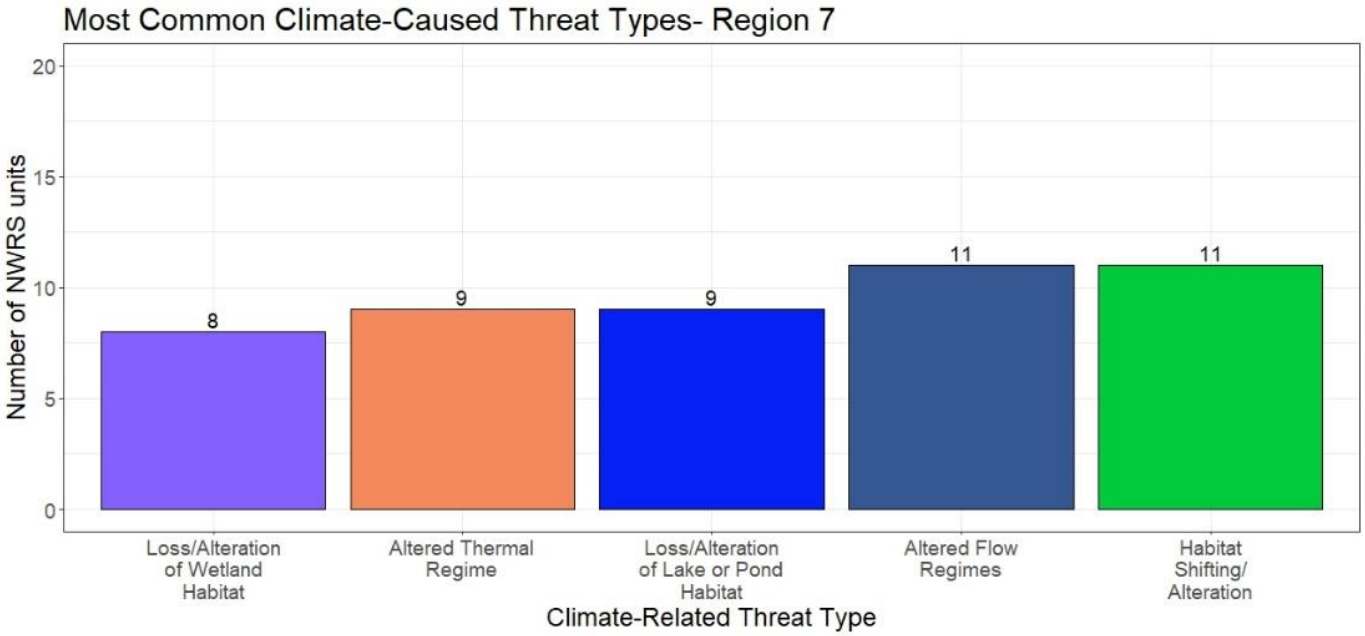


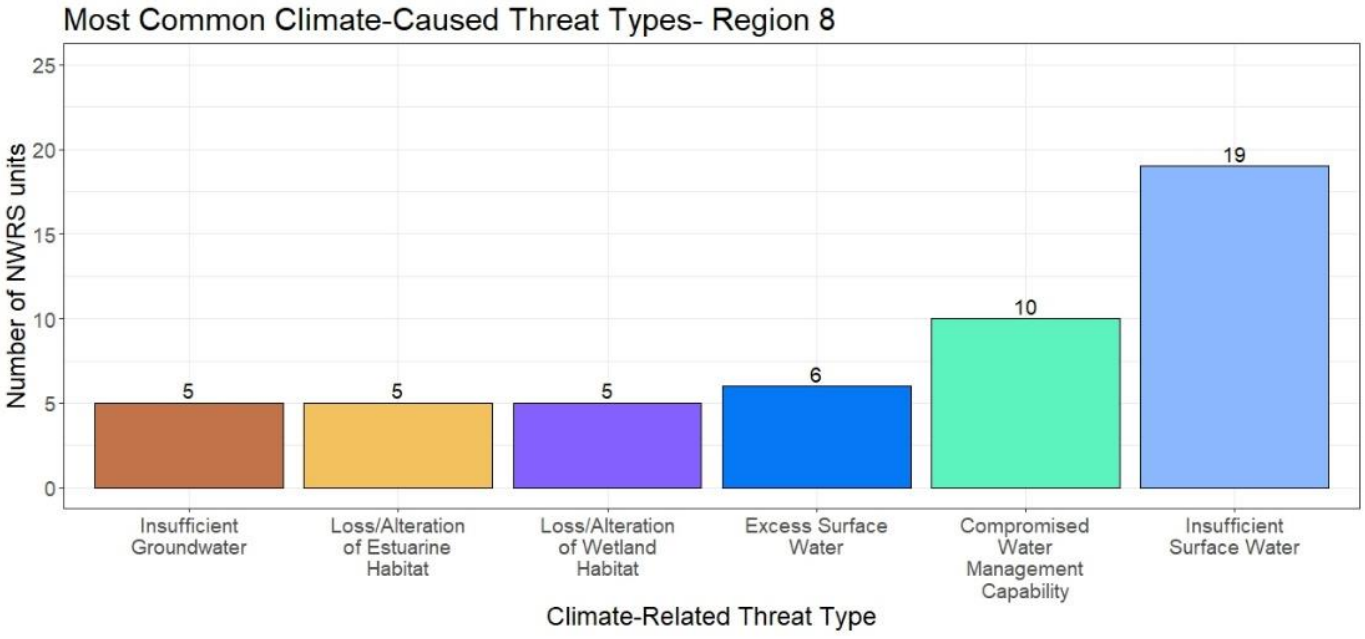

Most Common Climate-Caused Threat Types- Region 3
Number of NWRS units
0
10
20
30
9
10
13
28
32
Habitat Shifting/ Alteration
Altered Thermal Regime
Insufficient Surface Water
Excess Surface Water
Altered Flow Regimes
Climate-Related Threat Type


Most Common Climate-Caused Threat Types- Region 4
Number of NWRS units
0
10
20
30
4
4
6
10
12
19
Excess Surface Water
Salinity/TDS/ Chlorides/ Sulfates
Altered Flow Regimes
Insufficient Surface Water
Habitat Shifting/ Alteration
Insufficient Groundwater
Climate-Related Threat Type

