

Climate Change Vulnerability Assessment: Point Reyes National Seashore

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Abstract

Climate change and its consequences for natural communities pose major challenges to conservation management. Working with managers at Point Reyes National Seashore, we have taken a step towards addressing this challenge with a site-specific climate change vulnerability assessment. We took a multi-faceted approach: 1) we synthesized expert judgment regarding how climate change threatens 12 communities in the park with empirical literature reviews, 2) we quantitatively compared vegetation community distribution predictions of community niche models based on three different global circulation models, 3) we mapped predicted sea level rise and erosion hazard onto vegetation communities at the park and analyzed the potential impacts to the park's communities, and 4) we assessed the vulnerabilities of some individual species to climate change using NatureServe's Climate Change Vulnerability Index. This report documents our process and presents the results of the process; we hope that it serves park managers as a resource in scenario planning and prioritizing management decisions, as well as a blueprint for revisiting the implications of climate change for the natural communities in the park as new data become available.

Introduction

Project goals and process

The purpose of this report is to synthesize the best available assessments of the vulnerability of the natural communities in Point Reyes National Seashore to climate change and to document our process in this endeavor so that park managers may revisit the process as new data and refined predictions become available. This report is part of a larger climate change planning project that Point Reyes National Seashore is undertaking. This climate change vulnerability assessment constitutes the second of three parts in the park's plan:

1. A scenario planning exercise will provide insights into the possible climate futures of Point Reyes
2. This climate change vulnerability assessment synthesizes the best available information regarding how the park's communities may respond to climate change and establishes a blueprint for revisiting the assessment
3. A management plan for Point Reyes National Seashore that takes climate change into account

This report draws on many sources of information. We have synthesized the expertise of government, nonprofit, and academic ecology experts, the outputs of climate-informed model predictions, and conclusions from empirical literature to evaluate the vulnerability of the natural communities in the park. We have evaluated the strengths and weaknesses of all of our sources of information and each method, we have compared their predictions, and we have attempted to

highlight where they contradict one another. Our aim is to present and contextualize all of the currently available information so that managers at Point Reyes National Seashore may weigh the relevant information and make the best informed management decisions.

We outlined the approach for this climate change vulnerability assessment in coordination with managers and scientists at Point Reyes National Seashore through a series of meetings in the spring of 2010. The first decision to come out of those meetings was that the climate change vulnerability assessment would focus on the park's communities rather than its individual species. Chapters providing a synthesis summary of the vulnerability of each community to climate change are ordered according to the priorities of park managers.

As there is currently no comprehensive tool to evaluate the vulnerability of habitats to climate change, the approach taken has four parts, each of which is described in detail in a chapter of the report:

1. Expert judgment & literature review
2. Predictive vegetation shifts generated by a climatic niche models
3. Predicted coastline changes modeled according to sea level rise and predicted wave patterns
4. Vulnerability assessments of key species using NatureServe's Climate Change Vulnerability Index

The report is organized into two main sections – the first section, Project Methods, outlines and evaluates each of the four parts of our approach. The Project Methods section is meant to provide guidance for reading the outcomes of the report presented in the second section, and to provide a blueprint for revisiting the assessment in the future as new data become available. The second section is the focus of the report. It provides the climate change vulnerability assessment for each of the park's natural communities. It is organized into chapters by community type. The community climate change vulnerability assessments found in the second section of the report are meant for use in scenario planning and should be considered in prioritizing management decisions.

Uncertainty

IPCC definition of uncertainty (2007a):

An expression of the degree to which a value (e.g. the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) and/or by qualitative statements (e.g., reflecting the judgment of a team of experts).

Assessing the vulnerability of communities to climate change involves much uncertainty. Uncertainty is layered upon uncertainty. We are uncertain about future green house gas emissions, and even if we knew future emissions, we are uncertain about the future atmospheric green house gas levels. Even if we had accurate atmospheric green house gas predictions, we still would not be sure about global climatic responses, and we would be even less sure about local climatic changes. In addition to our uncertainty with respect to the magnitude of these changes, we are also uncertain about the rate of change we will see in the future. All of this uncertainty, however, does not mean that we do not know anything about future green house gases and their effects on the future. We are fairly confident in the direction of change with respect to green house gases in the atmosphere as well as global climate responses to the increases in those gases (IPCC 2007b).

Uncertainty, though, grows exponentially as we consider biotic responses to climatic changes. Not only do we not know how individual species will respond to the synergistic environmental changes caused by global climate change, particularly in light of the uncertain rates of evolution and migration for most species (Parmesan 2006), but we also do not know how complex interspecific interactions and interaction with abiotic factors unrelated to climate change will mediate community-level responses to climate changes (Pearson and Dawson 2003). A potentially important dynamic that ecologists are not currently able to predict is that of ecological thresholds – when incremental environmental change results in disproportionately large ecological responses (Markham 1996, Burkett et al. 2005).

In light of all the uncertainty involved in assessing natural communities' vulnerability to climate change, we attempt to clearly communicate degrees of certainty throughout this report. The primary way in which we communicate the uncertainty involved in the community vulnerability assessments is through the detailed discussions of our methods. In addition to clearly outlining our methods, we evaluate the strengths and weaknesses of each set methods we used to develop this report.

Throughout the report we approach assessing vulnerability to climate change comparatively. We compare expert opinions to one another and to empirical literature when possible, and highlight areas of disagreement as well as uncertainty. We contextualize empirical literature with respect to the time, place, and scope of the study in order to clarify its relevance to the park's communities. We take a comparative approach to vegetative shift models – we have three spatial vegetation predictions based on three different global climate models and two green house gas emission projections. We seek to emphasize the predictions on which all the models agree as well as point out the assumptions common to all the models that could cause all of them to make inaccurate predictions.

This report does not make any definitive statements about the future of any community type in Point Reyes National Seashore, however, we believe our syntheses aptly communicate the available information and the degree to which this information points consistently in a particular direction. The uncertainty communicated in this report should be helpful for identifying research priorities for the park, and for identifying new tools and information useful in filling some of the gaps in this vulnerability assessment.

Community assembly and climate change

From a management perspective, it is often practical to consider communities rather than individual species. Communities are assemblages of taxa that may be identified by certain key or dominant species and characteristic abiotic components. However, the title given to a community may be used to refer to a collection of species that varies temporally and spatially. For example, a rocky intertidal community in northern California will not have the same species makeup as a rocky intertidal community in Maine, but each community can be readily identified by its respective biotic (e.g. species composition) and abiotic (e.g. environment) components. These biotic and abiotic features shape the distribution of plant and animal species in what is known as the community assembly process (Ackerly 2003).

Although community structure changes over the long-term, it tends to be relatively stable over the management time-scale, allowing managers to associate species within a given assemblage and, to a certain extent, manage communities as units. However, paleoecological records show that during times of climatic shift, species within communities respond to the changing environment individually (Graham & Grimm 1990). With rates of climatic change in coming decades likely to be more accelerated than during previous shifts, this difference in reaction may be even more obvious, and result in rapid changes to current community assemblages (Graham & Grimm 1990).

The response of each species within a given community will vary depending on its ability to adapt and its ability to disperse. Ackerly (2003) provides four potential responses to changes in the local environment:

- populations may shift locally, perhaps changing altitude or following a shifting microclimate
- populations may shift much more broadly, moving into new habitats and abandoning portions of its previous range
- species may adapt to new climatic conditions
- species may go extinct.

While it is likely that individual responses will be more nuanced than the four broad possibilities Ackerly presents, options for individual species in changing climates remain limited.

As species' ranges shift, whether in elevation, latitude, or microclimate, community assemblages will change. There may be temporary or prolonged increases in species richness, as new species move into an area; this is especially likely in areas with heterogeneous elevation. Upslope communities previously identified by few species may have additional species expanding into that area, while existing species may be limited in their ability to move, particularly if they are already at peak elevation (Walther et al. 2002). Within a given community, the ability to respond, the type of response, and time to respond will differ for various populations (Sagarin et al. 1999). Birds have been shown to be fairly rapid responders, and generally are able to disperse widely. While smaller faunal species, such as insects, may be limited in dispersal, they have a greater ability to adapt, and may also be able to shift ranges over time. Long-living plant species, such as redwoods and bay oak may react much more slowly. This can be especially

troublesome when symbiotic systems, e.g. a plant and an obligate pollinator, respond to climate change at different rates or in different ways.

Alterations of elevation or latitude by individual populations will cause current community assemblages to break down. Over time, new communities will almost certainly be established as the community assembly process takes place. These non-analog communities may occur at the microclimate level, the park level, or at greater scales (Keith et al. 2009). Non-analog communities are composed of currently existing species, but will include associations between species that do not interact in the present system, or interactions that are not currently taking place.

It is difficult to predict the species makeup of future communities, because the community assembly process is both deterministic and stochastic. As population ranges shift, early dispersers will have to compete with established species for resources. In addition, the propagules of early colonizers will face added difficulty in establishing within a community due to demographic stochasticity (Tilman 2004). Until a substantial portion of a population shifts its home range, low-density factors, such as decreased ability to find mates, will also negatively impact colonizers. However, as species that are currently located within a community shift their range, they will free up space and other resources for new species to move in.

There is sufficient paleoecological evidence of non-analog communities, as well as evidence from shifting communities over the past century, to provide strong support to the expectation that species-level response to climate change may differ from overall community response. From a management perspective, this means that a bay oak stand in fifty years may be significantly different from a bay oak stand today, and will possibly need to be managed differently. It also means that species currently not found within park boundaries may move in, and may need to be managed as part of an existing community type.

Throughout this report, we largely treat community types as “units,” knowing that this is not an entirely accurate description. However, the benefit of focusing on community-level vulnerability to climate change is that the approach acknowledges that species within a given community have a high level of interaction, and changes in species composition will have ramifications throughout a community. Being aware of this, and monitoring for such changes, may allow park managers to make proactive decisions in maintaining the health and viability of park species, both those that currently call Point Reyes National Seashore home, and those that will do so in the future.

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Project Methods

Method I: Eliciting expert judgment

Overview

Expert judgment has become an accepted source of assessment in data-poor circumstances in ecology and conservation (Teck et al. 2010). Many assessments that rely on expert judgment attempt to either build consensus among experts or to quantify the degree of disagreement among experts (Parson et al. 2003, MacMillan and Marshall 2006, Glick et al. 2011). The Delphi method attempts to build consensus among experts through an iterative process (MacMillan and Marshall 2006). It involves asking experts to revisit the synthesis of their original responses in order to reconsider their own responses as well as evaluate those of their peers; the review process may involve multiple iterations.

Expert Judgment in this report

Part 1 of our approach to assessing the vulnerabilities of communities at Point Reyes National Seashore involved soliciting expert judgment on the vulnerabilities of these communities from scientists who have extensive experience working in the park's communities and synthesizing their expert judgment with salient literature. We worked with park scientists and managers to identify the community types of management interest. We originally identified 14 community types, ranked by management priority, but we ultimately combined freshwater wetlands and streams with riparian areas and Douglas fir/mixed evergreen forests with coastal redwood forests for a final total of only 12 communities. These combinations were made because the experts for these combined communities overlapped and they indicated in their responses to our survey questions that their answers for one community applied to the other as well. Although we have one chapter that covers freshwater wetlands, streams, and riparian areas and one chapter that covers Douglas fir/mixed evergreen forests and coastal redwood forests, any assessments that pertain to only one of the community types covered are clearly indicated. This report, then, is organized into twelve chapters outlining community-level vulnerability to climate change:

- 1) Freshwater wetlands, streams and riparian areas
- 2) Coastal scrub
- 3) Grasslands
- 4) Eelgrass beds
- 5) Douglas fir and coastal redwood forests
- 6) Estuarine communities
- 7) Hardwood forests
- 8) Sandy beaches and coastal dunes
- 9) Maritime chaparral
- 10) Rocky intertidal communities
- 11) Bishop pine forests
- 12) Kelp forests

We identified experts with extensive experience working in the park's communities primarily through a list that had been generated for prior projects in the park, as well as through word-of-mouth and literature searches. We contacted 35 potential experts. Nineteen experts participated by responding to one or more community surveys either in writing or through an interview (see Appendix A for list of experts and their affiliations).

After much deliberation and a consultation with Dr. David Ackerly at the University of California, Berkeley, we choose to develop an expert judgment survey with open-ended questions that did not presume a particular future climate for Point Reyes National Seashore. We invited experts to outline possible community responses to a wide variety of possible local environmental changes due to global climate change, including both average changes (as in average temperature increases) and changes in the frequency or distribution of extreme conditions. Given the incredible amount of uncertainty associated with any prediction of the future climate in the park, this approach offers the most flexible and useful results. Assuming a particular predicted climate for the park would result in community vulnerability assessments that are not relevant if, in fact, the predicted climate is not in line with the realized climate. Instead, our report focuses on the wide variety of possibilities; for example, we asked experts to consider the community implications for increases in average temperatures as well as decreases in average temperatures (see Question 1 below).

Multiple stressors in natural communities pose a challenge for assessing community vulnerability (Parson et al. 2003). The ways in which communities respond to climate change will be have much to do with confounding interactions. In an attempt to address this challenge, we also asked experts to consider how other pressures, such as pollution, recreational use, and commercial use, as well as biotic interactions, including invasive species, might affect their responses to environmental changes (see Question 4 below).

Expert Judgment Questions (example: coastal scrub):

- 1) Coastal scrub in Point Reyes National Seashore is sensitive to what climate changes? Consider all possible changes related to temperature, wind, and precipitation, averages and extremes. For each climate condition, please explain why and in what ways the community is sensitive to changes and how the community might respond.
- 2) In Point Reyes, how close is this community to any of its range limits (latitudinal or elevation/depth)?
- 3) Are there biotic or abiotic interactions that may make this community type more or less sensitive to environmental changes? Explain how each interaction may affect the community's sensitivity to environmental changes.
- 4) What human activities, if any, is this community in Point Reyes sensitive to (please consider recreational and commercial activities in the park, as well as human activities outside of the park that impact the community in the park)? Please explain why and in what ways the community is sensitive to these activities as well as how the community is responding to these activities.

After synthesizing expert judgments and the salient literature, we asked experts to review our syntheses and provide feedback. We received a total of 40 expert surveys distributed across the 12 communities and 14 reviews of community vulnerability syntheses. With the feedback we did receive, we finalized the syntheses and developed a table to summarize experts' positive and negative expectations for each community, given each potential environmental change. The resulting chart is fairly unwieldy in size for a printed report, but is included as an excel file in the digital supplements to this report (see digital file CCVA_Communities_Chart in the electronic supplements to this report). It is meant to provide a visual reference of which communities may be most threatened by a particular environmental change.

Evaluation of expert judgment

Strengths

The greatest strength of this part of our approach to assessing Point Reyes National Seashore's community vulnerabilities to climate change is in the experts themselves. Because we were able to find experts with extensive experience in the communities of the park, we benefit from their ability to identify sensitivities particular to the park's communities. These experts are in the best position to weigh the salient literature against the context of their experiences in the park's communities. They are also the best suited to identify confounding stressors and interactions that will affect how the park's communities respond to climate change. Given the dearth of reliable downscaled climate change projections, expert judgment may be the best assessment of community vulnerability to climate change that is currently available. Point Reyes National Seashore is fortunate to have access to so many scientists with so much experience in the park's communities.

An additional benefit of our use of the Delphi approach to collecting and synthesizing expert judgment was in providing an important check on the authors of this report with respect to communicating opinions and literature accurately. Expert reviews of the syntheses identified statements that misconstrued experts' responses to our questions. The reviewers also pointed out salient literature that we had not included. The Delphi approach resulted in a more complete product with more faithful syntheses of expert judgment.

Weaknesses

The shortcomings of the expert judgment portion of this report have to do with the subjective and qualitative nature of the approach. Expert judgment is necessarily subjective, and it may be biased with respect to the experts who chose to participate in this vulnerability assessment. Experts may weigh more heavily those environmental factors, species, and interactions with which they are most familiar. Just as models of community responses to climate change leave out many factors we know to be relevant, so too may experts leave out many relevant factors as they grapple with the complexities of predicting community responses to environmental changes. Expert judgments may be based on community responses to past environmental changes, though these past observations may be misleading with respect to future responses to climate change (Parson et al. 2003).

We began the process with the intention of asking all experts to quantify their level of confidence in each of their predictions using a scale of 1 to 3 – a technique used in other expert judgment-based climate change vulnerability assessments (Glick et al. 2011). We abandoned this practice, however, when it became clear that the responses were overwhelmingly twos. Without the system, however, we have no method of attempting to quantify expert confidence in predictions.

The number of participating experts per community type was uneven across community types, such that two communities were only considered by two experts, while others were considered by as many as five experts (see Appendix A). We would have preferred three or more participating experts for each community type in the park. We found that over half of the experts who responded to our survey did not participate in providing feedback to us on the syntheses – this too is a weakness of the expert judgment portion of this report.

The intent of the expert judgment portion of this report is to allow managers to consider all possible climatic futures for Point Reyes National Seashore in considering management priorities. The hope is that the expert judgment syntheses will also allow park managers to focus in on relevant predicted community responses as particular environmental changes are observed in the park. Expert judgment syntheses can be found at the beginning of each community section.

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Method II: Predictive vegetation mapping

Overview

This vulnerability assessment for Point Reyes National Seashore includes outputs from predictive models that groups in the scientific community have spent many years developing. These computer models make predictions about where the vegetation communities that exist today may exist in a climatically changed future. The outputs are in the form of maps, and while there is a staggering amount of uncertainty in the spatial predictions the maps depict, the outputs may provide useful insights into the future and into research needs for the management of the National Seashore.

In order to make predictions about the future locations of vegetation communities, modelers begin with a prediction about greenhouse gas emissions, which feed into a model of the global climate: this is referred to as a global circulation model, or GCM. This GCM, in turn, informs a model of how vegetation community varies with climate, and the result is a prediction of where a vegetation community may be located in the future given a certain understanding of global climate and a certain amount of atmospheric greenhouse gasses.

IPCC emissions scenarios

Most often, researchers use one of the greenhouse gas emissions scenarios developed by the Intergovernmental Panel on Climate Change (IPCC 2001). In 2000, this group developed six greenhouse gas emissions scenarios that span the years 2000 to 2100. These scenarios are based on socio-political actions over the next century and discuss how many greenhouse gases might be released over that time period.

The mapped predictions used in this report are all based on the IPCC's A2 emissions scenario. Known colloquially as the "business as usual" scenario, the A2 imagines a world with these attributes:

- independently operating, self-reliant nations
- Continuously increasing global population
- Regionally oriented economic development
- Slower and more fragmented technological changes and improvements to per capita income. (IPCC 2001).

Actual emissions in the first decade of the 21st century are exceeding the emissions in this scenario (Garnaut et al. 2008), indicating that the A2 scenario – the most liberal of the IPCC's six emissions scenarios – may actually be overly conservative.

General circulation models

Emissions scenarios inform one of several general circulation models (GCM) to make predictions about what the future climate may look like. These GCMs are computer models of how oceans and atmosphere determine climate. There are at least 25 different GCMs that have been developed by 16 international modeling teams (Glick et al. 2011). The models use three-dimensional grids across the globe that are spaced at a climatically relevant size. The grid size at which these models operate is quite large (70 to 350 miles to a side), and does not capture some smaller-scale climate-driving phenomena, including cloud cover or fog. This is one of the sources of uncertainty in GCMs. Regional models may be nested within the GCM and provide better estimates of local climates, which are needed for analyses of local impacts. The most common approach to making regionally downscaled models is through a process called “statistical downscaling” that uses historical correlations between large- and regional-scaled climate conditions. Downscaling is a further source of uncertainty in climate model predictions. Regional climate models (RCM) are another way of looking at predicted climate on a smaller scale. These models capture variation in local topography, distance from coast, smaller scale atmospheric dynamics, and variation due to latitude and are able to fine-tune predictions about regional climate. Each GCM can be run with any emissions scenario to make a broad range of predictions about the future of the world’s climate.

Vegetation modeling

Results of a climate-prediction exercise may be used to make further predictions about the future distributions of vegetation communities. Generally, there are two ways of making these vegetation community predictions: climate envelope (or niche) models, and dynamic vegetation models (DVM).

Climate envelope models

Climate envelope models are based on the idea that species or vegetation communities occupy their realized niche, a sub-section of their actual niche (Hutchinson 1957). For the purposes of these models, the climate niche is based on the current distribution of a species or community or on a set of physiological responses observed in various laboratory settings. Predictions are then made based on the idea that as the climate changes, the places with a suitable climate for that species or community will also change. Because factors other than climate are often important co-drivers of a community’s realized niche, there is a fair amount of uncertainty in this type of modeling. For example, climate envelope niche models may not capture the role of dispersal barriers that may prevent a species from occupying suitable habitat.

Climate envelope modeling looks at the current-day correlation between climate and community type, it then looks at where certain climate parameters are predicted to be in the future and makes predictions about where community types may be located in the future. Often times, to improve their performance, climate envelope models will use parameters like soil characteristics and access to groundwater in addition to climate variables.

Dynamic vegetation models

Dynamic vegetation models (DVMs) are similar to climate envelope models, but are more mechanistic. Rather than simply correlating a conifer forest with a certain climate, DVMs look at the dynamic interactions between regional climate and regional vegetation—they capture how climate influences vegetation and vice versa. These models are quite complex and include inputs such as precipitation, evapotranspiration, canopy interception of precipitation, evaporation, runoff, and infiltration at several depths of soil (Figure VM-1). Additionally, these models consider other important parameters that drive vegetation community distributions. For example, temperatures are used to bound the distributions of certain plants (e.g., broad-leaf deciduous trees), wind plays a part in determining evapotranspiration rates, and disturbance regimes (e.g., fire intensity and return intervals) influence the results of competition between woody and herbaceous vegetation types. These models are computationally intensive to run and are not able to provide predictions at the individual species level.

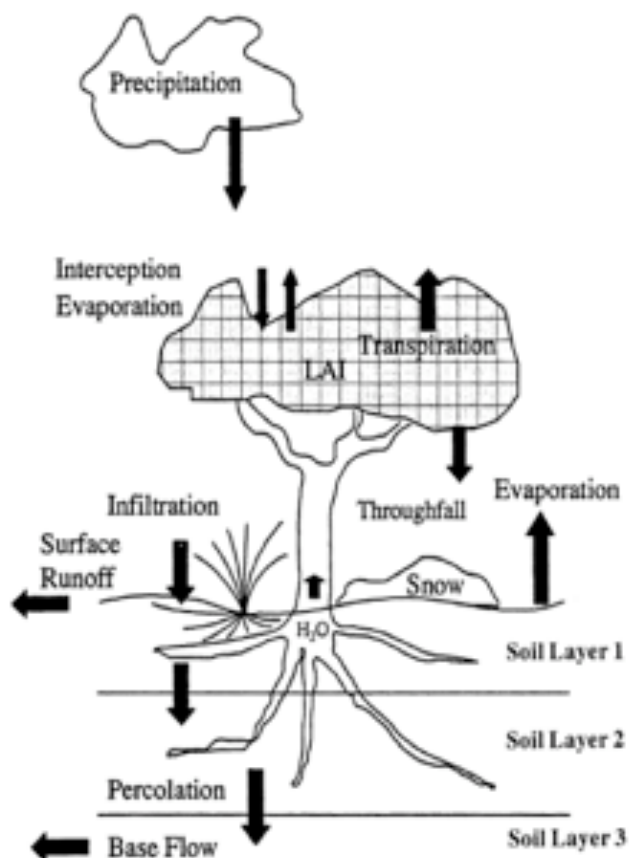
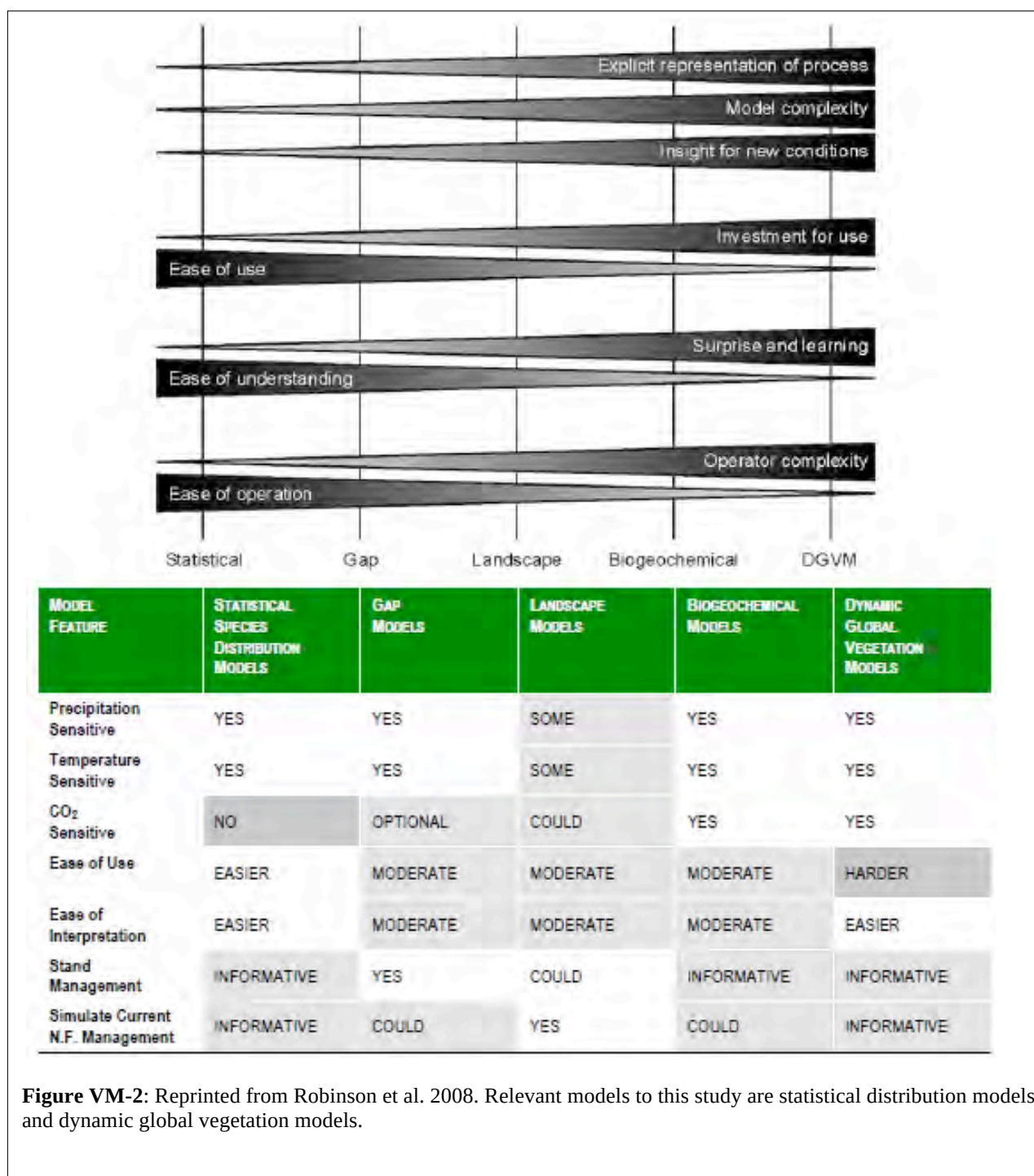


Figure VM-1: Conceptual diagram of MAPSS. Reprinted from Nielson 1995

Rather than making predictions about currently named plant communities (e.g. Northern coastal scrub, or Montane hardwood-Conifer forest), these models use categories of plants to describe the type of vegetation that may be found in a given location (Table VM-1).

Table VM-1: vegetation classifications by MAPSS, a dynamic vegetation model (Nielson 1995)			
Community type	Leaf phenology	Leaf type	Local example
Grasslands	n/a	n/a	Northern coastal grasslands
Shrublands	Evergreen	Broad-leaf	Maritime chaparral
		Narrow-leaf	Northern coastal scrub
	Deciduous	Broad leaf	Riparian shrublands
		Narrow leaf	Sage scrub
Forests	Evergreen	Broad-leaf	Bay-oak hardwood
		Narrow-leaf	Bishop pine forest
	Deciduous	Broad-leaf	Blue oak woodland

Robinson et al. 2008 created visual comparisons of several different types of vegetation modeling, including climate envelope models (statistical distribution models) and dynamic vegetation models (Fig VM-2).



Predictive vegetation mapping in this report

A major portion of this vulnerability assessment involves looking at the results of predictive mapping projects to get a broad range of what has been predicted for the spatial distribution of vegetation communities currently found at Point Reyes National Seashore. All of these outputs are associated with quite a high level of uncertainty and so we do not recommend using any of

them as a definitive picture of the future. Rather, our goal was to provide managers with all the available information with respect to available downscaled vegetation models. Comparing the outputs of these spatial modeling projects side by side highlights areas of uncertainty. Areas of consensus over a broad range of climatic predictions and using a range of predictive mapping approaches highlights areas of less uncertainty, though it is important to note that the different models make some of the same assumptions and therefore may show consensus that should not be mistaken for certainty. Due to the scale of this data, and because it does not include species-species mechanisms and in some cases does not include species-processes interactions, this section will serve as a compliment to the expert opinion section outlined above.

Unfortunately, because new downscaled DVM models were not completed by the conclusion of this report, they are not included here. Contact information for the teams working on DVM projects for the Point Reyes region are listed below.

Climate envelope models

In 2009, PRBO published the results of a study predicting bird communities in the future (Stralberg et al. 2009). For this study, PRBO used the A2 IPCC emissions scenario to inform three GCMs (results from two were published in the study). They used the GCM predictions to predict the future distribution of vegetation communities across the state of California, and based on these vegetation communities predicted bird communities in the future.

For the purposes of this vulnerability assessment, PRBO has shared its vegetation community predictions. The predictions are based on the IPCC A2 emissions scenario, the GCMs: NCAR-CCSM3.0, GFDL-CM2.1, and NCAR-CSM1.2 (Table VM-2). Their predictions are based on eight bioclimatic variables, three soil variables, and two topographic variables (Table VM-3). Current climate data were based on interpolated weather station data and downscaled to an 800m grid by the PRISM group (Daly et al. 1994). Future climate data were downscaled by applying the delta values (difference for temperature; ratio for precipitation) between current and future regional climate model values to the 800m monthly PRISM grids.

Table VM-3: Summary of variables used for the climate envelope model (Stralberg et al. 2009)	
Variable type	Definition
Climatic	Annual mean temperature (°C)
Climatic	Mean diurnal range (°C) (mean of monthly temperature range)
Climatic	Isothermality ((Bio_2/Bio_7 ²) * 100)
Climatic	Temperature seasonality (standard deviation *100)
Climatic	Mean temperature of warmest quarter (°C)
Climatic	Annual precipitation (mm * 10)
Climatic	Precipitation seasonality (coefficient of variation)
Climatic	Precipitation of driest quarter (mm * 10)
Solar	Average yearly solar radiation (watt-hours / m ²)
Slope	Maximum rate of change in elevation (degrees)
Soil	Soil acidity/alkalinity (pH)
Soil	Soil permeability (inches of H ₂ O held / inch of soil)
Soil	Soil available water capacity (inches of H ₂ O / hour)

Maps of climate predictions may be viewed on the PRBO website:
www.prbo.org/climatemaps

Current vegetation was based on the California GAP Analysis project (Table VM-4) (Davis et al. 1998). The dominant vegetation community in each 800m grid cell was used to describe the cell, although a variety of vegetation communities may have been present to a lesser degree. This resolution is one of the sources of uncertainty in this project.

Table VM-4: Vegetation classes modeled. Greyed classes do not currently exist in the park
Annual Grassland, Perennial Grassland
Blue Oak Woodland, Blue Oak-Foothill Pine
Desert Scrub, Alkali Desert Scrub, Desert Succulent Shrub
Eastside Pine, Juniper, Pinyon-Juniper
Mixed Chaparral, Chamise-Redshank Chaparral, Coastal Scrub
Montane Hardwood-Conifer, Douglas Fir
Montane Hardwood, Coastal Oak Woodland
Ponderosa Pine, Klamath Mixed Conifer
Redwood, Closed-Cone Pine Cypress
Red Fir, Lodgepole Pine, Subalpine Conifer
Sagebrush, Bitterbrush, Low Sage
Sierran Mixed Conifer, White Fir, Jeffrey Pine

Another source of uncertainty in this mapping project is that the vegetation community management units used by Point Reyes National Seashore do not always align directly with the nomenclature used by PRBO. Table VM-5 shows all the community types from the PRBO mapping project that are located within the park in the left-hand column. The table illustrates where the community types do and do not align with the vegetation community types PORE uses for management purposes (Table VM-5). For example, the park's "Douglas fir/Mixed evergreen

forest” could fall into either the “Montane hardwood, coastal oak woodland” class or into the “Redwood, closed-cone pine, cypress” class. While mis-matches like these are not a large problem, they may make the results a bit more difficult to interpret. The results of this predictive vegetation mapping project are shown at the end of this section (Figures VM-3, VM-4, VM-5 and VM-6).

Our point of contact for this predictive mapping exercise has been Dennis Jongsomjit, who can be reached at djongsomjit@prbo.org. The organization’s spatial ecologist, Sam Veloz may also be a helpful contact: sveloz@prbo.org.

Table VM-5	
Classification on PRBO maps	Classification on PORE maps
• Annual Grasslands, Perennial Grasslands	• Grasslands • Pasture
• Mixed Chaparral, Chamise-Redshank Chaparral, Coastal Scrub	• Northern coastal scrub • Maritime chaparral
• Montane Hardwood-Conifer, Douglas Fir	• Douglas fir/ coast redwood
• Montane Hardwood, Coastal Oak Woodland	• Bay oak hardwood
• Redwood, Closed-Cone Pine, Cypress	• Bishop pine • Douglas fir/ coast redwood