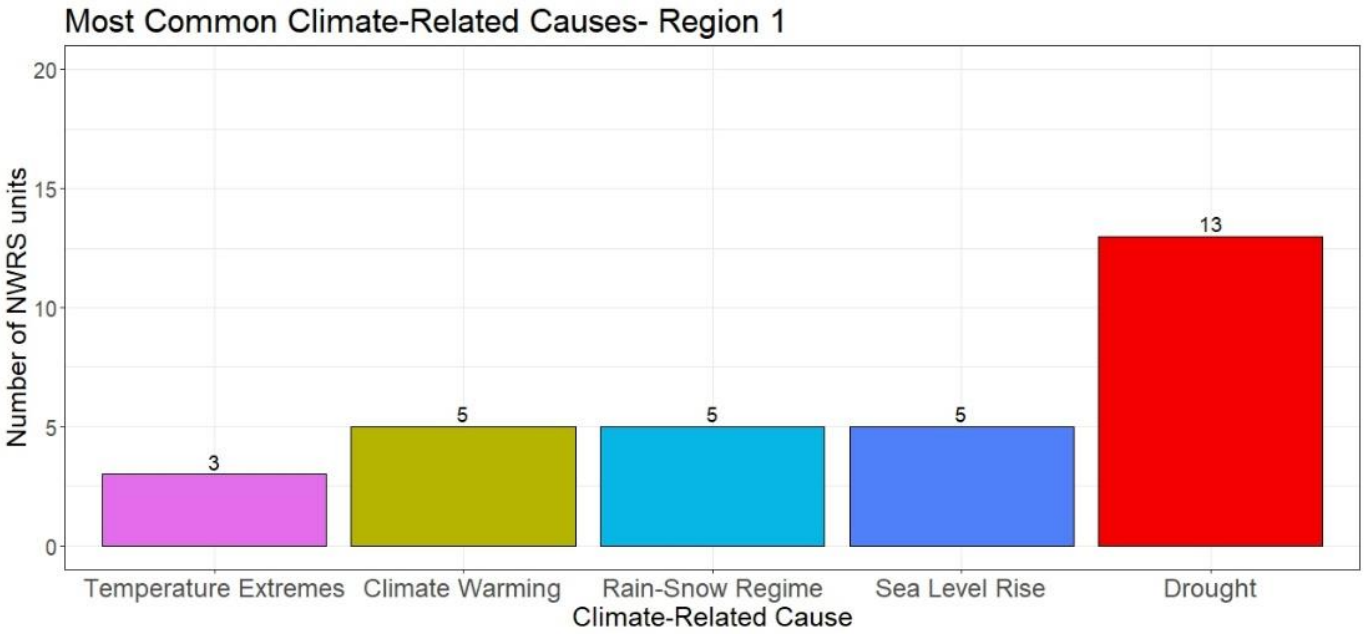

Most Common Climate-Caused Threat Types- Region 5
Number of NWRS units
0
10
20
30
5
5
7
7
8
13
Bank Erosion/ Channel Incision Sedimentation
Insufficient Surface Water
Loss/Alteration of Wetland Habitat
Salinity/TDS/ Chlorides/ Sulfates
Loss/Alteration of Estuarine Habitat
Excess Surface Water
Climate-Related Threat Type

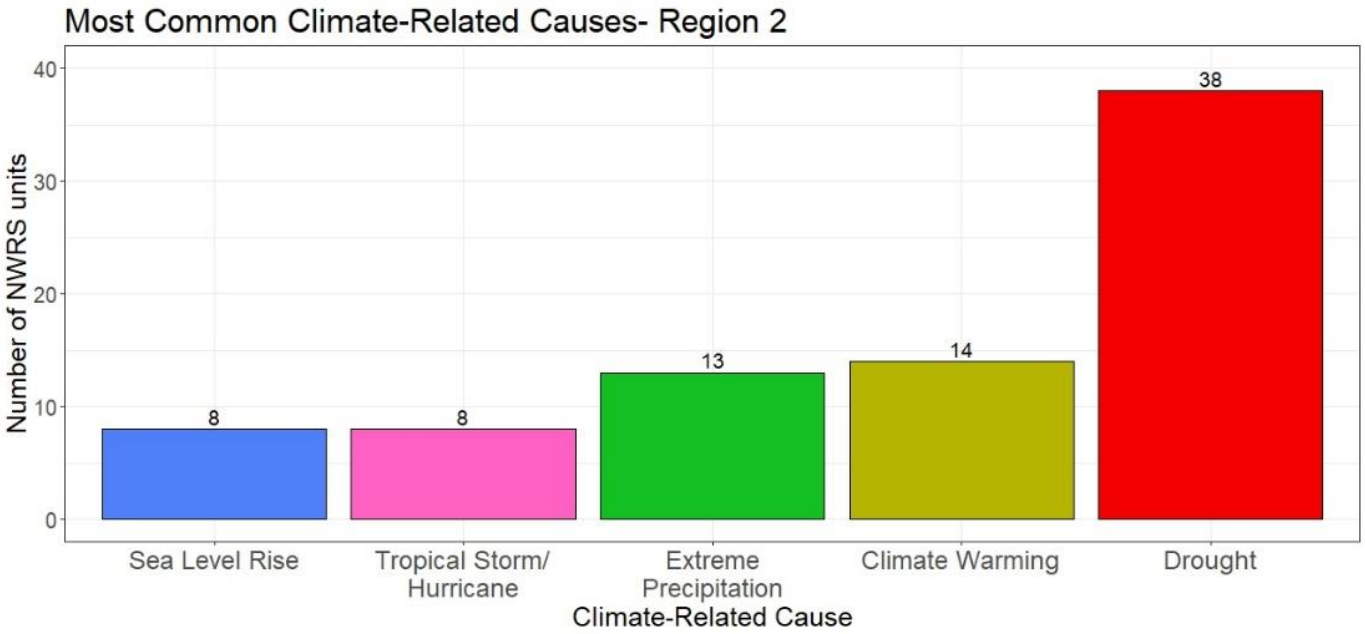

Most Common Climate-Caused Threat Types- Region 6
Number of NWRS units
0
10
20
30
6
6
6
9
12
15
Compromised Water Management Capability
Loss/Alteration of Wetland Habitat
Pesticides
Excess Surface Water
Habitat Shifting/ Alteration
Altered Flow Regimes
Climate-Related Threat Type