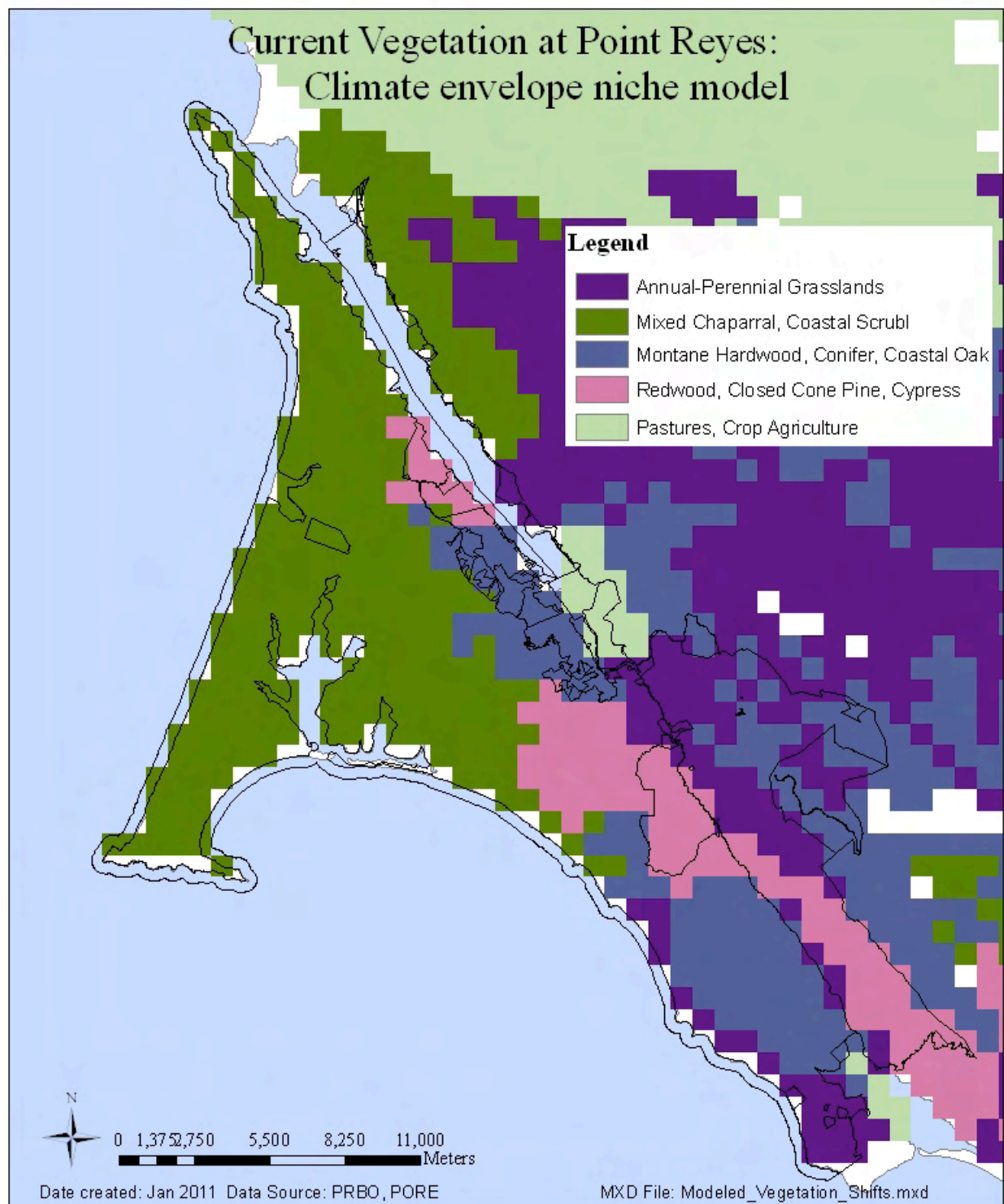


Figure VM-3

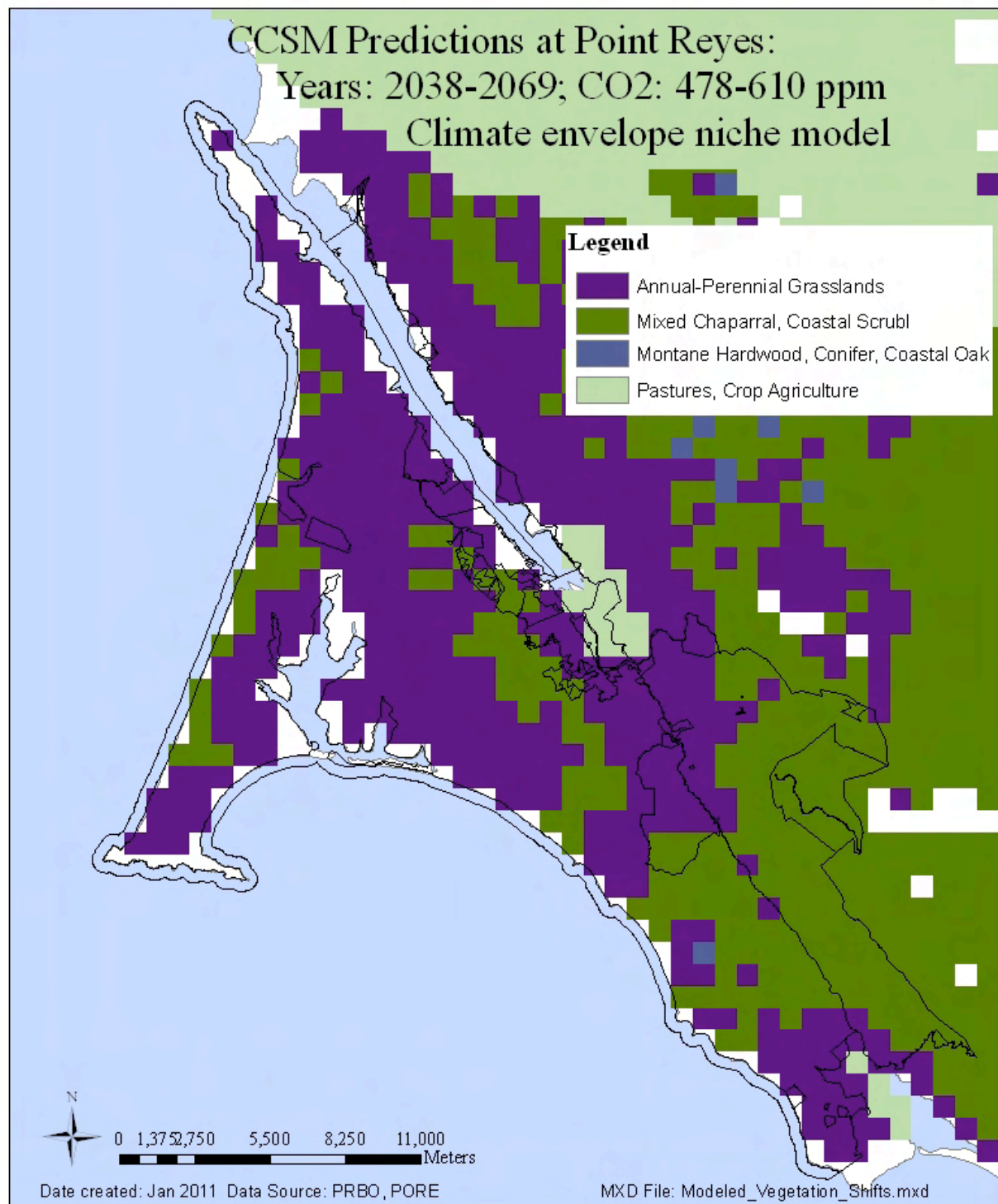


Figure VM-4

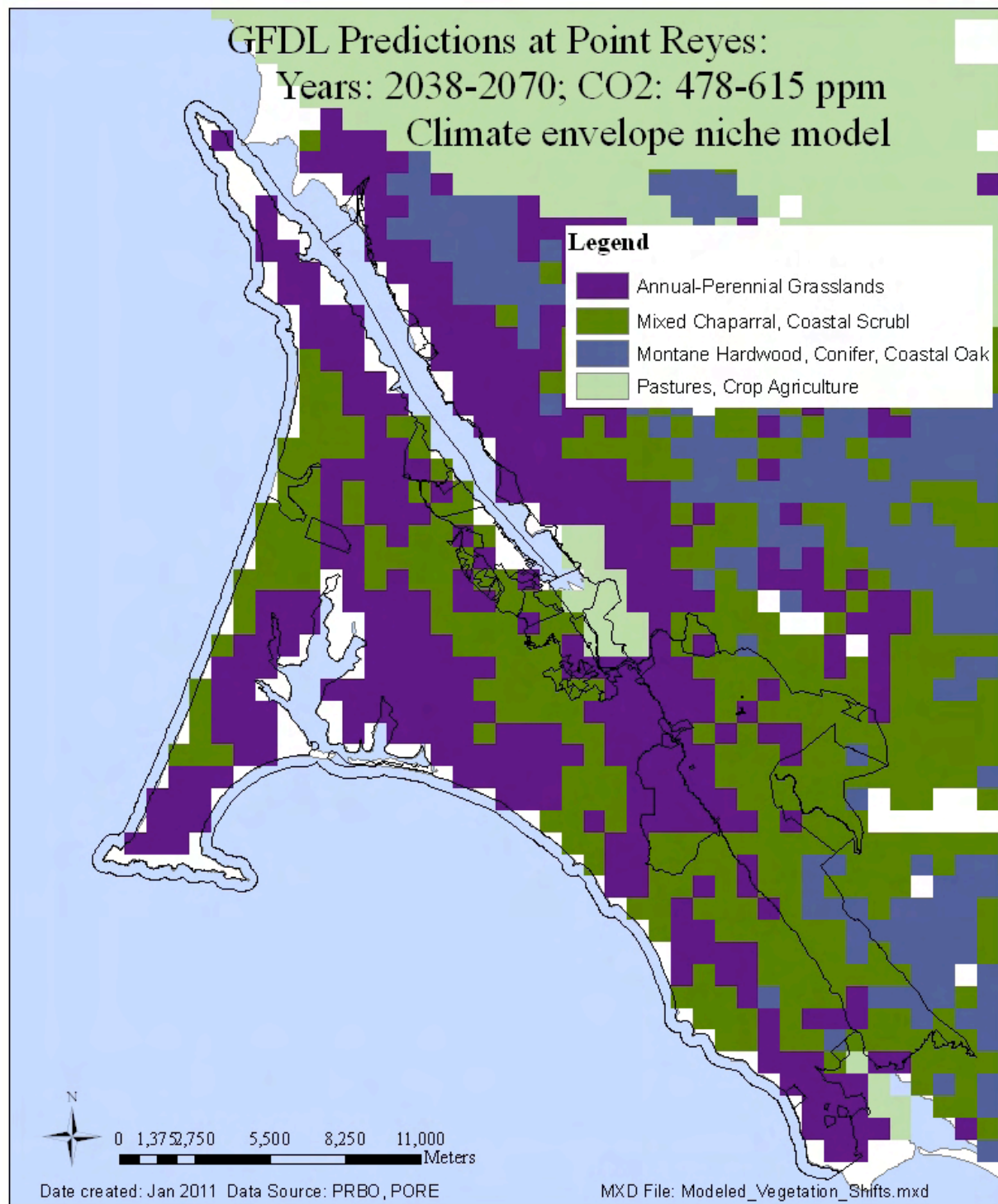


Figure VM-5

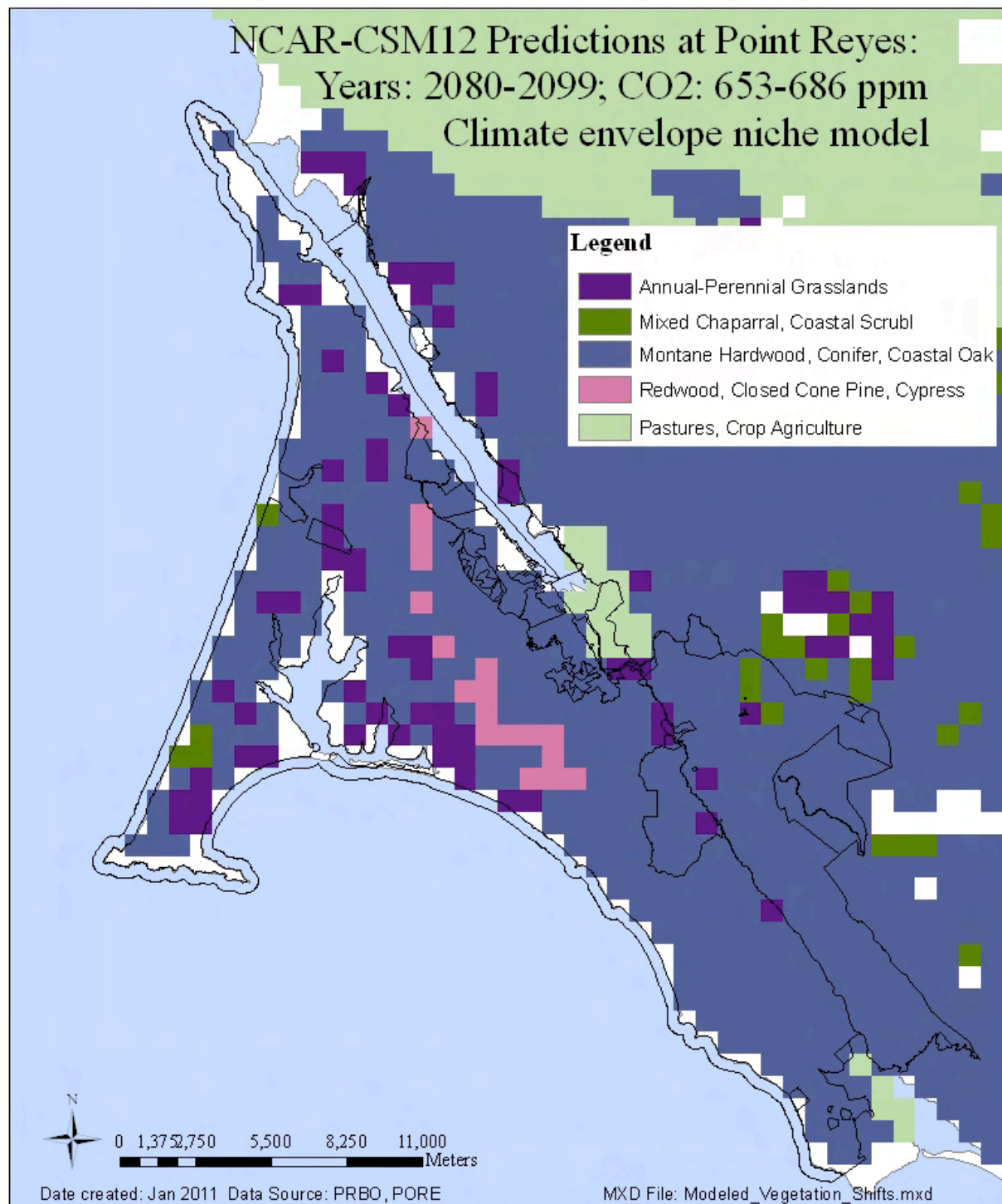


Figure VM-6

Dynamic vegetation models

In 1995 a team of researchers for the Forest Service in Corvallis, OR and Oregon State University published a paper on the results of their dynamic vegetation modeling project (Neilson 1995). The model was called the Mapped Atmosphere-Plant-Soil System (MAPSS), and could make predictions about vegetation communities on a global scale. The original model could make predictions based on a steady-state average climate and was built around a grid with 10km cell size. Since 1995, the team has been refining the model. It is now able to make predictions of vegetation community distributions based on IPCC emissions scenarios and GCMs. It will also include a better representation of disturbance regimes, such as fire, that are important in the competitive dynamics between woody and herbaceous species. Additionally, the team is attempting to run the model at an 800m cell size to make the model's outputs more helpful at a management scale.

Undoubtedly, like the outputs of any model of this type, the MAPSS team's newest output will have many uncertainties associated with it. However, it will be informative to compare its outputs with those of the PRBO climate envelope modeling project in order to highlight areas of consensus and disagreement. The MAPSS team may have results for Point Reyes National Seashore at an 800m grid resolution within the year.

Our point of contact for this predictive mapping exercise has been Bear Pitts.

Future points of contact will be:

Bear Pitts, Information Space Navigator, Oregon State University:

bear.pitts@oregonstate.edu

Office: 541-758-8805

and Jim Thorne, Research Scientist, U. C. Davis:

jhthorne@ucdavis.edu

Office: 530-752-4389

More information on the MAPSS project can be found at:

<http://www.fs.fed.us/pnw/mdr/mapss/index.shtml>

William Cornwell, post-doctoral scholar in Dr. David Ackerley's lab at University of California, Berkeley, is also working on a dynamic vegetation model (similar to the MAPSS models) to make predictions about vegetation community shifts. He is using climate data that has been further downscaled to a 60m grid. This method may provide better resolution of vegetation communities. Although there is an additional layer of uncertainty when climate models are downscaled, it could prove fruitful to compare the predictions of this model to those of PRBO's niche model and the MAPSS DVM.

Dr. Cornwell's model is up and running, however, the model outputs are so large that they cannot currently be compared with other model outputs in ArcGIS. He is hoping to fix this problem in the future. Dr. Cornwell may be contacted at wcornwell@gmail.com.

Predictive vegetation maps

The spatial predictions provided by PRBO's model may give some insight into which vegetation communities in the park are most vulnerable to climate change, and which specific climate factors could drive the trends. However, the maps presenting these spatial predictions cannot be taken as accurate pictures of what the vegetation communities will look like in the park in 2100 due to the uncertainty inherent in the models. These maps should be used to supplement rather than inform other sections of the report.

Within the sections of this report where results of each community type are explained, individual maps have been produced which explore the predictions made by PRBO. In displaying the maps for each community type we first show the current distribution of the community as given by PRBO, because these distributions do not always match up with the current vegetation map from Point Reyes National Seashore. We then show the three modeled predictions in one map to display the areas of consensus. In these maps white grid cells are cells where none of the three models predict that vegetation type, light cells are those where one of the three models predicts it, medium cells are those where two of the models predict it, and dark cells are those where all three models predict that vegetation type. The white and dark cells carry more certainty about the future absence or presence, respectively, of the vegetation type than the light and medium cells. Additionally, the information and files used to create each map have been included in supplementary digital files supplied to the park. Each map is labeled with a jpeg title that is an image of that particular map. Each map is further labeled with .mxd file names, pointing to the corresponding ArcGIS map. Further, each map is labeled with the sources of the data contained in the map, e.g. PRBO (see individual community sections).

It is recommended that park managers revisit this exercise when more information becomes available from other groups, other mapping methods, and more precise data. Comparisons of more models will allow managers to determine the areas and vegetation types that are very consistently or inconsistently predicted.

Evaluation of predictive vegetation mapping

Strengths

Predictive vegetation mapping is a quantitative mechanistic approach to understanding changes of vegetation communities due to climate change. The maps produced may give managers an idea of how vegetation may change in the future. Additionally, this approach allows for quantitative comparisons among various predictions (different emission scenarios, different global circulation models, different vegetation mapping methods such as climatic niche models or dynamic vegetation models). Identifying the areas of consensus and discrepancies among these models can indicate certainty levels and identify research needs.

There are many ways in which species distribution mapping may be used in conservation and ecology (Table VM-6) (Guisan and Thuiller 2005). Similar uses could be found for vegetation community distribution mapping.

Table VM-6: Some uses of species distribution modeling. Compiled by Guisan and Thuiller 2005
Quantifying the environmental niche of species
Testing biogeographical, ecological and evolutionary hypotheses
Assessing species invasion and proliferation
Assessing the impact of climate, land use and other environmental changes on species distributions
Suggesting unsurveyed sites of high potential occurrence for rare species
Supporting appropriate management plans for species recovery and mapping suitable sites for species reintroduction
Supporting conservation planning and reserve selection
Modeling species assemblages (biodiversity, composition) from individual species predictions
Building bio- or ecogeographic regions
Improving the calculation of ecological distance between patches in landscape meta-population dynamic and gene flow models

Weaknesses

One major weakness of this approach is that there are many layers of uncertainty that can build on each other in the models. This can be particularly dangerous in mapping because a quantitative output is given as a visual graphic that does not, in and of itself, show these uncertainties. Below we first discuss weaknesses of the approach not related to uncertainty, and then discuss areas of uncertainty.

Weaknesses not related to uncertainty

When comparing models it is important to understand that the different types of biotic response models (e.g. climatic niche model vs. dynamic vegetation model) may use some of the same underlying assumptions and are therefore not entirely independent of each other.

Some of the predicted changes are not feasible in the time horizon of the model. For example, although the climatic niche of Douglas fir forests may shift northwestward in the next 50 years, it is not likely that forests of mature Douglas fir trees will be in the “new” location in 50 years while the trees in the “old” location all die and decompose, giving way to a different community. Vegetation changes, especially those involving long-lived organisms such as trees, are likely to happen more slowly than their climatic niche is predicted to shift. This can give misleading maps, where the predicted communities will likely not have had enough time to fully establish in the region where they are mapped.

In addition, these models predict shifts in entire vegetation communities. Many species make up each community and all associated species are not likely to move as one unit. This was discussed in more detail in the introduction to this report.

It can be difficult to compare models from different organizations because the community classifications do not always match up. The three different model outputs we were able to

compare for this report do not match perfectly in terms of the number of years out they project. This is due to the different global circulation models available to the modelers at PRBO, though it is the belief of Dennis Jongsomjit, GIS specialist at PRBO, that the discrepancies between the dates of these projections do not significantly affect the predicted vegetation shifts.

Uncertainty

First, we are not certain of the quantity of greenhouse gases that will be emitted in the future. We are also uncertain about how exactly those gases will affect the future climate. These large uncertainties are undoubtedly important, but a recent paper examining the strengths and weaknesses associated with species distribution modeling stated that “[u]ncertainty provided by the combination of different analyses, spatial resolutions, scales, modeling techniques and evaluation methods may be greater than the variability of using different climate change scenarios” (Guisan and Thuiller 2005). This emphasizes that we cannot forget about other sources of uncertainty. While models contain a high degree of uncertainty, they still allow for the study of potential impacts of climate change and are one of the few methods that allow this type of evaluation at a broad scale.

The scale at which these predictions are made can also add uncertainty. This is particularly important at Point Reyes National Seashore because microclimates are so important to many of the organisms.

There are also several inherent sources of uncertainty in species distribution models (which may also apply to community distribution models). They assume that communities are at equilibrium (Guisan and Thuiller 2005), which is often not the case. They rely heavily on the concept of a community’s niche: that the fundamental niche is geographically restricted by environmental and biotic interactions into the realized niche. Communities could also be kept from filling their potential realized niche due to dispersal limitation. Likewise, they could be unsustainably dispersed beyond their fundamental niche in a source-sink situation, where a community exists in a location where the growth rate is less than one (Guisan and Thuiller 2005).

Community distribution models may not successfully make predictions in situations where communities are restricted by physical conditions on one edge of their range and competition on another edge of their range (Guisan and Thuiller 2005). This may be of particular importance in making predictions at Point Reyes National Seashore. For example, salt spray restricts the range of grasslands, which would otherwise presumably encroach on the range of coastal dune vegetation. On the other hand, a model including a factor like, “fine scale distance to coast” might capture these sorts of factors.

Finally, there is uncertainty in the biological responses to local and regional climate changes. Beyond behavioral and physiological responses at the species level, there is potential for the following factors to play major roles in biological responses to climate change: rapid evolution, changes in species interactions, ecological thresholds, interactions between climate change and other stressors, dispersal ability. Several of these species-level factors are addressed with the fourth method of this report using the NatureServe Climate Change Vulnerability Index.

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Method III: Predicted coastline changes mapping

Overview

The Pacific Institute (PI) and the California Climate Change Portal (CCCCP) have published reports, coastal maps, and GIS data on sea level change predictions. Using these resources, we have attempted to characterize potential impacts of sea level rise on the shorelines at Point Reyes. This approach has allowed us to visually demonstrate which communities are most at risk from sea level rise. We have also made use of quantifiable GIS data in order to calculate the acreage of each community type that is currently found within the erosion hazard zone, as identified by Pacific Institute (Appendix C).

The most recent study published by the CCCC, from 2009, includes sea level predictions through 2100. These projections estimate a mean higher high water increase of approximately 1.4 meters; increases may reach 45 centimeters by 2050 (Moser et al. 2009). Figure SL-1 provides a depiction of a 1.4 meter rise in sea level along the Point Reyes Headlands.

There are three primary contributing factors to sea level rise:

- (1) Ocean thermal expansion
- (2) Glacial melt, predominantly from Greenland and Antarctica
- (3) Changes in terrestrial water storage

Ocean thermal expansion occurs when the temperature of the oceans increases. As temperatures rise, the overall temperature of the oceans increases as well; in fact, due to the heat sinking nature of water, oceans are increasing in temperature more rapidly than the air (Willis et al. 2004). Thermal expansion is the increase in volume of ocean water that results from this increase in temperature. Glacial melt refers to the melting of glacial ice from large continental ice sheets, as opposed to sea ice. The melting of sea ice does not affect sea level, but the melting of freshwater ice sheets is expected to have a significant impact on sea level. We are also experiencing changes in terrestrial water storage; however, as certain human activities increase terrestrial run-off (such as clearing of land), other activities decrease it (e.g. dams and reservoirs). This essentially makes changes in terrestrial water storage negligible when calculating sea level rise (Church et al. 2001).

While the models currently used by California Climate Change Portal models do not include glacial melt in their sea level rise predictions, new sea level rise models include information on levels and rates of ice melt. These additions significantly raise predictions of sea level in the year 2100. New models predict increases upwards of three meters by 2100 (Dasgupta et al. 2009), while models used to predict shorelines in this report were based on predictions of a 1.4m rise in mean higher high water. A faster rate of increase and a higher sea level would change the

estimated amount of submerged coastline. It will be important to revisit this section of the vulnerability assessment as new GIS data for the California coastline become available.

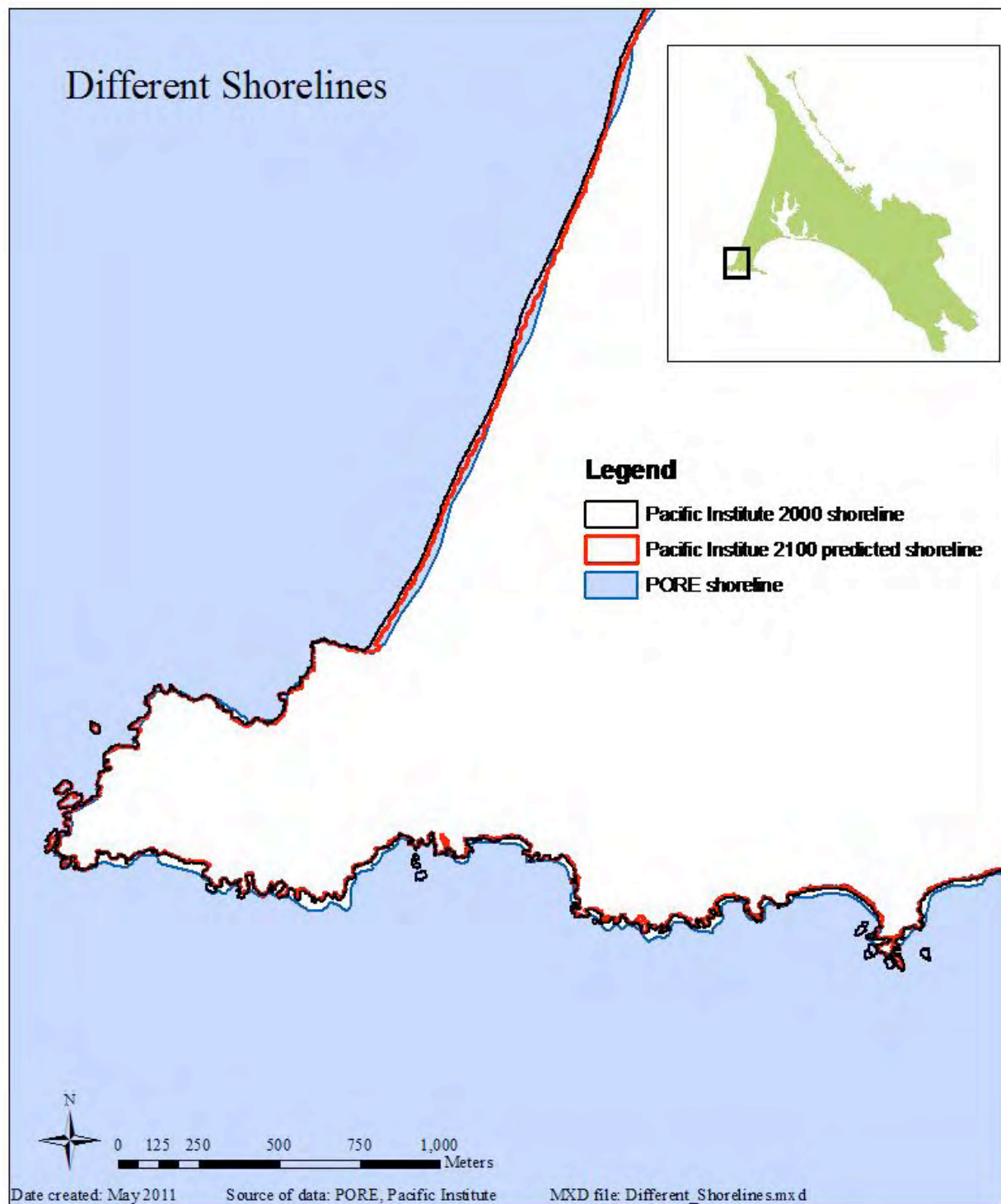


Figure SL-1

Predicted changes to coastline in this report

Point Reyes National Seashore is surrounded by water on three sides; the Pacific Ocean is located to the west and south, and Tomales Bay forms the eastern edge. Point Reyes National Seashore also contains estuaries, lagoons, coastal lakes, and other tidal habitats. Each of these can be expected to be affected by a rise of sea level, and the impacts associated with a changing ocean. Intertidal communities, coastal habitats, and marine ecosystems will be affected by the predicted increases in mean sea level, changes in high tide levels, and wave strength. It is expected that the extreme highs will last significantly longer than current extreme high sea level events. Such prolonged events could potentially damage intertidal habitat, specifically, and cause coastal erosion, more generally. Together, increased wave strength and mean higher high water (MHHW) levels could lead to considerable coastal damage (Cayan et al. 2008).

Habitats within Point Reyes National Seashore that may be affected by changes to the coastline include:

- Beaches and coastal dunes
- Coastal scrub
- Kelp beds
- Eelgrass beds
- Rocky intertidal communities
- Estuarine communities
- Grasslands
- Bay-oak hardwood forests

As well as:

- Seabird nesting sites
- Pinniped haul out sites

Primary impacts to Point Reyes National Seashore communities include changes in sea level for all subtidal, intertidal, and supertidal communities. Changes in shoreline due to erosion can also be expected, and may potentially lead to inward migration of coastal communities where such movement is supported by biotic and abiotic factors. There may be a general increase in salt spray due to changes in wave height and wave strength, which will have some effect on soil salinity. CCCP models also predict an elevated erosion hazard, particularly for dunes, grasslands, and other coastal communities (Figure SL-2).

Projections of sea level rise impacts and erosion hazards have been provided in the individual community vulnerability assessments, as appropriate for the community type. Data for the maps was collected from Point Reyes National Seashore and CCCP. Specifically, figures reflect vegetation types as provided by Point Reyes in available GIS data, and the shoreline of the park as identified by Point Reyes in the Shapefile, "pore_admin." Sea level rise and erosion hazard data was collected from the CCCP website (links provided in References). The GIS data for the sea level for year 2000 was provided by PI; MHHW levels are interpolated from data provided by NOAA tide stations located along the California coast. The sea level for year 2100 was also provided by PI, and was created by adding 140 centimeters to the mhhw_2000 raster file.

The GIS erosion data used was also from PI. The dataset used represents both bluff and dune erosion hazards, given a 1.4m rise in sea level. The data was developed by Philip Williams & Associates for publication by PI (Philip Williams 2009).



Figure SL-2

Evaluation of predicted changes to coastline

Strengths

The goal of this report is to incorporate outputs from a variety of data types in order to provide a clear and thorough overview of community vulnerabilities within the park, given current knowledge. This method provides both visual and quantifiable data on which communities will most likely be impacted by a rise in sea level, and factors associated with this rise. Despite the fact that the 1.4m sea level rise indicated is based on a model that is not currently incorporating sea level rise, there is value to the depictions of sea level rise provided throughout the report. Areas that are likely to be threatened by sea level or erosion, given a 1.4m rise, will almost certainly be impacted by a rise greater than 1.4m. In addition, surrounding areas will likely be vulnerable, and therefore the figures provided can be used to highlight regions of potential concern, rather than specific location.

The figures contained within the community sections also make it obvious that some community types are clearly at a higher risk from changes in ocean condition than others, and will be worth monitoring over the coming century. Some of the more vulnerable communities include wetlands and dunes, both of which are highly susceptible to the impacts of erosion. Figures highlighting erosion hazard areas can be found within these two sections.