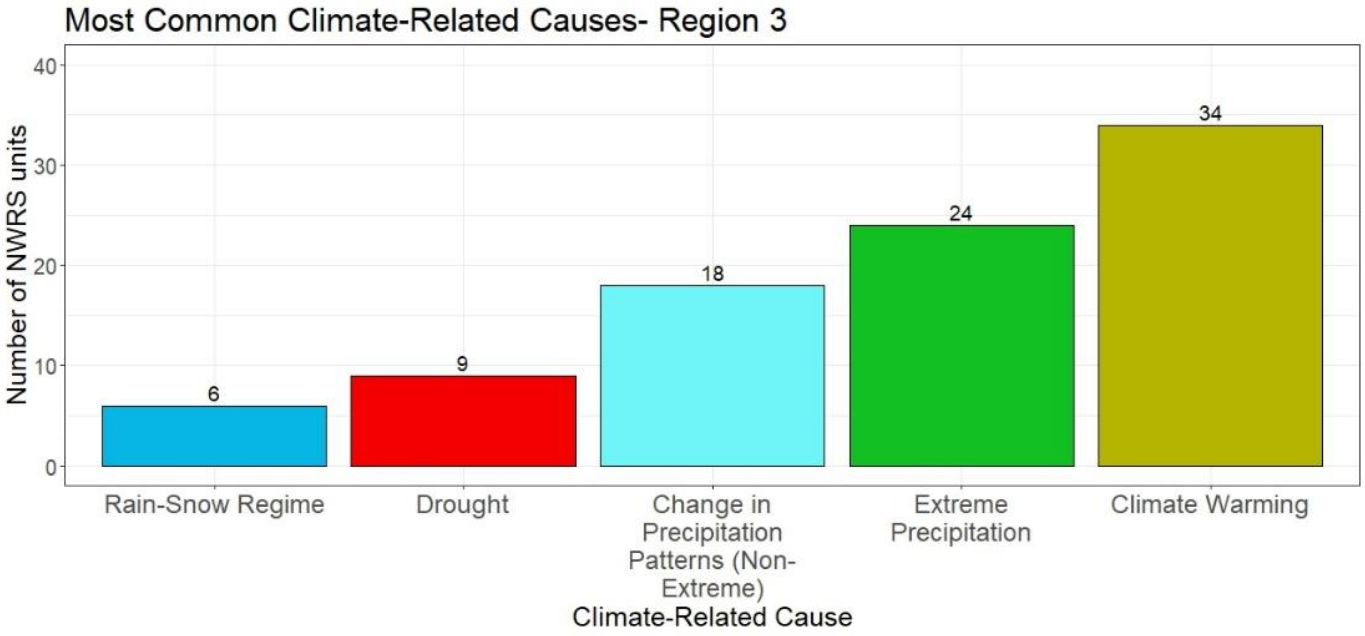

Most Common Climate-Caused Threat Types- Region 7
Number of NWRS units
0
5
10
15
20
8
9
9
11
11
Loss/Alteration of Wetland Habitat
Altered Thermal Regime
Loss/Alteration of Lake or Pond Habitat
Altered Flow Regimes
Habitat Shifting/ Alteration
Climate-Related Threat Type