Weaknesses

Obviously, our results are highly dependent on our data sources, and there were notable discrepancies between the shorelines identified by Point Reyes National Seashore and PI, as can be seen in figure SL-3. The PORE shoreline file, depicted below in dusky pink, differs from the 2000 shoreline data provided by PI. The areas shown in brick red are those currently defined as being underwater in the Pacific Institute's mean higher high water 2000 file. These discrepancies make it difficult to determine if changes in the shoreline between 2000 and 2100 will result in inundation of certain coastal areas. It is also uncertain which shoreline depiction, PORE shoreline or MHHW 2000, is more accurate.

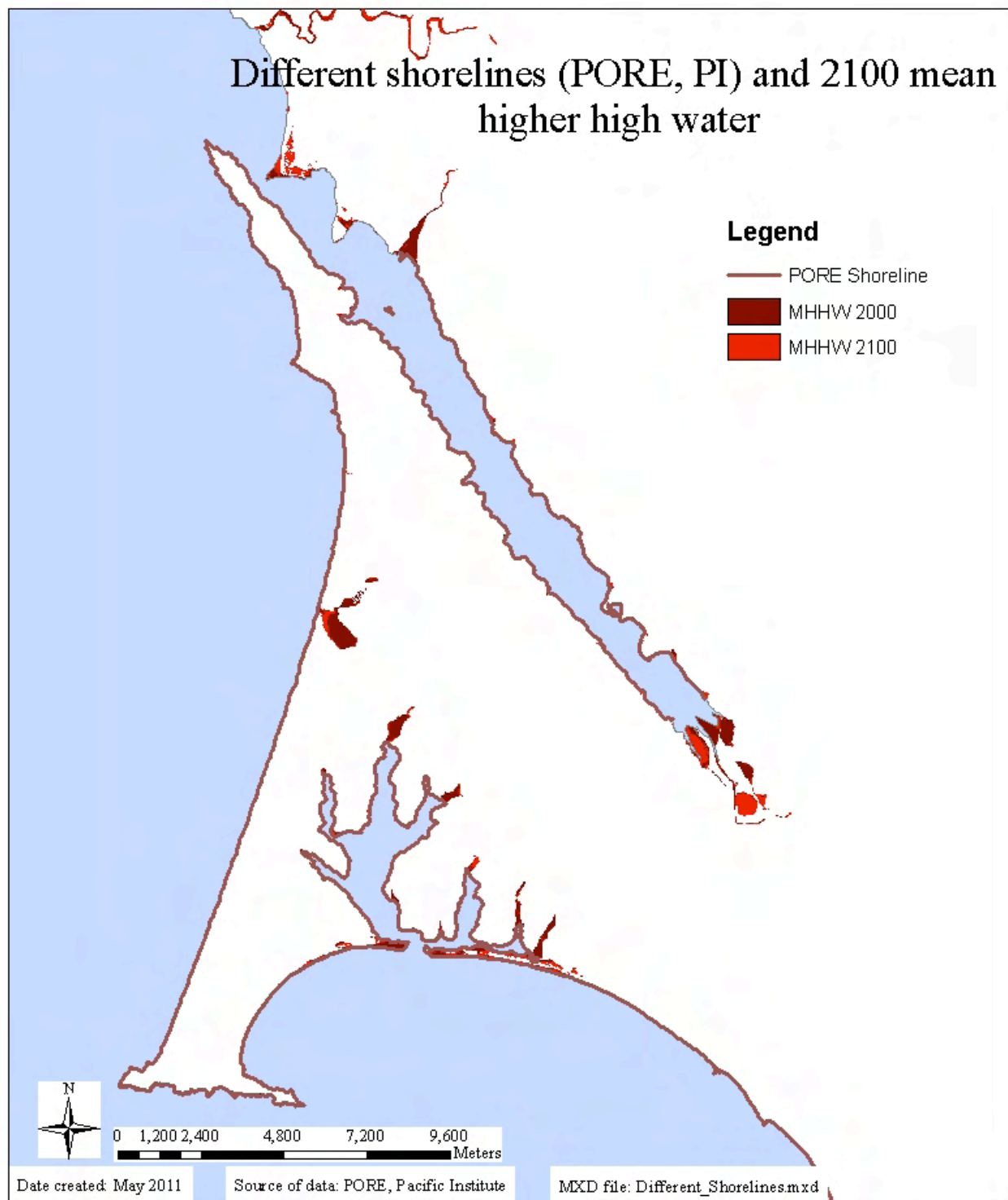


Figure SL-3

As mentioned, there are areas of the park that are shown to be underwater in PI MHHW 2000, but are not located underwater according to Point Reyes National Seashore data. Within this report, these areas will be shown as underwater, as per the PI data files. It is highly probable that

some of these are areas, such as salt marshes, that are often below MHHW levels but are not actually located below current mean sea level. Obviously, differences between the shorelines make clear predictions difficult. When better GIS data is available, our results can easily be updated. In the meantime, the projections in this report should provide an idea of park regions that may be impacted by sea level rise during the next century.

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Spatial coastline prediction sources:

- Pacific Institute: <http://www.pacinst.org>
- PI Sea Level Rise: http://www.pacinst.org/reports/sea_level_rise/index.htm
- PI Sea Level Rise Maps:
http://www.pacinst.org/reports/sea_level_rise/hazmaps.html
http://www.pacinst.org/reports/sea_level_rise/gmap.html
- PI Wetland Migration viability map:
http://www.pacinst.org/reports/sea_level_rise/PDF/Fig28_Wetland_Migration_SF.pdf
- California Climate Change Portal: <http://www.climatechange.ca.gov/>

Method IV: Species-level assessment using NatureServe's Climate Change Vulnerability Index

Overview

In this report we used NatureServe's Climate Change Vulnerability Index (CCVI) to assess species-level vulnerability to climate change in the park. The CCVI is a species-based tool designed to compare the relative vulnerabilities of individual species to climate change. It is designed to be used in conjunction with the general NatureServe conservation status and does not include factors which are already included in the general status such as global range reduction and population size.

The tool is an Excel-based spreadsheet that is free to download along with a user guide from <http://www.natureserve.org/prodServices/climatechange/ccvi.jsp>. In the tool the user enters information on predicted climate change in the area of interest as well as species information. As with any modeling, the results are only as accurate as the inputs, however, this tool can deal with uncertainty in the inputs. If there is uncertainty in the climate predictions the user can run the tool with the different possible predictions and examine the differences in results. If there is uncertainty in species characteristics, the user can input several values and the tool will run Monte-Carlo simulations with all possible values entered. The tool then gives a histogram of possible results given this uncertainty.

The climate information that is entered is the predicted temperature change and the predicted potential evapotranspiration for all parts of the species range in the area of study (Figure NS-1). Although there downscaled climate predictions for this area, for this assessment we used the Climate Wizard predictions (reasoning in section below). For Point Reyes National Seashore, the Climate Wizard predictions are not yet at a fine enough scale to divide the study area into more than one pixel.

Section A: Exposure to Local Climate Change (Calculate for species' range within assessment area)			
Temperature *		Hamon AET:PET Moisture Metric *	
Severity	Scope (percent of range)	Severity	Scope (percent of range)
>5.5° F (3.1° C) warmer		< -0.119	
5.1-5.5° F (2.8-3.1° C) warmer		-0.097 - -0.119	
4.5-5.0° F (2.5-2.7° C) warmer		-0.074 - -0.096	
3.9-4.4° F (2.2-2.4° C) warmer		-0.051 - -0.073	
< 3.9° F (2.2° C) warmer		-0.028 - -0.050	
Total:	0 (Must sum to 100)	Total:	0 (Must sum to 100)

Figure NS-1 Future climate information inputs in NatureServe tool

[illegible]

The tool creates a relative vulnerability score for each species. It does this in two ways. It presents the overall most likely vulnerability rating. It also presents a histogram of how likely each rating is given your data. These ratings are: extremely vulnerable, highly vulnerable, moderately vulnerable, not vulnerable/presumed stable, likely increasing, and insufficient evidence.

Species-level assessment using NatureServe's CCVI in this report

We received a list of species from park managers that were of management interest. These included threatened and endangered species, keystone and foundational species, invasive species, and species that are important for park visitors. We decided that we would run a few species through the tool to serve as a model for managers to run more species. One park manager, Natalie Gates has been trained in the tool and has written a report detailing her use of the tool. That report can serve as a more in-depth evaluation of the tool.

After working towards evaluating several species, we discovered that our unfamiliarity with the particular species of interest, the low response rate from experts, and our timeline made it difficult to evaluate many species. We concentrated on evaluating two species with which at least one member of our team was familiar and/or we got substantial expert response. The species we evaluated, using NatureServe's CCVI were the California red-legged frog-*Rana aurora*, and the American bullfrog – *Rana catesbeiana*. The full inputs used for these species can be found in Appendix D.

In conducting the evaluations we first thoroughly read the guidelines for the NatureServe tool. We then completed literature searches to determine which information was known for the species. We also identified local experts for each species and conducted phone or email interviews to confirm or gain knowledge. We used Climate Wizard to obtain climate predictions to use in the tool. Although there are more scaled-down climate predictions for this area, we chose to use Climate Wizard because it is recommended by NatureServe and used in many other studies that use the NatureServe tool (Glick et al. 2011). Therefore, by using these predictions we are better able to compare our results with other studies.

The following is a time estimate for conducting these evaluations.

Becoming familiar with the tool	3 hours
Obtaining climate information	1 hour
Literature searches	3 hours per species
Conversing with experts	1 hour per species
Putting information into the tool and checking it	2 hours per species
Interpreting results/identifying research needs and main vulnerabilities	2 hours per species
Miscellaneous problems	1 hour per species

This gives a total of 4 hours of overall preparation and 9 hours per species.

Evaluation of species-level assessment using NatureServe's CCVI

Strengths

This tool allows for a systematic comparison of species' vulnerability to climate change that can be compared among species of interest. This is particularly useful because managers often have to manage for individual species for various reasons. It can be relatively straight-forward and

objective if the user is familiar with the species and/or there is an abundance of information available about the species.

The tool can be used as a sensitivity test to identify research needs by identifying the main sources causing variation in results. In addition, looking at the factors which score highest in the vulnerability ratings can help managers identify which factors are causing their species to be vulnerable and work to address these factors.

Another strength of this tool is the option to enter several risk levels for each factor. This allows the user to express uncertainty in the information and determine how much the uncertainty affects the outcome.

It can also be used to highlight the concept of non-analog communities. In our other approaches, communities were treated as relatively cohesive groups of species that change together. This approach allows the user to determine when species in the same community may respond differently to climate change.

Weaknesses

One major limitation of this tool is that it does not currently handle marine or estuarine species. The tool uses a series of specific questions that are designed to address life histories of terrestrial and freshwater species, but do not address marine species. There are likely to be future modifications to the tool that allow it to handle marine species. This is particularly important for Point Reyes National Seashore because of the park's management concern for some marine species. The tool is also difficult to use for species that migrate in and out of the park such as waterbirds.

This tool may be difficult and time-consuming if the user is unfamiliar with the species they are evaluating. It may even give wildly inaccurate results if a species in question is little-studied or there is little information available. Although the tool is largely quantitative and specific, there is some degree of subjectivity and different users may get different vulnerabilities for the same species.

This approach also has spatial limitations. Although it allows for the input of the proportion of the range that will be affected in various ways by climate change, it does not include spatial arrangement of climate extremes, barriers, or microclimates. It is also difficult to take into consideration various boundaries like park limits. For example, the focal species may be a good disperser, but if there is no suitable habitat right outside of the park boundary, this species may have nowhere to or from which to disperse.

The tool does address loss of specific positive species interactions among species. However, affects of climate change on a species that interacts with the focal species are difficult to capture in the tool. For instance, if an invasive predator or competitor or disease might do better with climate change, it is difficult to include this in the calculations.

The outputs of the evaluated species will occur in the community sections with which the species are associated (freshwater wetlands, streams, and riparian areas). They will include a histogram

of the possible vulnerability scores as well as a discussion about what specific factors were most influential for the given vulnerability score.

Reference

Glick, P, B.A. Stein, N.A. Edelson, eds. 2011. *Scanning the Conservation Horizon: A guide to climate change vulnerability assessment*. National Wildlife Federation, Washington, D.C.

Community Climate Change Vulnerability Assessments

Freshwater wetlands, streams, and riparian areas

Introduction

Freshwater wetlands and streams are areas where surface water is present for at least part of the year. They are found throughout the world, but species composition varies on regional and local scales. In this region, many of these areas dry in the summers. Several of the organisms that exist in freshwater ecosystems are adapted to them and cannot survive elsewhere.

Riparian habitats are areas near flowing water. These areas are considered an especially important refuge habitat due to their relative ecological resilience, their ability to decrease stream temperatures through shading, and because they can act as wildlife corridors and buffers between and among other habitats. They are also important in providing organic material to streams that provide the base of many aquatic and terrestrial food webs. The park has a network of streams that flow through a wide variety of habitats in addition to riparian.

In the park, these habitats are especially important for California red-legged frogs (*Rana draytonii*), which are federally listed as threatened. This species breeds in freshwater wetlands and uses cool riparian areas to escape the summer heat and dryness. Coho salmon and steelhead trout breed in streams in the park. The population of Coho salmon in that occurs the park is federally listed as endangered and the population of steelhead trout is federally listed as threatened. In addition, the federally endangered California freshwater shrimp is found in streams in the park. The park also contains the federally endangered California freshwater shrimp (*Syncaris pacifica*).

Wetlands, streams, and riparian areas can be particularly vulnerable to climate change because they are heavily influenced by the amount and timing of water inputs, outflows, and evapotranspiration (Erwin 2009). These changes may greatly impact the amount of water in wetlands and streams throughout and among years as well as the sediment, nutrient, and pathogen inputs into the systems (Hartig et al. 1997).

The wetlands, streams, and riparian areas in Point Reyes National Seashore are likely less vulnerable to climate change than most of the freshwater systems in the region because they are less impacted by humans through damming, draining, and use for agriculture and urban areas. The current distribution of these habitats in the park is shown in Figure FW-1. As a note, herbaceous wetlands in Figure FW-1 are not necessarily freshwater as this community type is combined with saltwater marshes in the map.

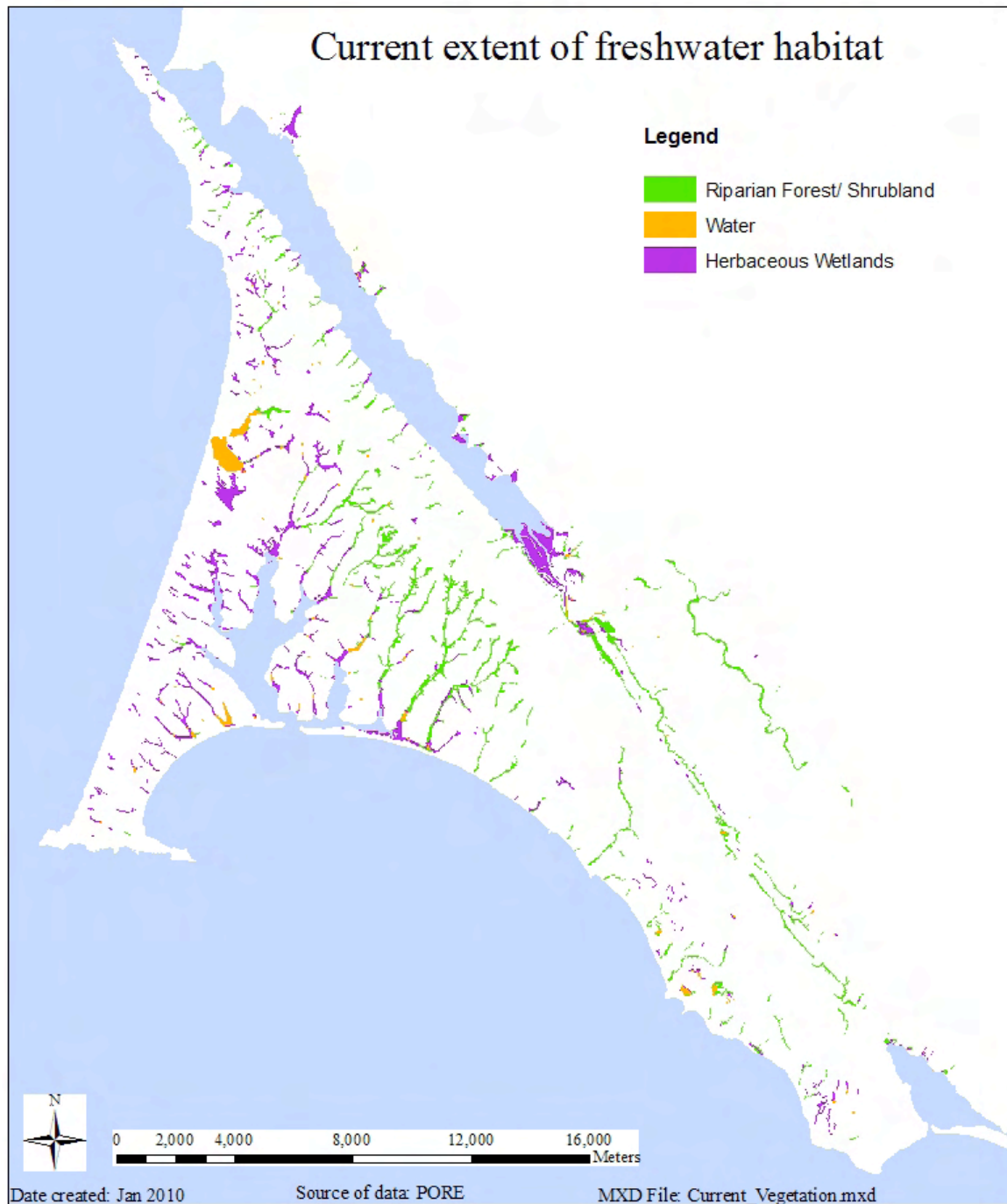


Figure FW-1

I. Expert Judgment

Contributing experts:

Lorraine Parsons, Point Reyes National Seashore
Sarah Allen, Point Reyes National Seashore
Gary Fellers, United States Geological Survey
Thomas Gardali, PRBO Conservation Science

Possible effects of a change in climate

Change in amount or timing of precipitation

A change in the amount or timing of precipitation could alter the hydroperiod of wetlands and streams in the park causing them to hold water for a longer or shorter period of time. This can impact organisms that are adapted to current hydroperiods. For instance, increased drought could cause a reduction in the current species of vegetation in the riparian areas. Predictive climate change models in other regions have shown that climate change will likely have dramatic effects on wetland vegetation composition over the next century (Poiani and Johnson 1993). A decreased hydroperiod of streams may lead to a reduction in their suitability as summer habitat for red-legged frogs or as breeding habitat for Coho salmon and steelhead trout. A shortened freshwater wetland hydroperiod could cause reduced suitability as California red-legged frog breeding sites.

California red-legged frogs generally spend most of the year near some water body (either a breeding pond or a non-breeding riparian site). Although they commonly cross open grasslands for 100-200m, longer movements in the park are generally along riparian corridors (Fellers and Kleeman 2007). Decreased hydroperiods of either breeding ponds or riparian areas could be detrimental to red-legged frogs. One study in Yellowstone National Park has shown that decreased winter precipitation (as well as increased summer temperatures) has caused declines in four amphibian species that were once common in the park (McMenamin et al. 2008). The study showed that in the 16 years prior to the study, the number of permanently dry ponds has increased four-fold, and the remaining ponds showed decreases in the abundance and diversity of amphibians.

Increased storm events

An increase in the intensity or frequency of storm events may increase short-term water inputs to freshwater systems. This could lead to an increase in runoff, which can increase pollution input, nutrient loads, turbidity, pathogen loads, and sedimentation. It may cause resident species as well as debris and refuse to be flushed out of streams at a higher rate. Individuals that have been washed out may find it difficult to return to suitable habitat. Washed out debris and refuse is detrimental to organisms which depend on this structure, including salmonids and red-legged frogs. Increased storms may cause streams to erode, channelize, and straighten. More frequent or more severe storms may also cause additional trees to fall on stream banks.

Sea level rise

An increase in sea level may increase salinity in marshes or streams. It may also cause some marshes and streams that were not previously affected by tides to become tidally influenced.

This may have negative impacts on organisms that are adapted to lower salinities or non-tidal waters such as the California freshwater shrimp, the tidewater goby, and the California red-legged frog.

Increase in temperature

Increased average or extreme temperatures could lead to reduced hydroperiods for wetlands and streams by causing them to fill later or dry sooner. It could also cause bodies of water to be shallower. These changes could impact all of the organisms associated with these habitats. Organisms of particular concern are salmonids, California red-legged frogs, and California freshwater shrimp. These are species of conservation concern and they all need sufficient depth and hydroperiod to breed and develop. Coho salmon and steelhead trout are currently near their southern range limits, and increased temperature may drive them north, out of Point Reyes National Seashore entirely. One study in Yellowstone National Park has shown that increased summer temperatures (as well as decreased winter precipitation) has caused declines in four amphibian species that were once common in the park (McMenamin et al. 2008).

Invasive American bullfrogs (*Lithobates catesbeianus*) do better in warmer temperatures, and therefore would benefit from increased temperatures. These frogs consume and compete with native species as well as carry diseases. Species of invasive crayfish found close outside the park may also do better with increased temperatures and become a problem in the park.

Increased temperatures may also increase the frequency or severity of fires, which could impact freshwater habitats by burning the surrounding vegetation. If fires are too frequent or severe, it may be difficult for freshwater vegetation to reestablish. Fires can also increase erosion by destroying the plants that hold the water and soil in place. This can increase sediment, nutrient, and pathogen inputs into freshwater habitats.

The hydrology of wetlands can be affected by the extent and duration of sediment freezing (Kont et al. 2007). Increased temperature may lead to decreased sediment freezing which may impact wetland hydrology.

Riparian vegetation has potential to mitigate the effects of increased temperatures on streams. As a rule of thumb, a 10% increase in shade for riparian and wetland areas is required to mitigate the temperature impacts of every 1°C rise in temperature (Davies 2010).

Changes in wind

Changes in wind patterns and speeds may affect evapotranspiration rates of freshwater habitats, altering hydroperiods and affecting communities as in previous sections.

Changes in fog

Fog prevents desiccation in dispersing California red-legged frogs. Reduced summer fog could be detrimental for this species by making dispersal among breeding sites or to and from non-breeding sites more difficult (Fellers and Kleeman 2007).