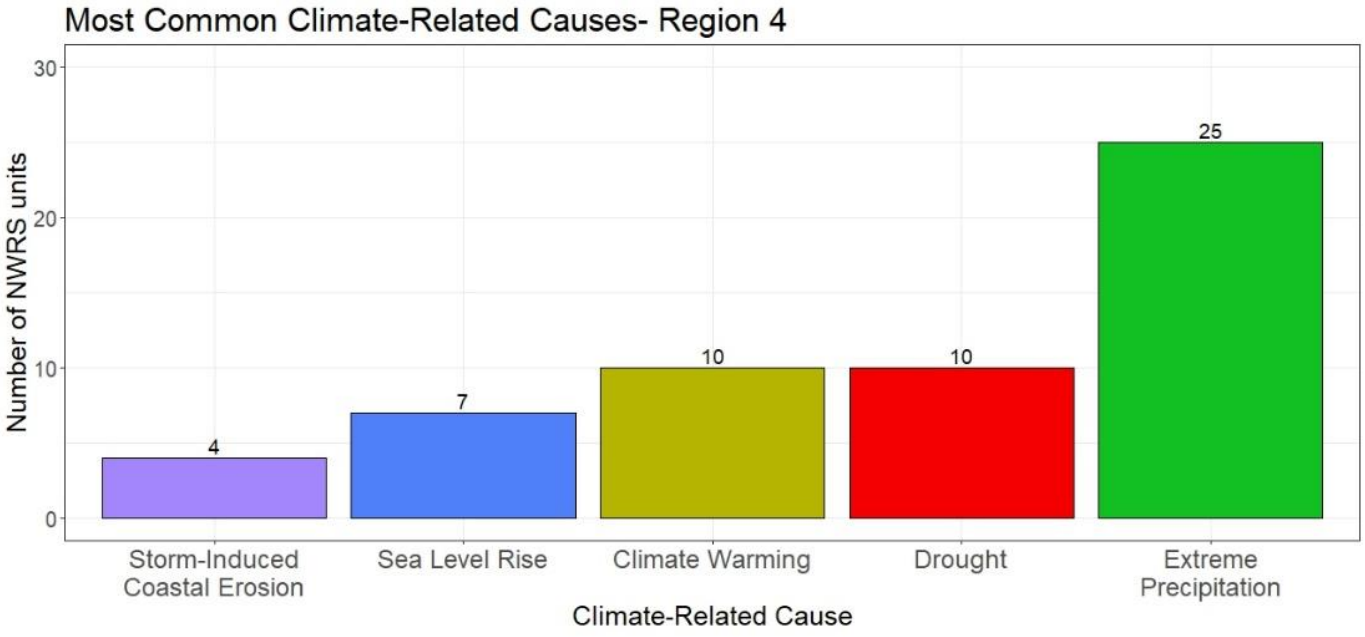

Most Common Climate-Caused Threat Types- Region 8
Number of NWRS units
0
5
10
15
20
25
5
5
5
6
10
19
Insufficient Groundwater
Loss/Alteration of Estuarine Habitat
Loss/Alteration of Wetland Habitat
Excess Surface Water
Compromised Water Management Capability
Insufficient Surface Water
Climate-Related Threat Type