Confounding Factors

Cattle grazing

The grazing of cattle in and near streams has a number of impacts on riparian habitat. Cattle decrease riparian vegetation through consumption and trampling. Decreased vegetation and trampling increases bank erosion, which in turn increases stream turbidity and sedimentation.

Invasive species

Bullfrogs consume, compete with, and carry diseases to native species, especially California red-legged frogs. Invasive crayfish have been found in Giacomini Wetlands and could invade streams in the park. Both of these invasive species may do better with warming temperatures.

Cape ivy is present in the park and takes over riparian zones and eliminates some of the species and strata diversity in these habitats, thereby reducing their value to wildlife.

Runoff

Water running off from roads and dairy farms causes sediments, pollutants, and nutrients to flow into freshwater systems that can be detrimental to the freshwater communities in a number of ways.

Dams and water diversion

Dammed and water-diverted streams (such as Lagunitas Creek) can cause negative impacts on downstream communities, depending on how much water is released downstream and when. Reduced water in a stream can cause it to be too shallow for some organisms. When a lot of water is released at once, this can flush out small invertebrates and plants and cause a reduction in the food base.

Upstream development

Development can cause increased erosion, turbidity, sedimentation, pollution, and nutrient loads in downstream communities that can be detrimental to the freshwater communities in a number of ways.

II. Predictive vegetation modeling

Freshwater habitats are dispersed throughout the Point Reyes National Seashore (Figure FW-1). The vegetation maps used does not distinguish between salt water and freshwater wetlands and open water, and therefore many of the areas shown in Figure FW-1 are really estuarine (e.g. Abbotts Lagoon) or salt marshes (e.g. Giacomini Wetlands). Freshwater habitats were not modeled in PRBO's climatic niche modeling. These habitats are generally more defined by the presence of water than by any specific climatic niche. There will very likely be freshwater wetlands, streams, and riparian areas in the park into the future, but the species composition may change as species with specific niches shift in location.

III. Predicted coastline changes mapping

Some of the areas that the park defines as riparian forest shrubland in the “fingers” of Drakes Estero and Estero de Limantour are shown as being below the mean higher high water of 2000, but that sea level rise between 2000 and 2100 will not affect that area much.

In general freshwater habitats are not at high risk from erosion by 2100 because they are not located in direct proximity to the ocean (Figures FW-2 and FW-3).

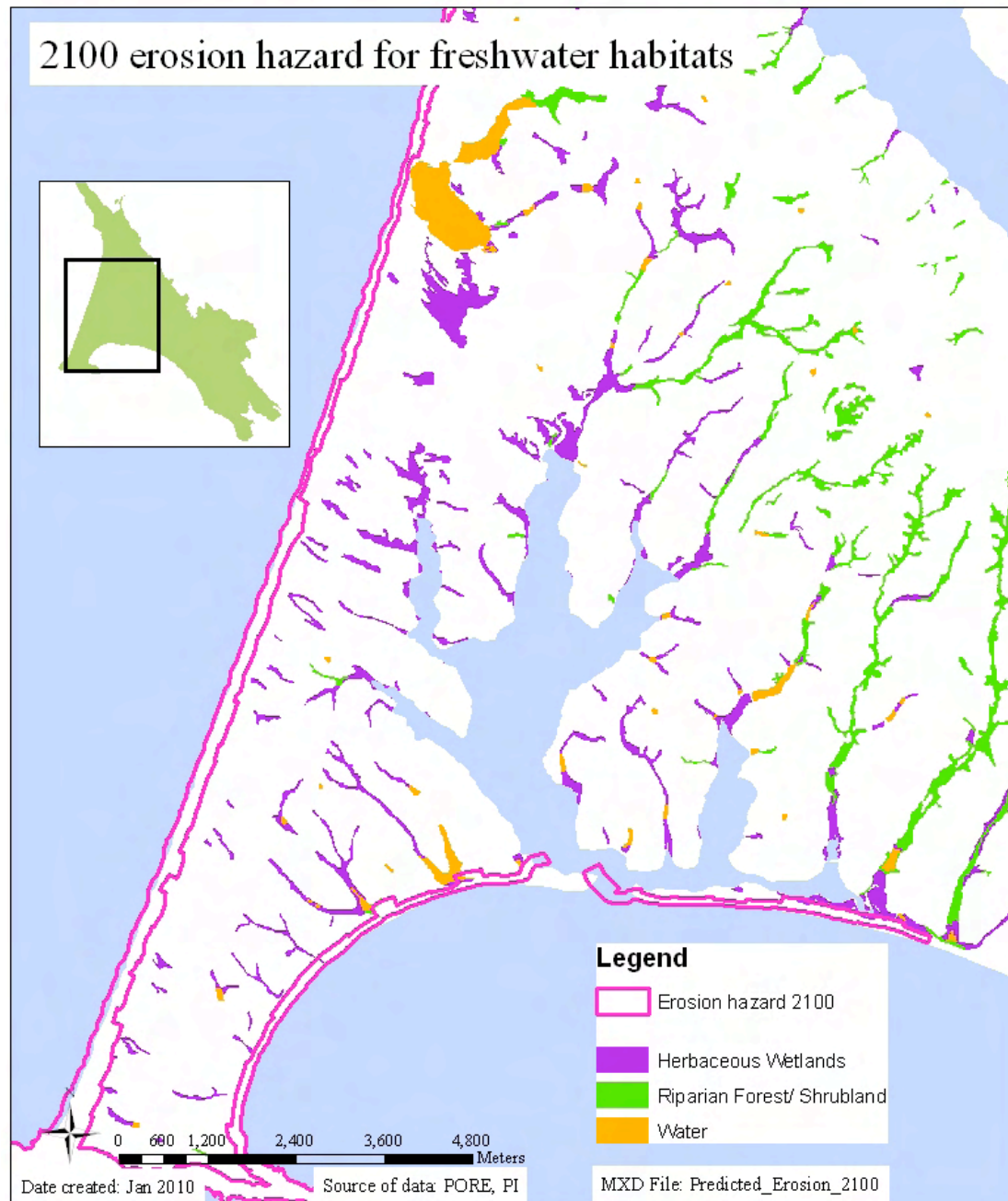


Figure FW-2

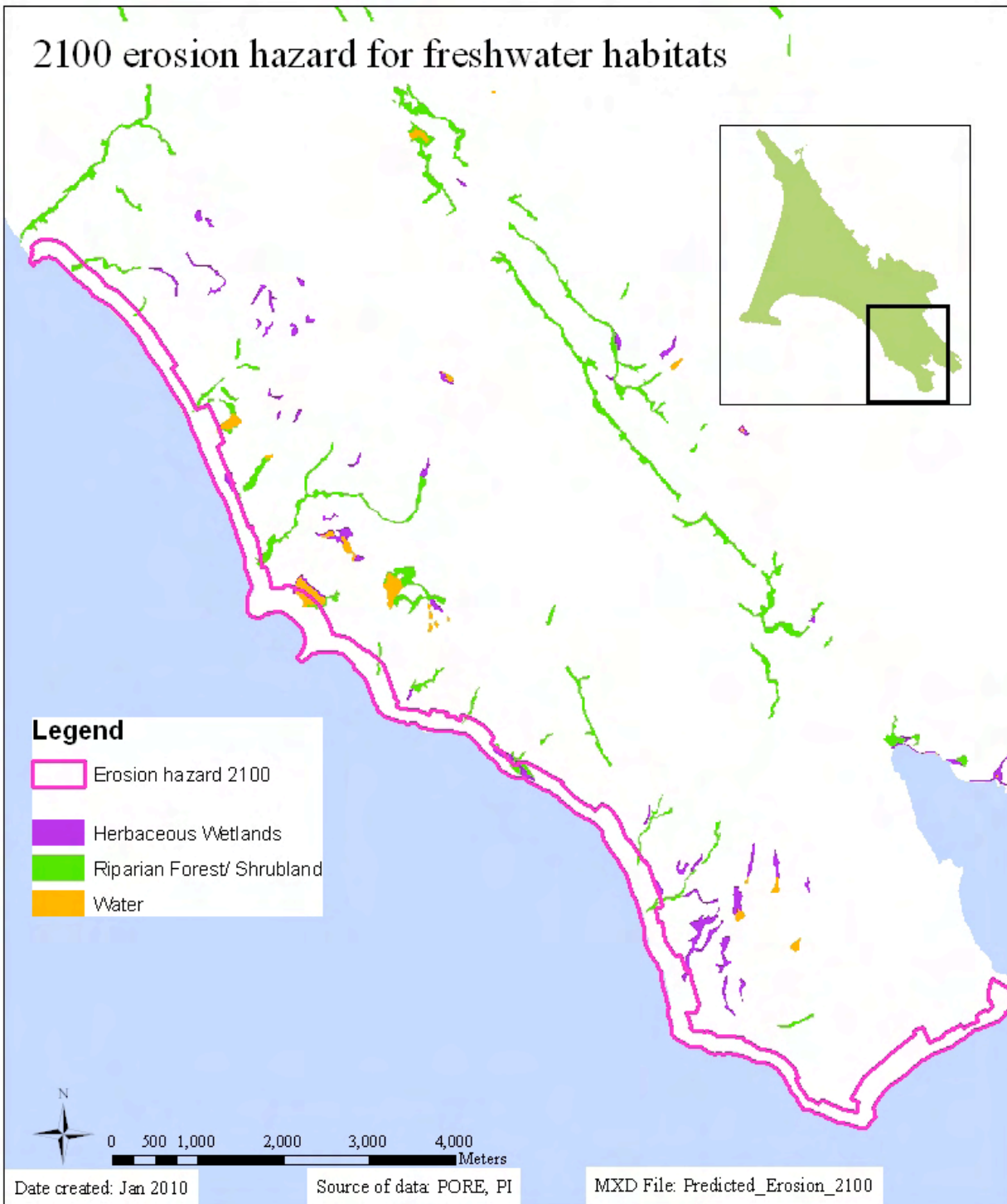


Figure FW-3

IV. Species-level vulnerability-NatureServe's CCVI tool

Two freshwater species were analyzed using NatureServe's Climate Change Vulnerability Index: the California red-legged frog-*Rana draytonii* and the American bullfrog-*Rana catesbeiana*. These two species were chosen because they are closely related species that utilize similar habitats but have important differences that are likely to cause them to respond differently to climate change. The red-legged frog is federally listed as threatened, although it is quite abundant in the park. The American bullfrog is native to the eastern United States and is considered an introduced invasive in the park.

Probabilities of vulnerability categories as assessed by the tool for each of these two species are shown in Figure FW-5. Red-legged frogs are predicted to be most likely moderately vulnerable to climate change, with a possibility of being not vulnerable/presumed stable. The software identified that the major source of climate vulnerability for this species was its association with water features that may warm or dry. A moderate source of vulnerability according to the software is the relative isolation of Point Reyes National Seashore from the mainland.

Bullfrogs are predicted to likely be not vulnerable/presumed stable, with a possibility of likely increasing. The software identified the factors that cause this species to have low vulnerability as the species dietary versatility, its high dispersal ability, and its thermal niche, which may be higher than current conditions.

The full input for these species can be found in Appendix D.

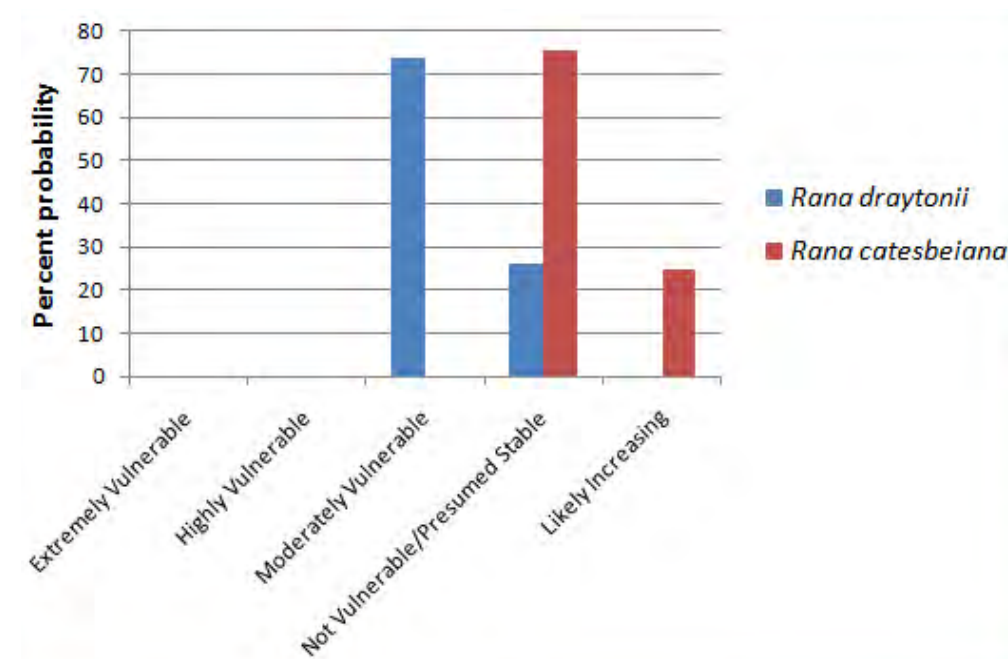


Figure FW-5 Vulnerability to climate change of two Ranid frog species as calculated by the NatureServe Climate Change Vulnerability Tool.

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Coastal scrub

Introduction

The coastal scrub habitat dominates much of Point Reyes National Seashore. It covers hillsides throughout the park, spreading from upper elevations to near the beach, covering more than 18,500 acres (Figure CS-1). Similar in many respects to maritime chaparral, coastal scrub is differentiated by its set of woody plants, and it occurs at lower elevations, on moister aspects with thicker soils and higher salt concentrations. There are few trees found within coastal scrub communities, although patches of Bishop pine, Douglas fir, bay laurel, and oaks may occur. Coyote bush (*Baccharis pilularis*) is a primary indicator species within northern aspect coastal scrub. This shrub is usually the first colonizer of grasslands, the result of natural succession (see Figure CS-2). Succession within the park may be limited by high-clay soils, summer drought, absence of fog, and frequent fire or herbivory. In addition to coyote bush, one is likely to find poison oak, bush lupine, ceanothus (“blue blossom”), and huckleberry in the more mature stands of coastal scrub at Point Reyes. Where the soil is drier and shallower, species composition tends towards those usually represented in coastal sagebrush scrub, with a primary indicator species of California sagebrush (*Artemisia californica*). Two sub-species of White-crowned sparrows (*Zonotrichia leucophrys nuttalli* and *Zonotrichia leucophrys pugetensis*) intergrade in coastal scrub habitats from Bodega Head through Humboldt County. In this region, plant communities grade from dominance by *Baccharis-Lupinus* scrub to coastal evergreen forests (Corbin and Wilkie 1988).

Coastal scrub at Point Reyes is likely not near any range limits (Ford and Hayes 2007), although there is often a distinct composition of coastal scrub on northern facing slopes and southern facing slopes. While certain species may be near their range limits, the communities as a whole have room within their climatic/geophysical envelope at Point Reyes to move and adapt to small or gradual climatic changes.

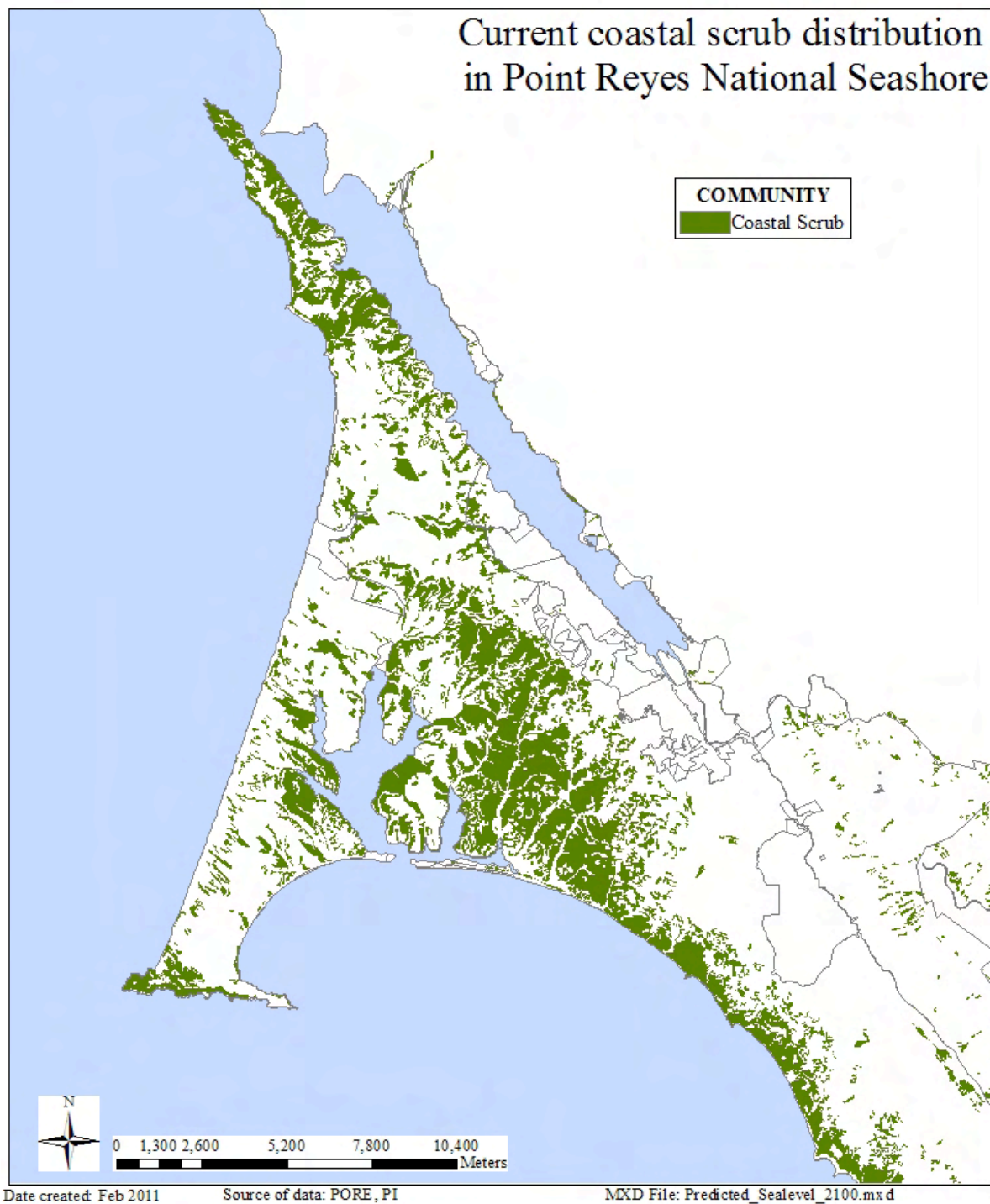


Figure CS-1

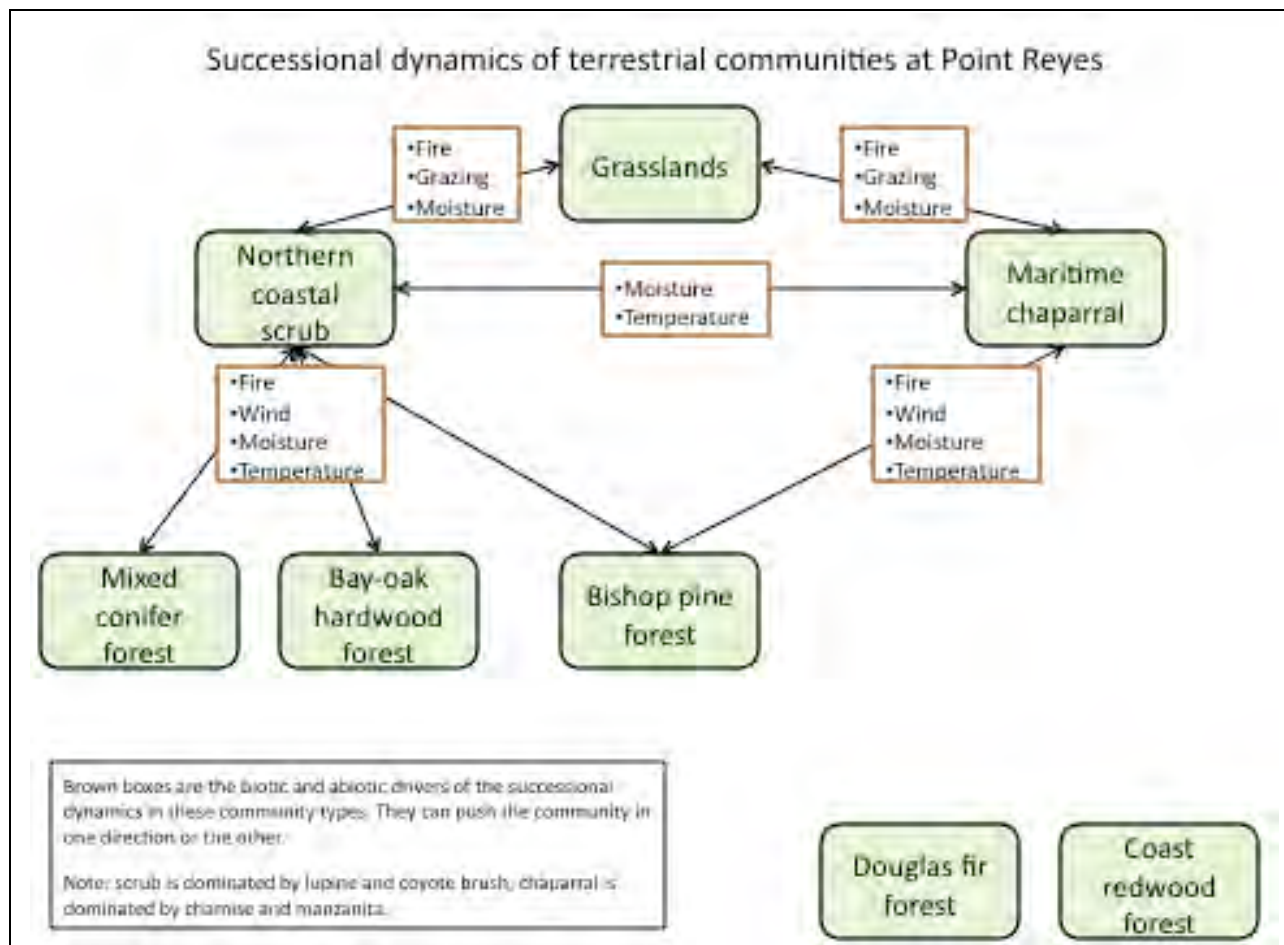


Figure CS-2

I. Expert judgment

Contributing experts

Lawrence D. Ford, University of California, Santa Cruz

Michael Barbour, University of California, Davis

Possible effects of a change in climate

More winter rain

Higher levels of rain in the winter could improve the recruitment and spread of native perennial grasses in the spaces between shrubs and in adjacent grasslands with appropriate soils and aspect, and may positively impact woody plant seedling establishment. Over time, the expansion and growth of woody plants will likely lead to increased natural succession events; native and non-native grasslands will convert to dominance by coastal scrub, which will in turn succeed to woodlands, eventually leading to increased oak regeneration.