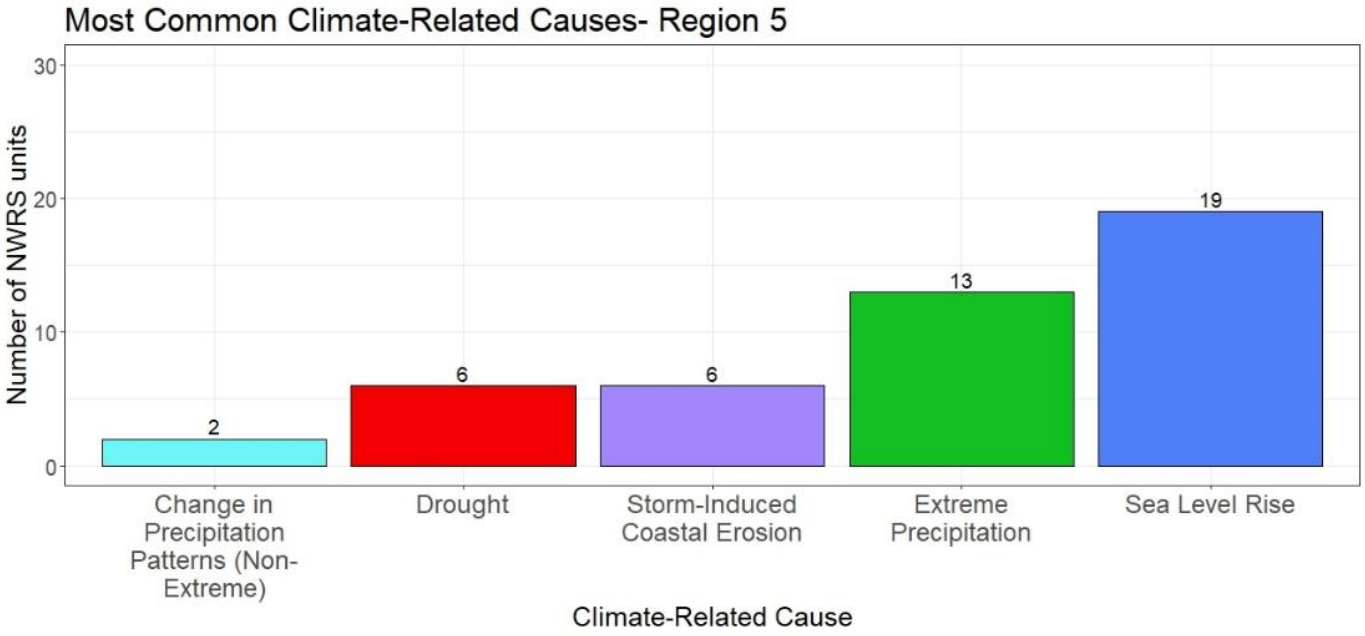
Regional trends in climate-influenced causes of threats