More late spring/early summer rain

Warm season rain events may lead to more rapid succession; long-term, this would mean more expansion of shrubs into grasslands and conversion to coastal scrub. An increase in coastal scrub within the park will result in higher levels of potential fire fuel.

Decrease in rain

If rain decreases, grasslands may spread more slowly, but coastal scrub will also be less healthy and less robust. This could allow grasslands to gradually encroach on coastal scrub, or decrease the rate of succession from grassland to coastal scrub. Decreased precipitation may cause poorer soil conditions, leading to the increased occurrence of the shrub composition typical of south-facing slopes. Additionally, even climate scenarios proposing an increase in total precipitation provide for the possibility that rain events may be less common over all (more rain during a given event, but fewer events altogether), resulting in increased drought periods. Coastal scrub requires consistent precipitation, and is “especially vulnerable in dry climate scenarios” (Mendelsohn 2006).

Temperature changes

Although changes in precipitation will almost certainly impact coastal scrub, these habitats will be far less sensitive to a change in temperature. For this reason, temperature change or fluxes are not expected to have a significant impact on the growth of coastal scrub. Temperatures may affect animal species living within coastal scrub, however, such as white-crowned sparrows.

Confounding Factors

Biotic Interactions

The current species composition (coyote brush, bush monkeyflower, poison oak) is likely a result of the absence of frequent fire or grazing. An increase in fire frequency or introduction of grazing could result in a significant increase in relative cover of grassland patches.

The large number of invasive species in the region has resulted in a lessening of overall floral diversity, which is thought to have caused a similar decrease in faunal diversity. Many bird populations have been negatively affected by the propagation of non-native species; for example, White-crowned Sparrow and Allen's Hummingbird populations are both decreasing due to a loss of native plant biodiversity.

Fire

Increased drought periods, combined with hotter temperatures and an increase in human visitors, may lead to increased fire events. This is not necessarily a negative effect for coastal scrub, as long as the fire events do not become too frequent. Occasional periods of repeated fires, or managed fires, could prevent succession of coastal scrub into woodlands, and grasslands into coastal scrub. A small change in the occurrence of fires would not change the composition of existing coastal scrub stands. Most northern coastal scrub shrubs reproduce asexually by sending up new stems from below-ground parts that survived the fire, and thus would not be killed by fires unless these occurred at high-frequency or were accompanied by severe long-term drought.

Grazing

From a management perspective, grazing may have the largest impact on coastal scrublands. Effectively managed grazing can be utilized by park managers to prevent encroachment of coastal scrub into grasslands, and targeted seasonal grazing can be used in a limited manner to decrease the spread of invasives. Conversely, reduction of grazing in certain areas could prevent the spread of grasslands, allowing coastal scrub expansion.

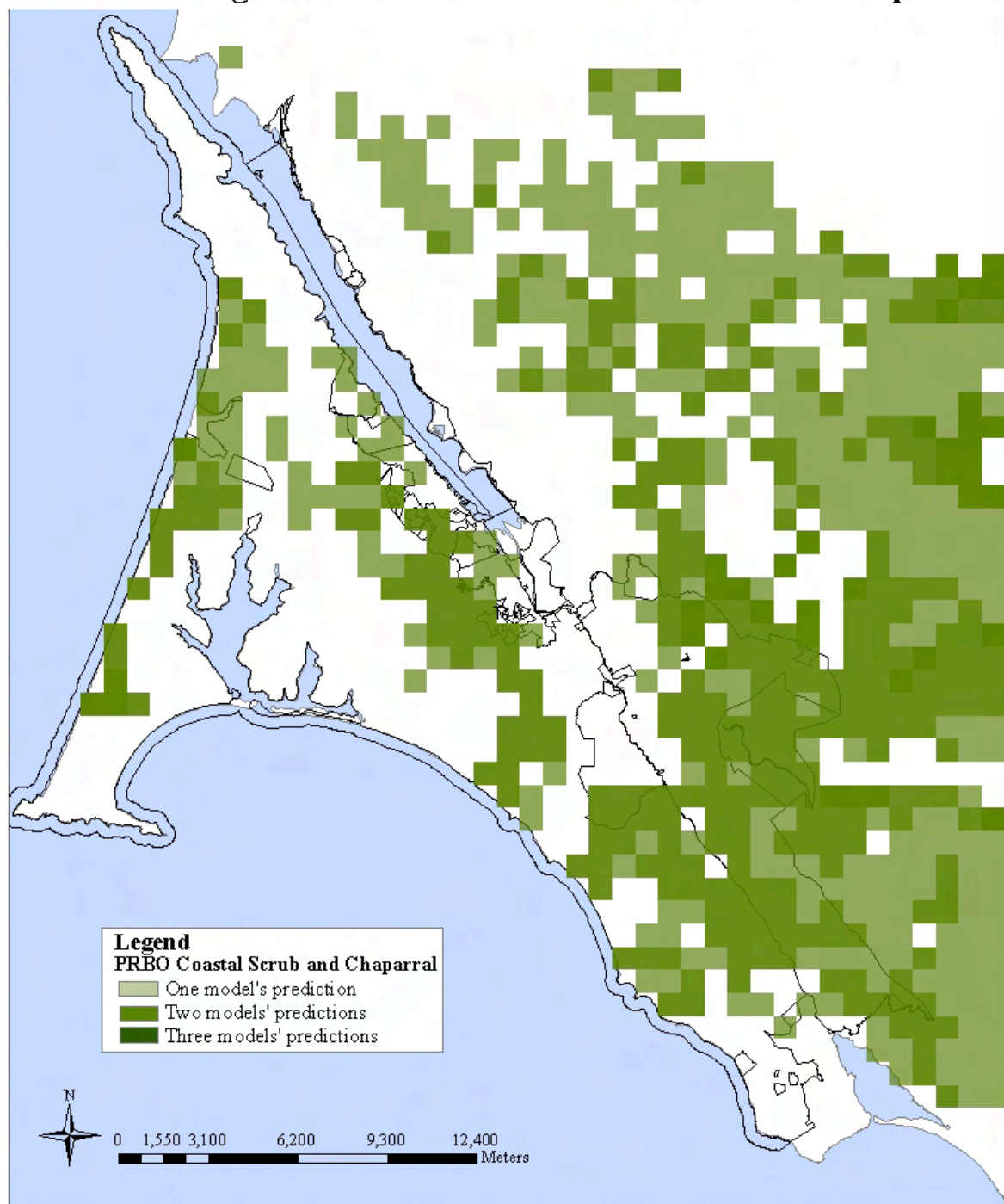
Encroachment

Anthropogenic encroachment could negatively impact coastal scrub communities in Point Reyes. Coastal species will be especially vulnerable to extinction or serious reduction in population size if they have no opportunity to migrate in the face of changing climates (Mendelsohn 2006). There is a possibility that roads, buildings, and other infrastructure could, if extensive enough, restrict migration of coastal communities within Point Reyes National Seashore.

II. Vegetation model predictions

In PRBO's climate envelop niche models, maritime chaparral and northern coastal scrub are mapped together (NPS and USGS 2004). This makes it difficult to tell which community type is expected to persist into the future, and where. Although all three predictive models indicate less coastal scrub and chaparral in the future than exists in the park today, it is highly likely that areas of coastal scrub will remain within park boundaries (Figure CS-4).

Predicted Vegetation Shift - Coastal Scrub and Chaparral



Date created: 06 Feb 2011

Source of data: PRBO, PORE

MXD File: Predicted_Vegetation_Shifts

Figure CS-4

Three global circulation models (GCMs) were used by PRBO to predict future vegetation distributions: NCAR-CSM1.2, NCAR-CCSM 3.0, and GFDL-CM 2.1. The associated timeframes and atmospheric CO² predicted by these models is provided in Table CS-1. The reason for the differences in timeframes for these climate models is that these GCM data are what were available to PRBO modelers. PRBO modelers do not believe that the discrepancy in timeframe is a major concern, because of the predictions models are making.

Climate Model	Years of prediction	Atmospheric CO ₂
NCAR-CSM1.2	2080-2099	653-686 ppm
NCAR-CCSM3.0	2038-2069	478-610 ppm
GFDL- CM2.1	2038-2070	478-615 ppm

Table CS-1

III. Predicted coastline changes mapping

Although coastal scrub is a maritime community, it is typically located at a distance far enough removed from the coast so as to not be immediately impacted by predicted changes in sea level. Figures CS-5 and CS-6 depict areas of coastal scrub, shown in dark green, which may be impacted by a rise in sea level. Both of these areas are fairly small. However, large regions of coastal scrub are found just beyond the predicted rise in sea level, which means that an increase greater than 1.4m will almost certainly impact these areas (Figure CS-7). In addition, many of the communities located between the coastline and coastal scrub will be affected, and it is possible that a rising sea level will cause an inland migration of these communities, which could potentially affect coastal scrub. In addition, oceanic changes could result in changes in soil salinity along the coast as MHHW levels increase, and erosion is a potential threat in many coastal areas (Figures CS-8 and CS-9). With a 1.4m increase in sea level, erosion is a risk for 2,250 acres. If sea level does indeed rise higher than 1.4m, that number is certain to increase.

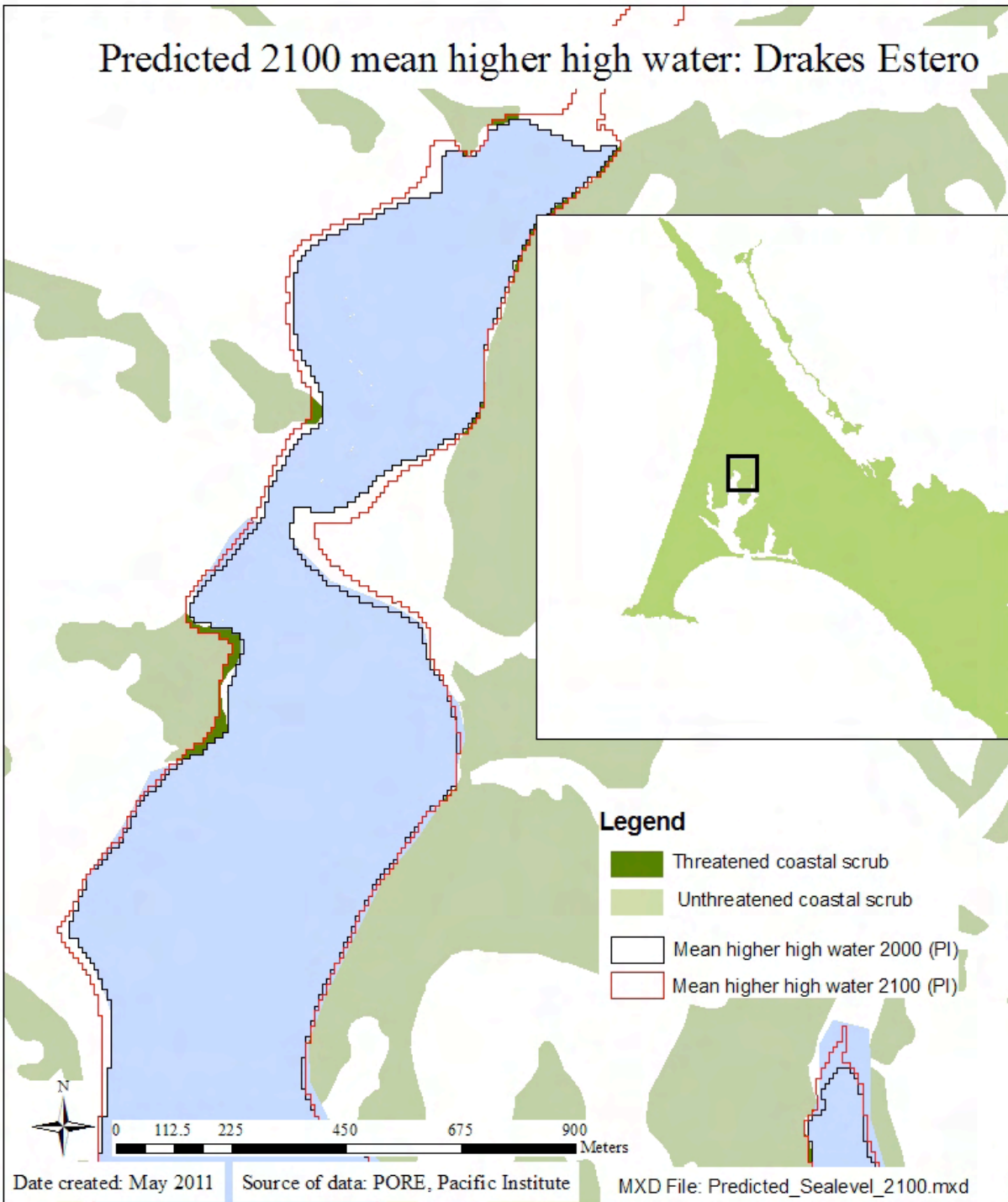


Figure CS-5

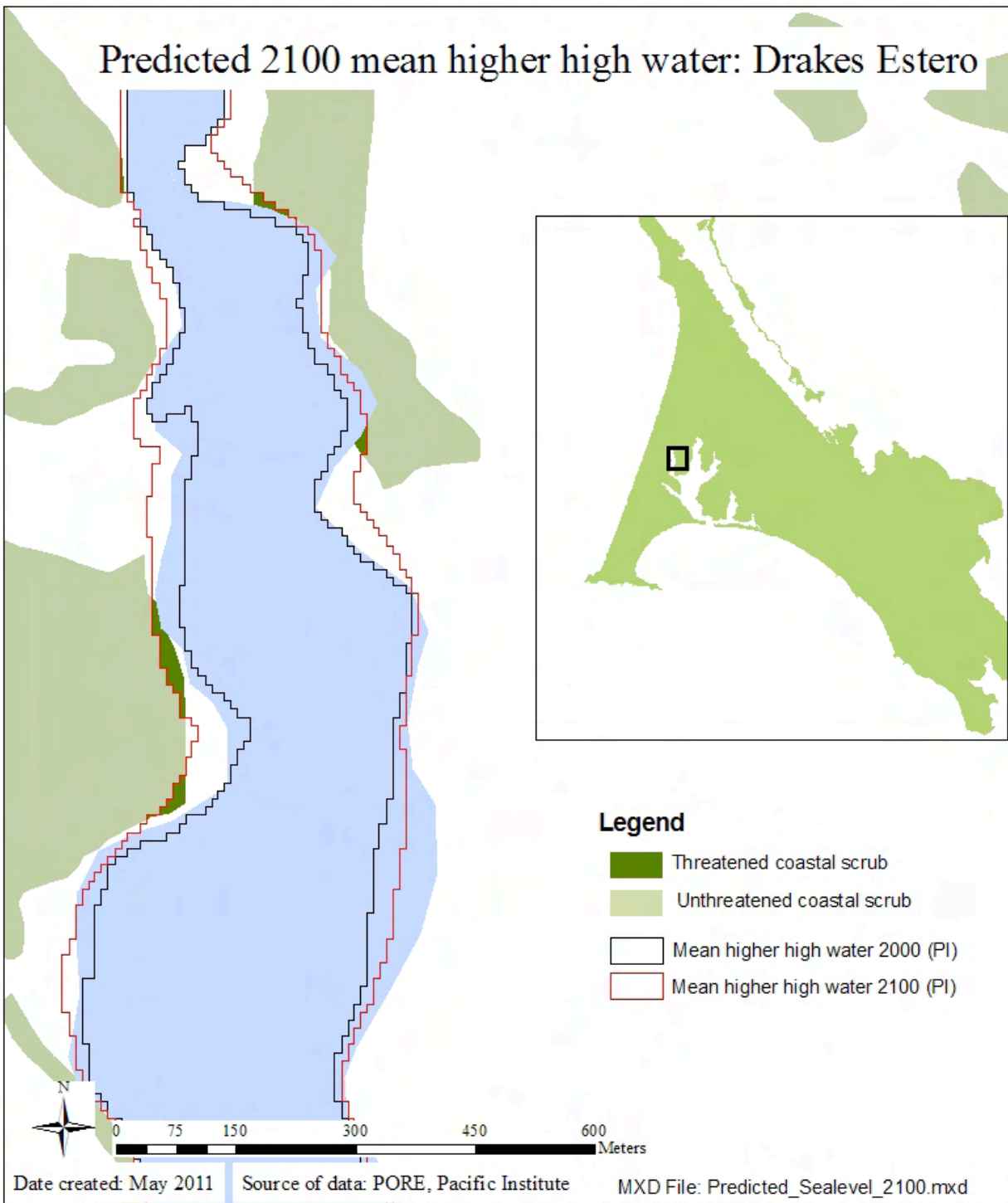


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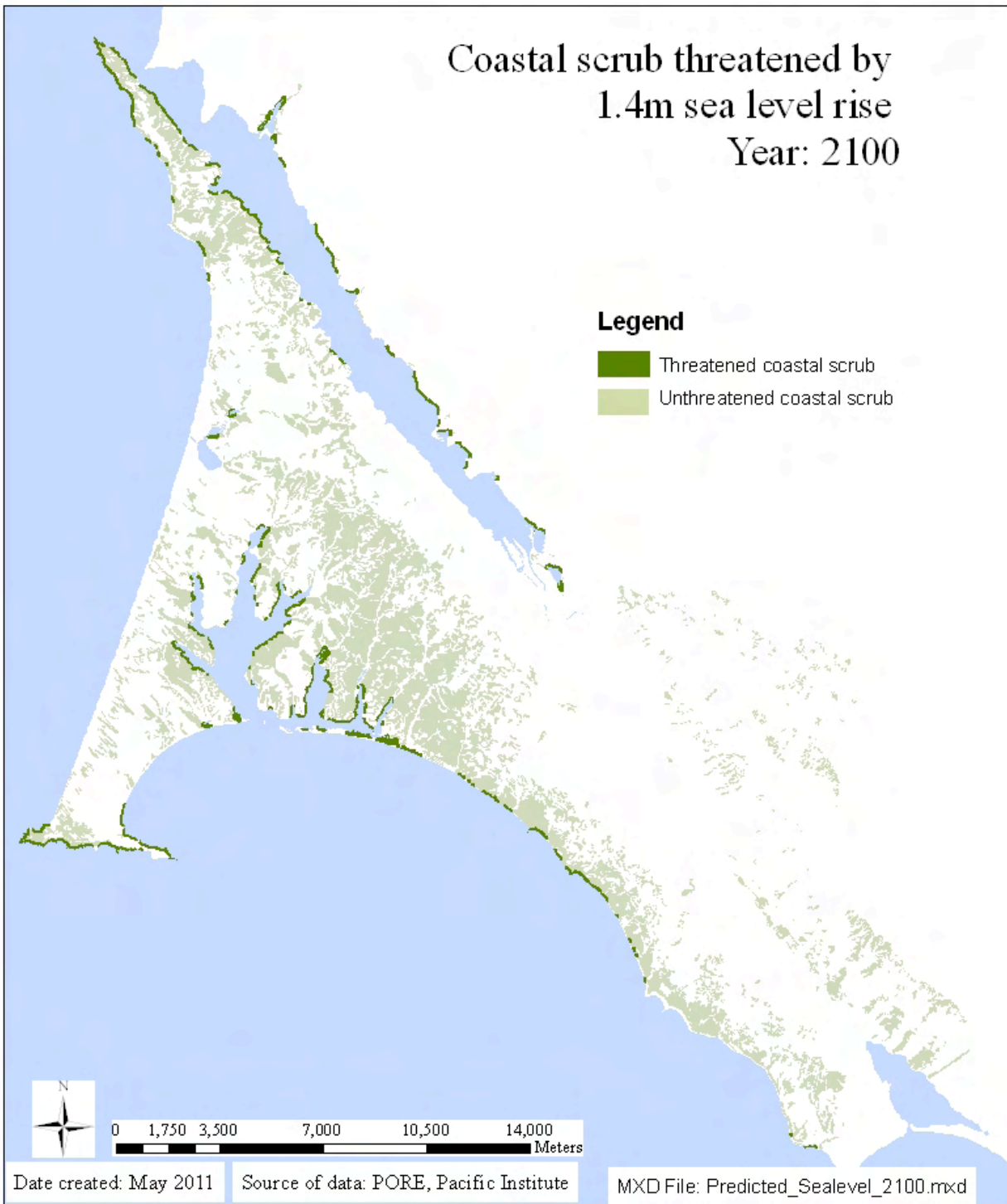


Figure CS-7

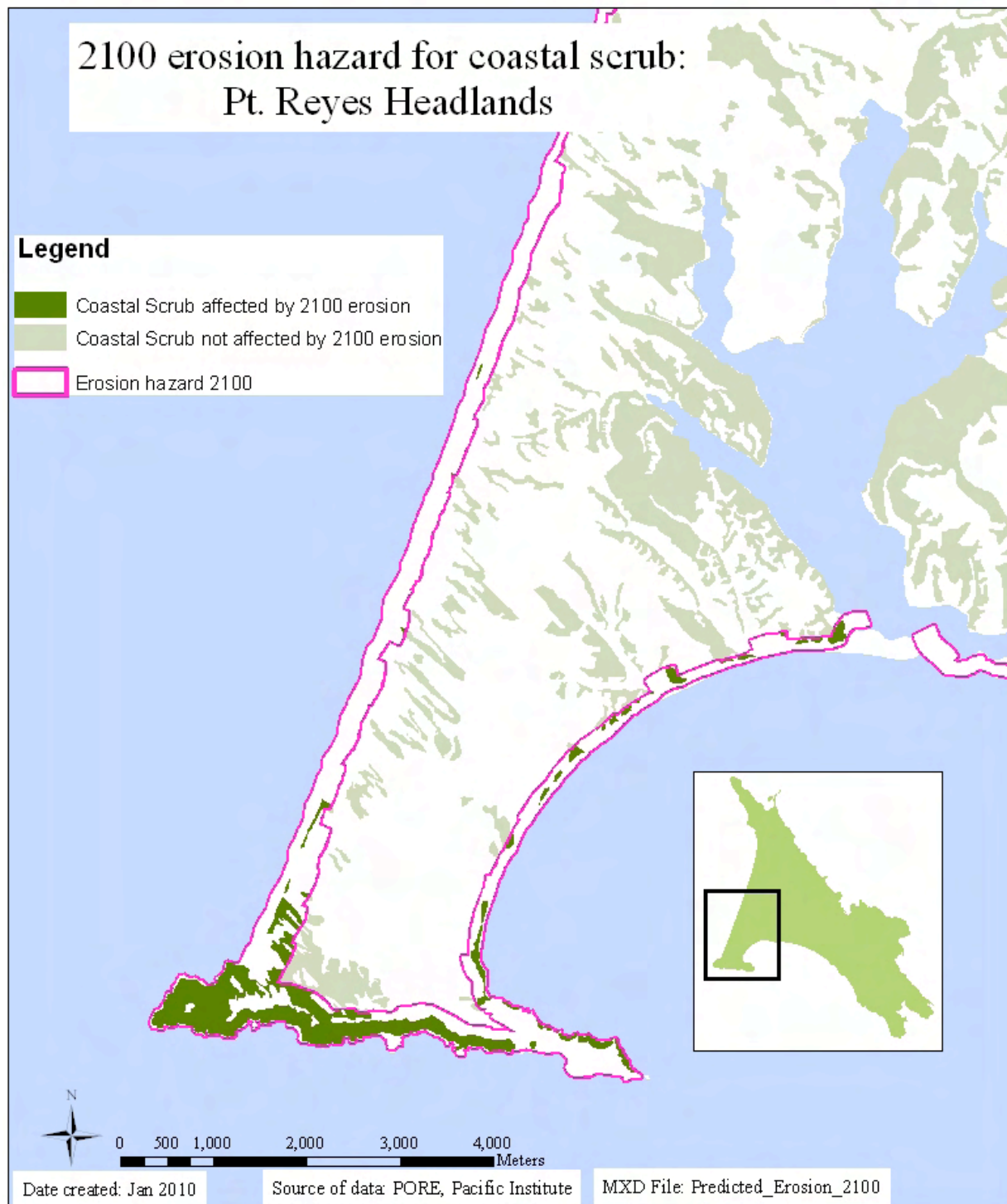


Figure CS-8

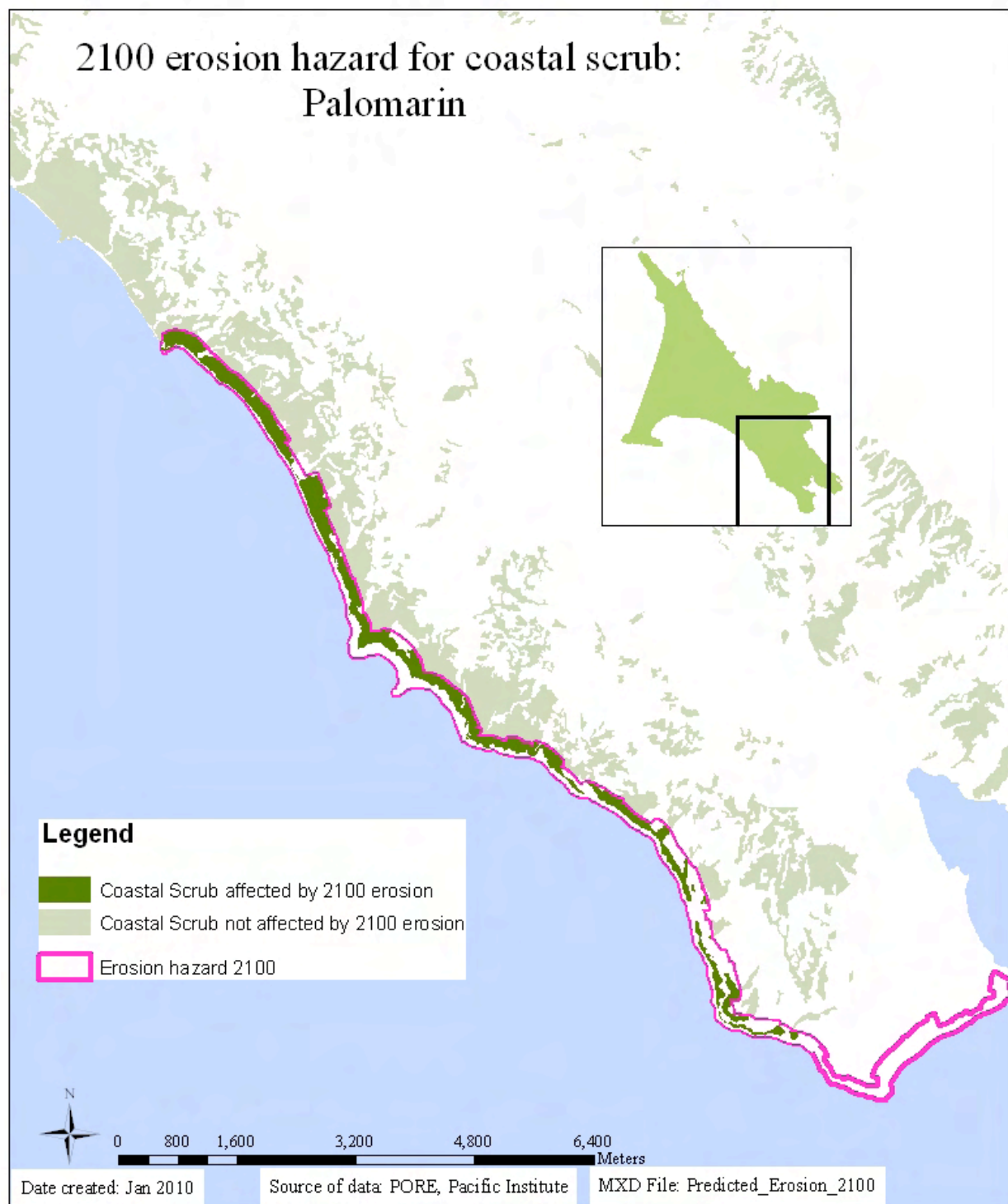


Figure CS-9

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Grasslands

Introduction

Grasslands at Point Reyes National Seashore are part of the park's undeveloped coastal environment. Like all communities in the park, grasslands may be susceptible to even minor changes in climatic conditions.

There are two coastal grasslands in California: northern and southern. Historically, the two types of coastal grasslands differed in plant species composition. Today, southern grasslands generally tend to be more dominated by non-native annual plants than northern grasslands are. Northern coastal grasslands at Point Reyes are in the middle of their latitudinal range. These coastal grassland communities generally occur below 1000 meters (3,300 feet) of elevation, often on ridges and south-facing slopes (Heady 1977). Grassland plant species composition is influenced by distance from the coast, and to a small extent by elevation.

At Point Reyes National Seashore, grassland communities are heavily invaded by exotic plants. However, they remain important for several rare and endangered plants and animals, including the Sonoma spineflower (*Chorizanthe valida*), showy Indian clover (*Trifolium amoenum*), and Myrtle's silverspot butterfly (*Speyeria zerene myrtleae*). The California red-legged frog (*Rana draytonii*) has been shown to migrate through grasslands between suitable wetland and riparian habitats (Fellers 2007). These grasslands are grazed by Tule elk which is a species of management concern as well as cattle. Historically, introduced axis and fallow deer, grazed these grasslands (Elliott & Barrett 1985). Though their diet consists largely of browse, native black-tailed are also important to the dynamics of grassland communities at Point Reyes.

Dynamics

Grasslands at Point Reyes may replace or be replaced by woody vegetation communities (Figure CS-2). Ecto-mycorrhizal fungi can be found in grasslands on forest edges and may facilitate invasion of Bishop pine (*Pinus muricata*) forests, especially after fires (Kennedy et al. 2007). Additionally, fog capture by saplings on the forest edge may facilitate invasion of bay-oak hardwood (*Umbellularia-Quercus*) and Douglas fir (*Pseudotsuga*) forests into grasslands in the park (Kennedy & Sousa 2006). Grasslands, such as the ones found at Point Reyes, may also be seral to northern coastal scrub, especially with the elimination of disturbances (Heady 1977). Between 1952 and 1993, there was a slight decline in grassland area at Point Reyes. This change may be related to fire suppression; over the same time period, the park saw an increase in woody vegetation cover (Russell & McBride 2003).

Ancient climate change

Around 10,000 years before present (at the Pleistocene-Holocene transition), there was a change at Point Reyes from closed canopy *Pseudotsuga-Abies* forest to grasslands and coastal scrub. Evidence suggests that the period from 12,000 to 10,000 years before present were characterized by more frequent high-intensity storms with higher levels of runoff (Rypins et al. 1989).

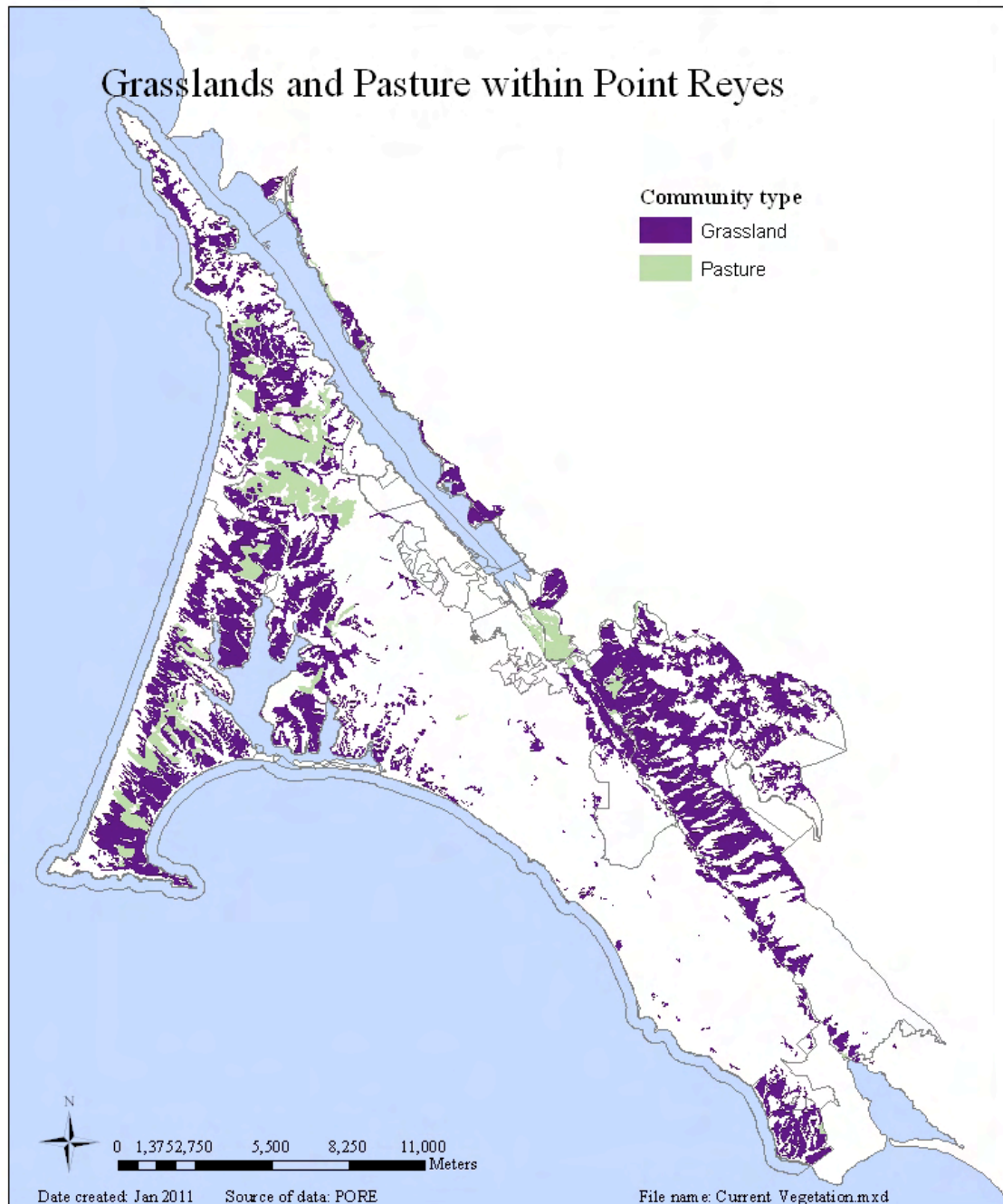


Figure GR-1

I. Expert judgment

Contributing experts:

Michael Barbour, University of California, Davis, emeritus
James Bartolome, University of California, Berkeley
Joe R. McBride, University of California, Berkeley
Thomas Bruns, University of California, Berkeley
Judd Howell, H. T. Harvey & Associates

Effects of a change in climate

The grasslands at Point Reyes National Seashore are the least pristine of any vegetation type. Therefore predicting the direction these plant communities may take in response to climate change is the least certain.

Increased precipitation

Precipitation is important in competitive dynamics in grassland systems at Point Reyes National Seashore. Common velvet grass (*Holcus lanatus*) can invade wetter coastal grasslands. If the moisture regime is shifted towards higher, more even (i.e. less seasonal variation) annual moisture, this species may be more able to out-compete natives.

Precipitation is also important in food web dynamics in these systems. Peak forage in these systems is significantly correlated with precipitation (Bartolome et al. 1980). Populations of Tule elk have been shown to increase in wet El Niño years (Howell et al. 2002). Additionally, changes in net primary productivity may affect the density of small mammal grazers and invertebrates that have a big impact on the shrub/grassland boundary

A colder, wetter climate may be beneficial to perennial grasses and coastal scrub communities. The grasslands in Point Reyes National Seashore are probably most susceptible to invasion by northern coastal scrub and by Douglas fir or Bishop pine forests if precipitation increases, the summer drought lessens, or fires are suppressed.

Timing and amount of precipitation are important in the life cycles of some grassland species. For example, fall and winter are the periods of greatest adult western black legged tick (*Ixodes pacificus*) activity in the region (Westrom et al. 1985). The host-seeking behavior of ticks carrying Lyme disease in Point Reyes National Seashore grasslands could be related to temperature and relative humidity (Lane & Stubbs 1990, Loye & Lane 1988). With an increase in precipitation, the park could see an increase in Lyme disease.

Distance from the coast is an important factor in determining the composition of the plant community in grasslands. A change in rainfall and fog could interact with a change in aerosols like salt to affect plant growth rates and distributions.

These systems are affected by differing fire regimes. Fire frequency in Marin County before European colonization was on average every 25 years, which is consistent with weather patterns that give rise to lightning and the average for chaparral fires. In the absence of human

intervention, fire frequency would likely shift as a function of climate change. This shift could happen as a direct result of climate, or as an indirect result of climate-driven effects on net primary productivity. In other words, fire frequency could change with climate effects like drier conditions or increased lightening. It could also change with an increase or decrease in the fuel produced.

Decreased precipitation

Grassland communities at Point Reyes National Seashore, as a whole, may be fairly resilient to hotter, drier climates. Some experts do not anticipate any significant decrease of grasslands in the park with drier conditions.

A shift towards drier climates may make these northern coastal grasslands more permeable to new exotics and may increase dominance by annual plants. For example, relic stands of native bunch grasses in the park may suffer from increasing temperature and decreasing moisture, which will favor exotic annual grasses.

Since peak forage in grasslands is correlated significantly with precipitation (Bartolome et al. 1980), populations of Tule elk could be reduced in drought years (Howell et al. 2002). Additionally, changes in net primary productivity may affect the density of small mammal grazers and invertebrates that have a big impact on the shrub/grassland boundary.

Fire dynamics could also change with a drier climate. If fog decreases, which is predicted under some climate models, fire frequency may decrease, shifting the mosaic of grass/shrubs towards more shrub dominance. A change in climate may relate a change in fire frequency in complex ways. For example, if precipitation decreases, grasslands will produce less plant biomass, which may result in a decrease in frequency or intensity of fires. On the other hand, an increase in precipitation could lead to fewer days of fire-friendly weather conditions.

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Greater inter-annual variability of temperatures and precipitation

If global climate change brings more inter-annual variation to Point Reyes National Seashore, it might move the southern boundary of northern coastal grasslands further north, possibly as far north as Point Reyes and Bodega Head. This could happen because introduced annual grasses in

the southern grassland are more tolerant of annual climatic fluctuations than the perennials of northern dominants. The result could be a decline in northern coastal grasslands in the park.

Confounding factors

Soil compaction & recreation

Recreational use generally has minimal effects on grasslands at Point Reyes National Seashore. However, because grassland soils are easily compacted, some impacts could result from foot, horse, or vehicular traffic.

Grazing

Grazing is an important factor influencing grassland composition and succession. Livestock, elk and deer graze grasslands at Point Reyes National Seashore. The historical effects of grazing, and especially the many plant introductions that resulted from it have had obvious impacts on this community. As it is currently practiced, grazing in the park reduces woody plant encroachment into grasslands. Grazing can also decrease the abundance of native bunch grasses, which, in conjunction with higher inter-annual climate variability, could severely threaten this functional group. Coastal prairies are also especially sensitive to grazing.

Vole burrows are associated with an increase in plant species richness in ungrazed grasslands (Fehmi & Bartolome 2002). Grassland associated species, like the Savannah sparrow, will thrive in grazed grasslands, but grazing can lead to a reduction in shrubs which results in lower numbers of shrub-associated birds (Holmes et al. 1999).

Proper grazing management may help to mitigate the effects of climate change on grasslands in the park. On the other hand, livestock grazing could make the grasslands more sensitive to increased temperature and shift grassland composition toward annual grasses that mature early in the spring.

Fire

Fire is an important factor influencing grassland ecosystems. Accidental human-ignited fires could increase fire frequency beyond what would be expected or observed during natural intervals. Proper fire management may help to mitigate the effects of climate change on grasslands in the park.

Exotic species

Grasslands, if not managed properly, are susceptible to invasion by exotic plant species. Gorse and several species of broom, all nitrogen-fixing shrubs, could become very problematic given the right conditions. Because gorse is a nitrogen fixer it could severely alter the nutrient dynamics in grassland-shrubland habitats in the park.

Brown-headed cowbirds are abundant at Point Reyes National Seashore in cattle pastureland, especially in the western part of the peninsula. These exotic birds are nest parasites and are especially detrimental to bird species found in nearby northern coastal scrub and maritime chaparral (Trail & Baptista 1993).

II. Predictive vegetation mapping

Spatial predictions of vegetation change provided by PRBO (Stralberg et al 2009).

The mapped current distribution of grasslands at Point Reyes National Seashore differs significantly according to the sources of the data. The detailed map provided by PORE shows a matrix of grasslands and shublands throughout the western part of the peninsula, while the data from PRBO shows this area as dominated by shrubland (GR-2). The reason for this discrepancy is likely that the size of the climate data PRBO was working (800m grid cells) with required them to average the vegetation in each of the cells. This initial discrepancy should be kept in mind when interpreting the results of the predictive maps.

As compared with the current distribution of grasslands in the park, CCSM and GFDL models predict a dramatic increase in areas that are climatically suitable for grasslands in the future (GR-3). The NCAR-CSM1.2 model predicts a dramatic redistribution of grasslands from the Bolinas region (current) to a small number of grid cells scattered throughout the peninsula. While the models disagree on the amount of area that will have a climate suitable to grasslands in the future, they do all agree that grassland-suited climate will be located in a few square kilometers on Point Reyes, surrounding Drake's Estero and on Tomales Point. Models generally predict more seasonality in precipitation at Point Reyes, which may be driving the predictions of an increase in grasslands.

These niche models make wide-ranging predictions about the future distribution of grassland-suited climate in the park. Additionally, the scale of the climate data requires that the mosaic of habitats in the park is reduced to nearly a square kilometer in resolution. However, they may be used as a broad-scale compliment to the threats experts foresee for this community type and its key species at Point Reyes National Seashore. Interviews with experts on grasslands have highlighted the importance of water and disturbance regimes in the successional dynamics of grasslands, shrublands and forests at Point Reyes. The reason for the differences in timeframes for these climate models is that these GCM data are what were available to PRBO modelers. PRBO modelers do not believe that the discrepancy in timeframe is a major concern, because of the predictions models are making.