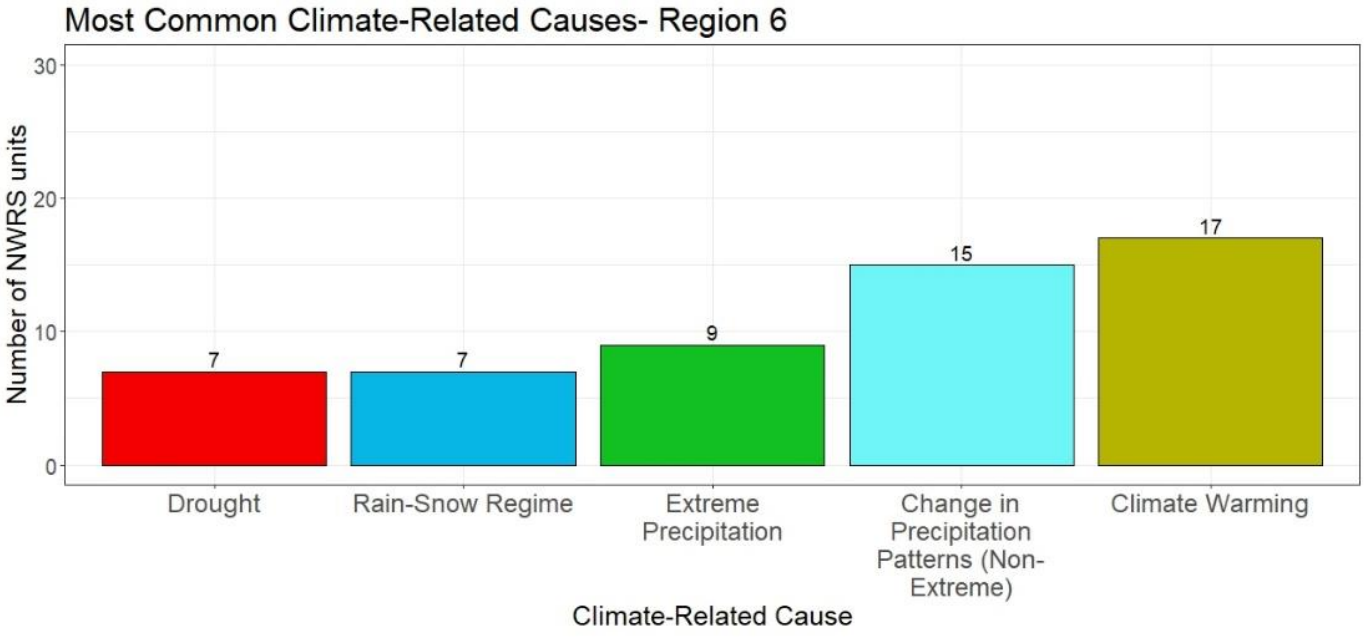


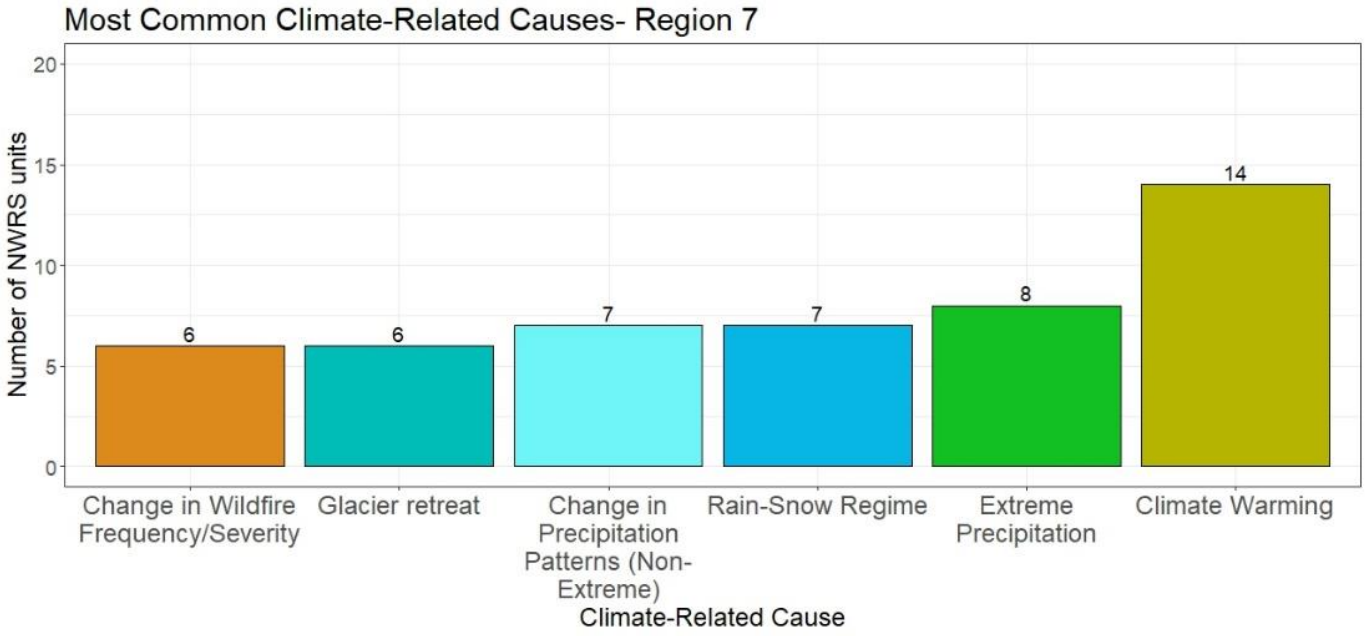


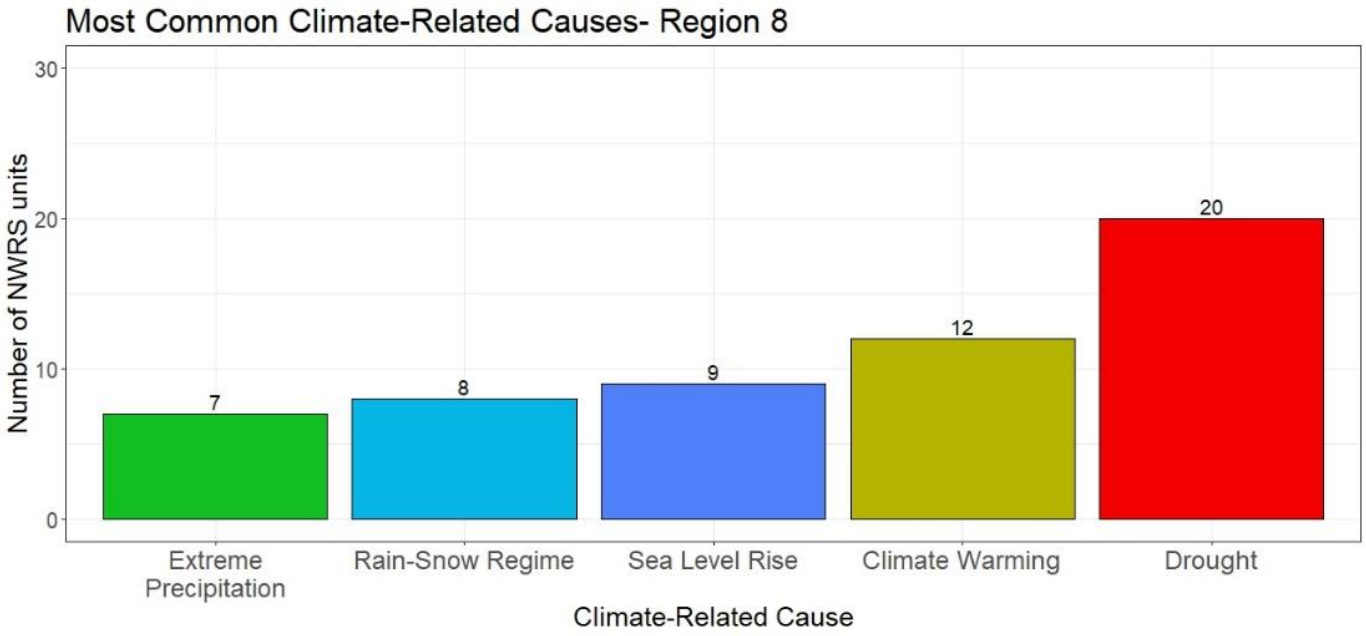

Most Common Climate-Related Causes- Region 3
Number of NWRS units
0
10
20
30
40
6
9
18
24
34
Rain-Snow Regime
Drought
Change in Precipitation Patterns (Non-Extreme)
Extreme Precipitation
Climate Warming
Climate-Related Cause


Most Common Climate-Related Causes- Region 4
Number of NWRS units
0
10
20
30
4
7
10
10
25
Storm-Induced Coastal Erosion
Sea Level Rise
Climate Warming
Drought
Extreme Precipitation
Climate-Related Cause


Most Common Climate-Related Causes- Region 5
Number of NWRS units
30
20
10
0
2
6
6
13
19
Change in Precipitation Patterns (Non-Extreme)
Drought
Storm-Induced Coastal Erosion
Extreme Precipitation
Sea Level Rise
Climate-Related Cause


Most Common Climate-Related Causes- Region 6
Number of NWRS units
30
20
10
0
7
7
9
15
17
Drought
Rain-Snow Regime
Extreme Precipitation
Change in Precipitation Patterns (Non-Extreme)
Climate Warming
Climate-Related Cause


Most Common Climate-Related Causes- Region 7
Number of NWRS units
20
15
10
5
0
6
6
7
7
8
14
Change in Wildfire Frequency/Severity
Glacier retreat
Change in Precipitation Patterns (Non-Extreme)
Rain-Snow Regime
Extreme Precipitation
Climate Warming
Climate-Related Cause


Most Common Climate-Related Causes- Region 8
Number of NWRS units
30
20
10
0
7
8
9
12
20
Extreme Precipitation
Rain-Snow Regime
Sea Level Rise
Climate Warming
Drought
Climate-Related Cause