Climate Model	Years of prediction	Atmospheric CO ₂
NCAR-CSM1.2	2080-2099	653-686 ppm
NCAR-CCSM3.0	2038-2069	478-610 ppm
GFDL- CM2.1	2038-2070	478-615 ppm

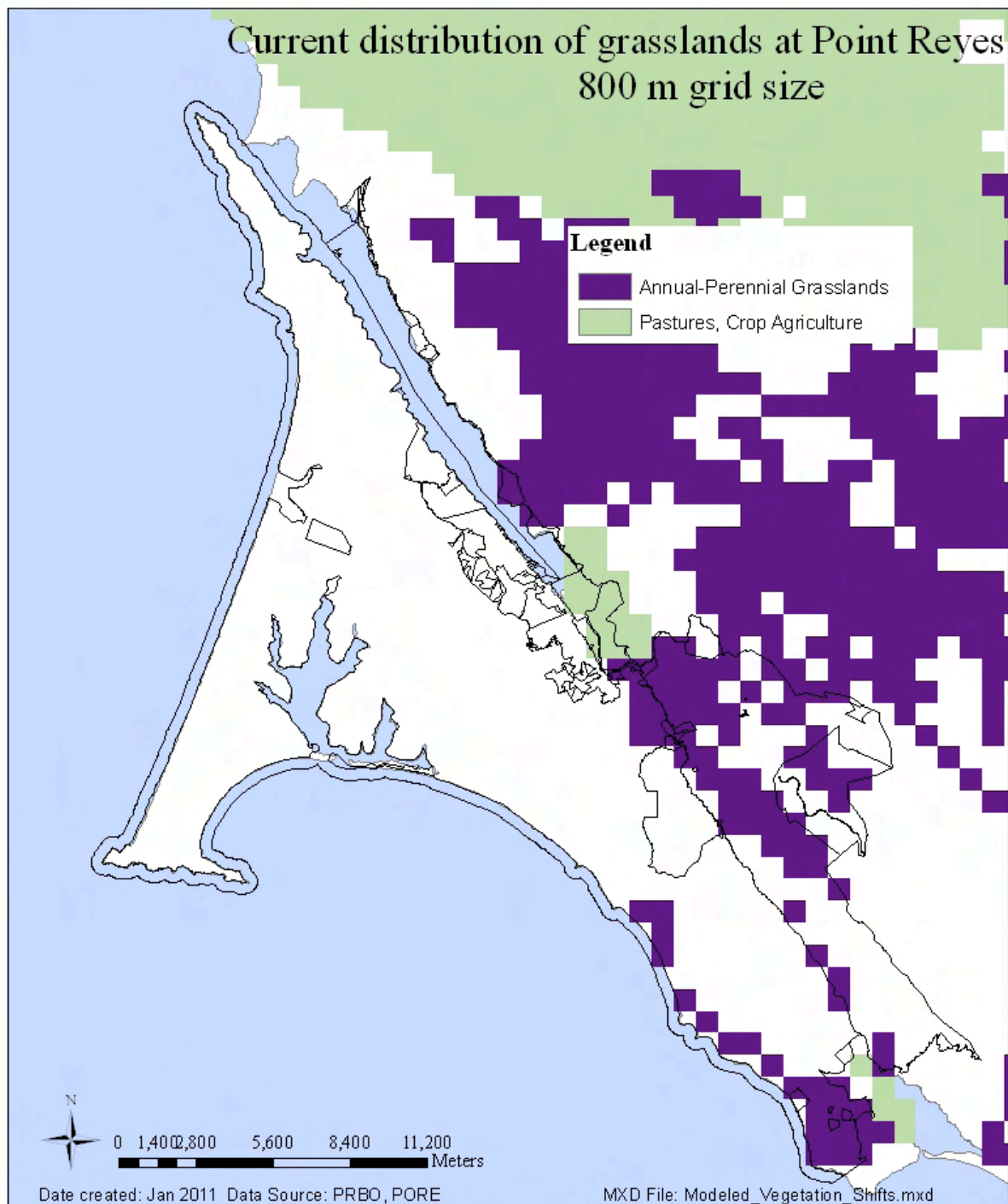


Figure GR-2: 800m grid size of current distributions of grasslands at Point Reyes National Seashore.

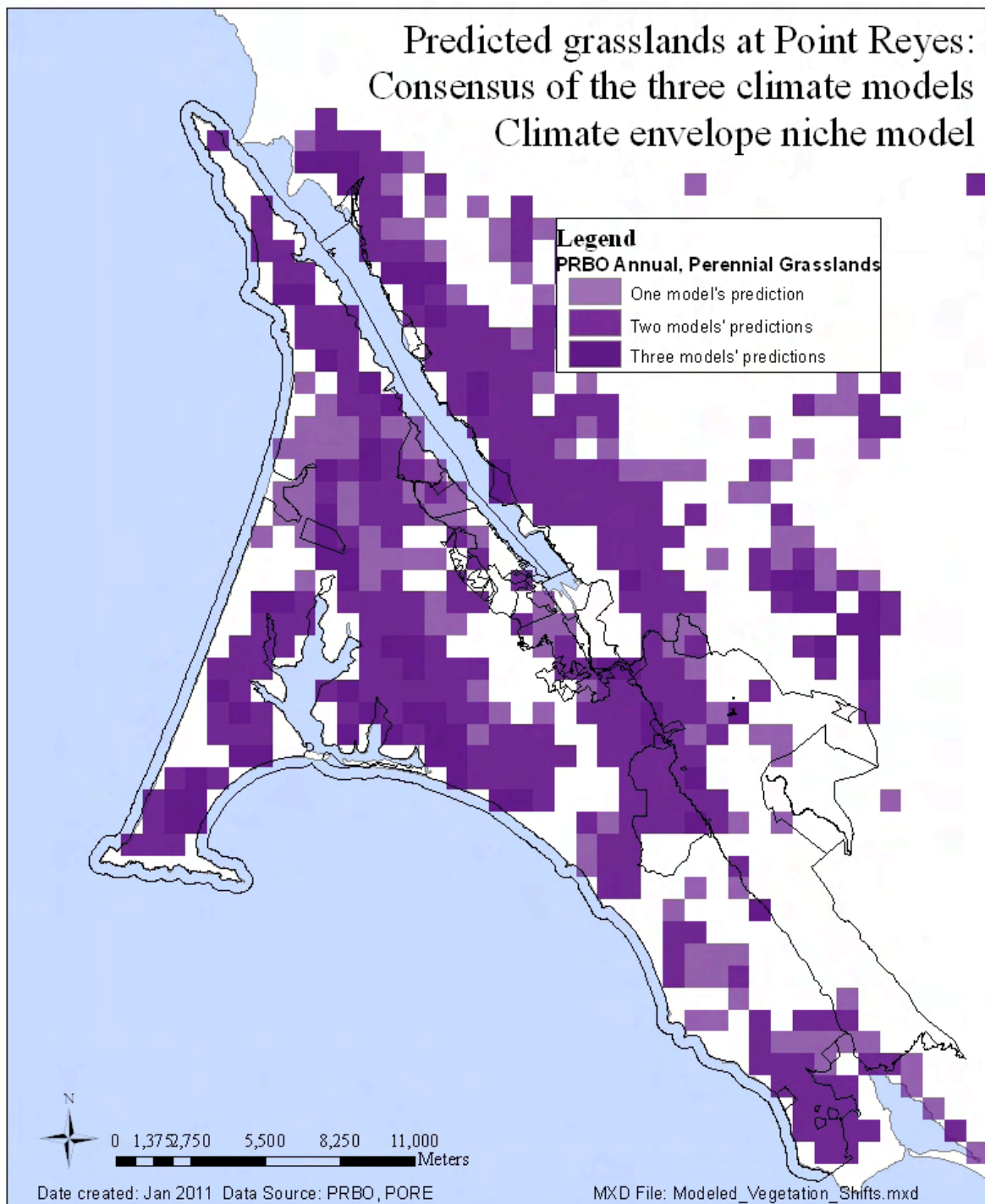


Figure GR-3: 800m grid size of predicted distributions of grasslands at Point Reyes National Seashore.

III. Predicted coastline changes mapping

A rise in the mean higher high water of 1.4 meters by 2100 does not pose a major threat to grassland communities at Point Reyes National Seashore (Figure GR-4). Indeed, the areas may be highlighted as threatened, especially adjacent to Drakes Estero may only be mapping errors and discrepancies in where the actual coast is currently located.

Because salinity affects plant community composition in grasslands and dunes, grasslands tend not to be located on the coast. However, as the sea level rises, it is possible that soil salinity will increase in areas currently occupied by grasslands. In this case, grasslands may be indirectly affected by a rise in sea level.

Areas where sea level rise may directly affect grassland communities are predominantly along Tomales Bay in areas where grasslands occur at low elevations and are not seated above bluffs.

While grasslands are not especially vulnerable to a 1.4 meter rise in sea level, they may be at risk from associated land erosion. In particular three areas at risk for erosion contain grasslands: western Tomales Point, southeastern Point Reyes and Bolinas (Figures GR-5, GR-6, GR-7, GR-8). Erosion hazard predictions are based on shoreline classifications (cliff or dune) and impacts of predicted increases in wave strength combined with historic erosion rates; these predictions may be slight over-estimates in an effort to account for subtle changes in geology of the coast (Heberger et al 2009).

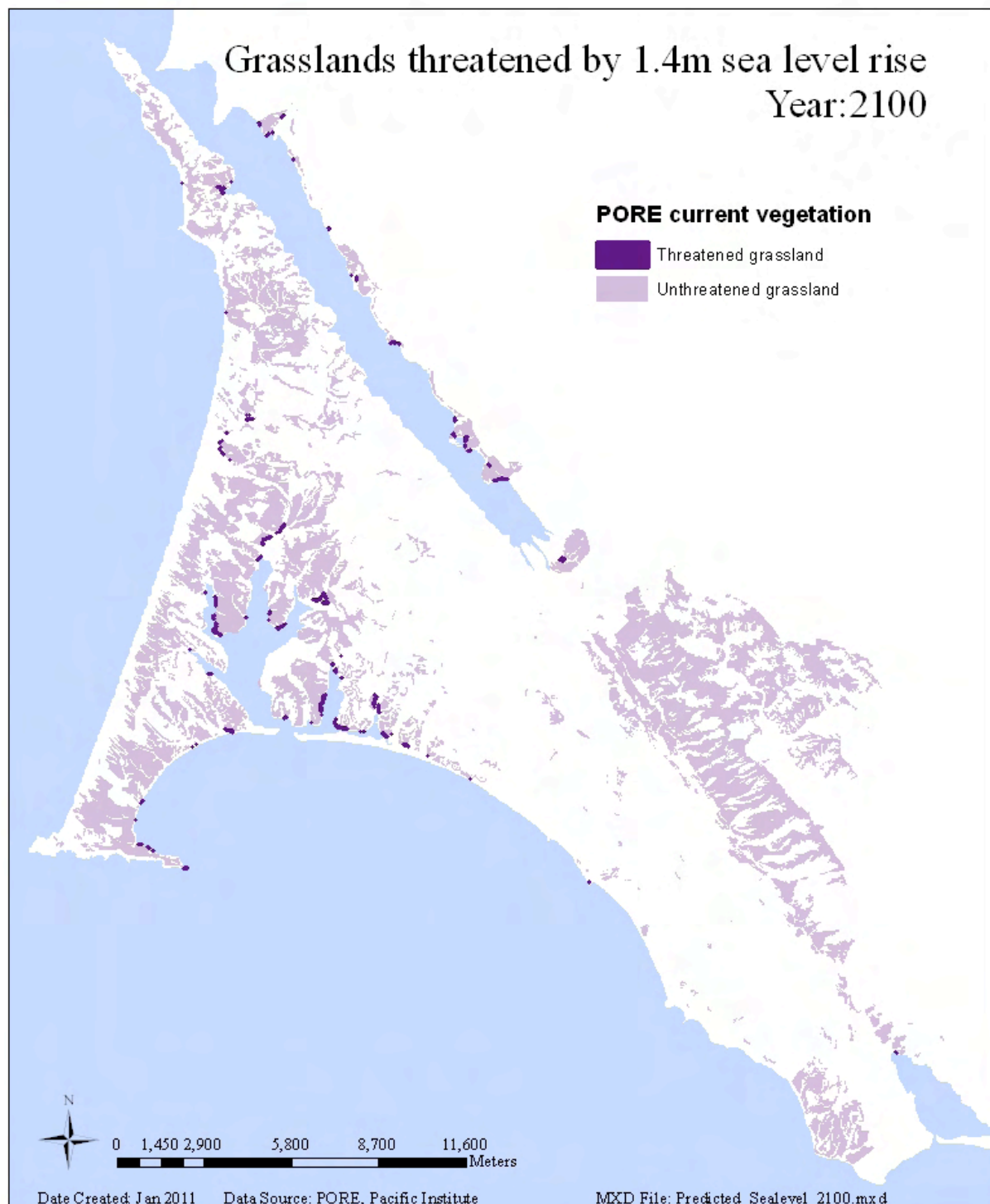


Figure GR-4

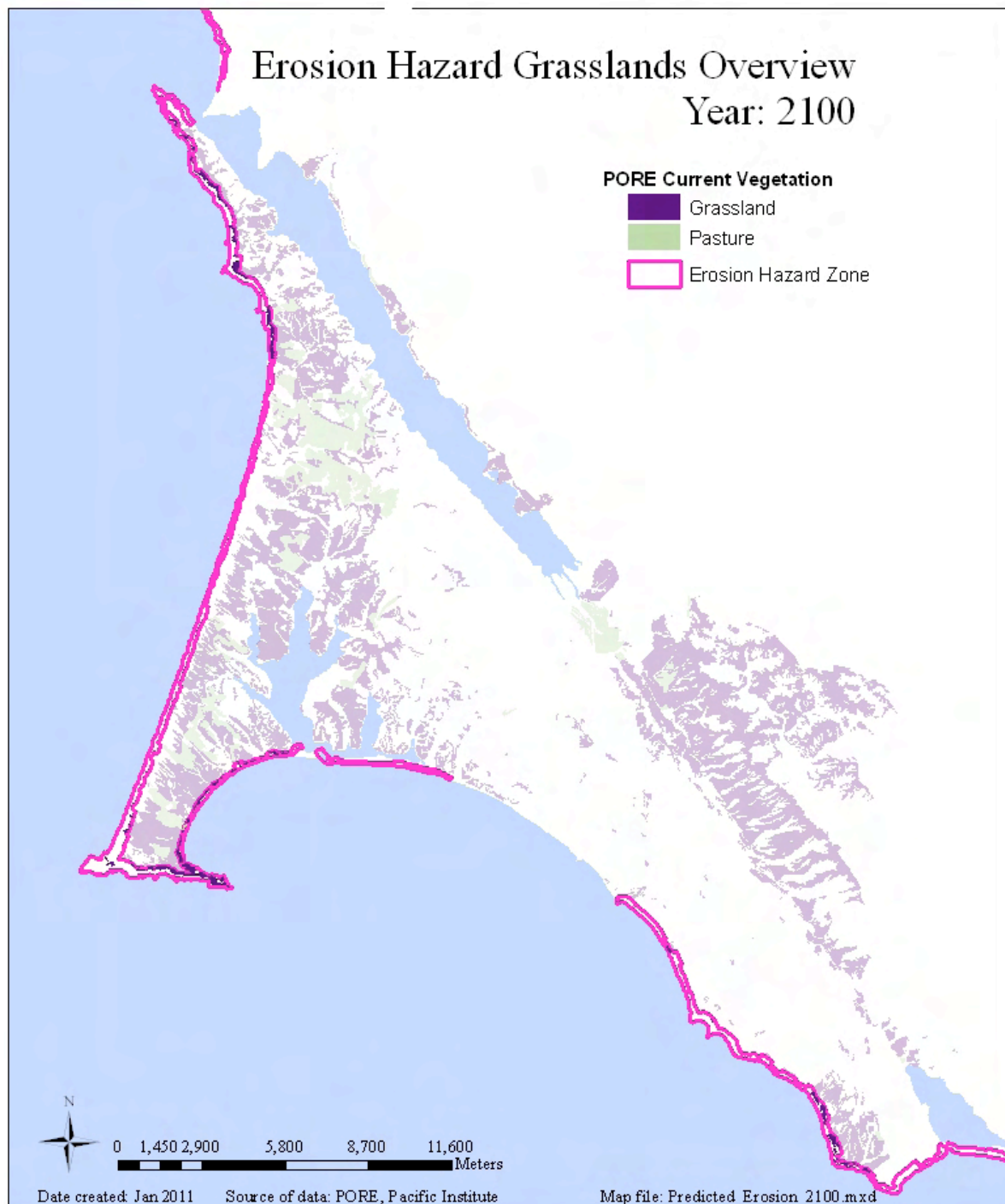


Figure GR-5

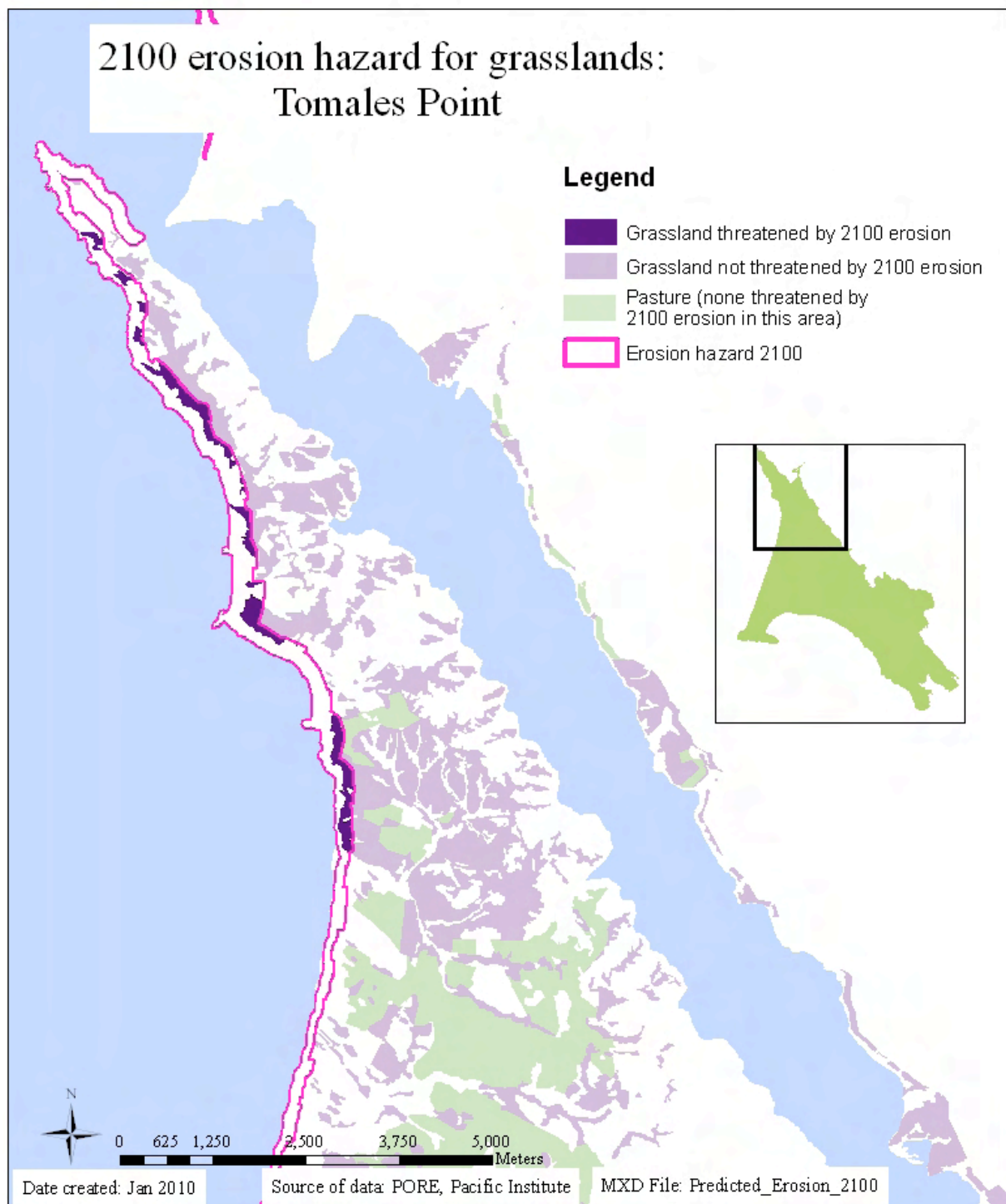


Figure GR-6

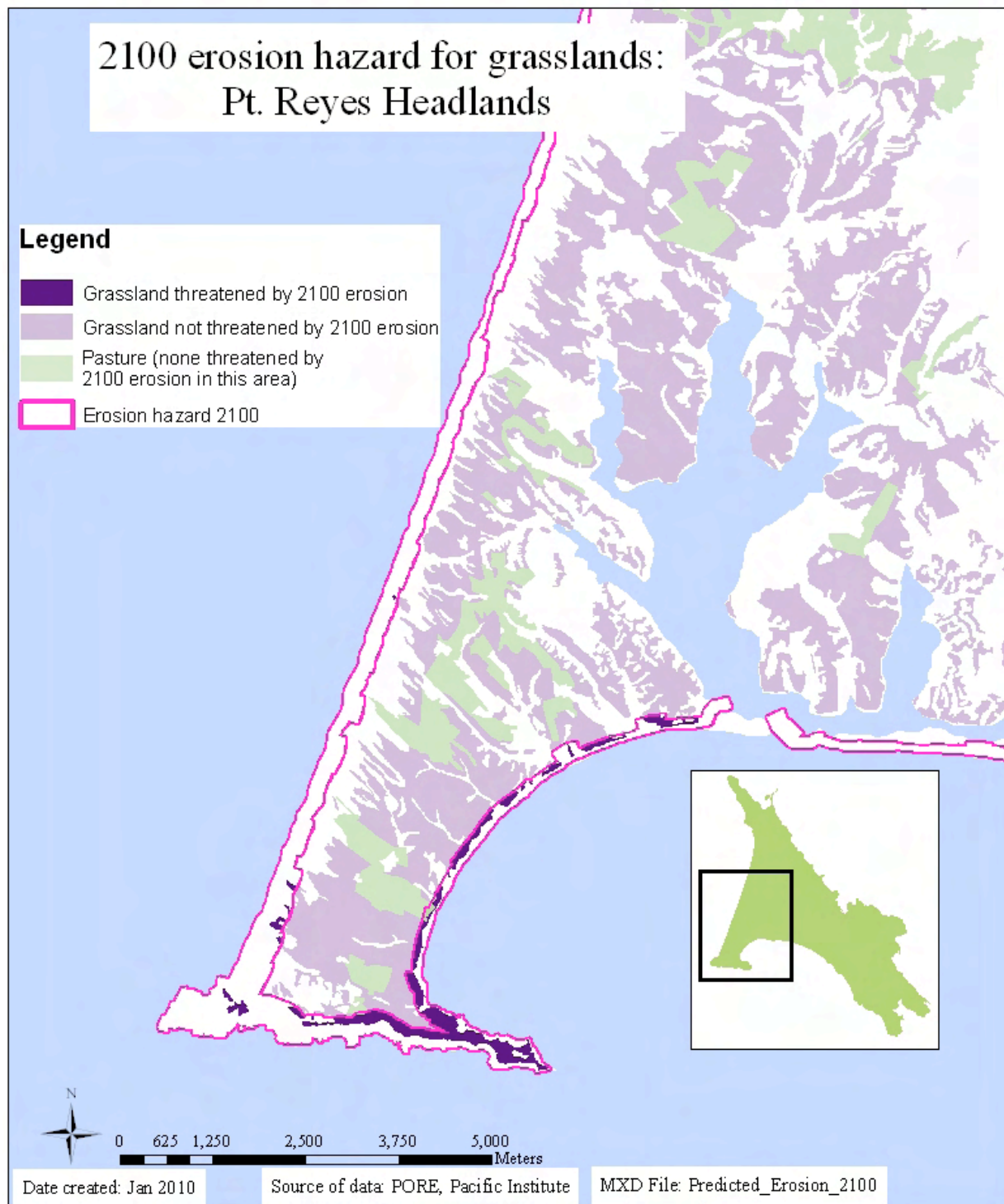


Figure GR-7

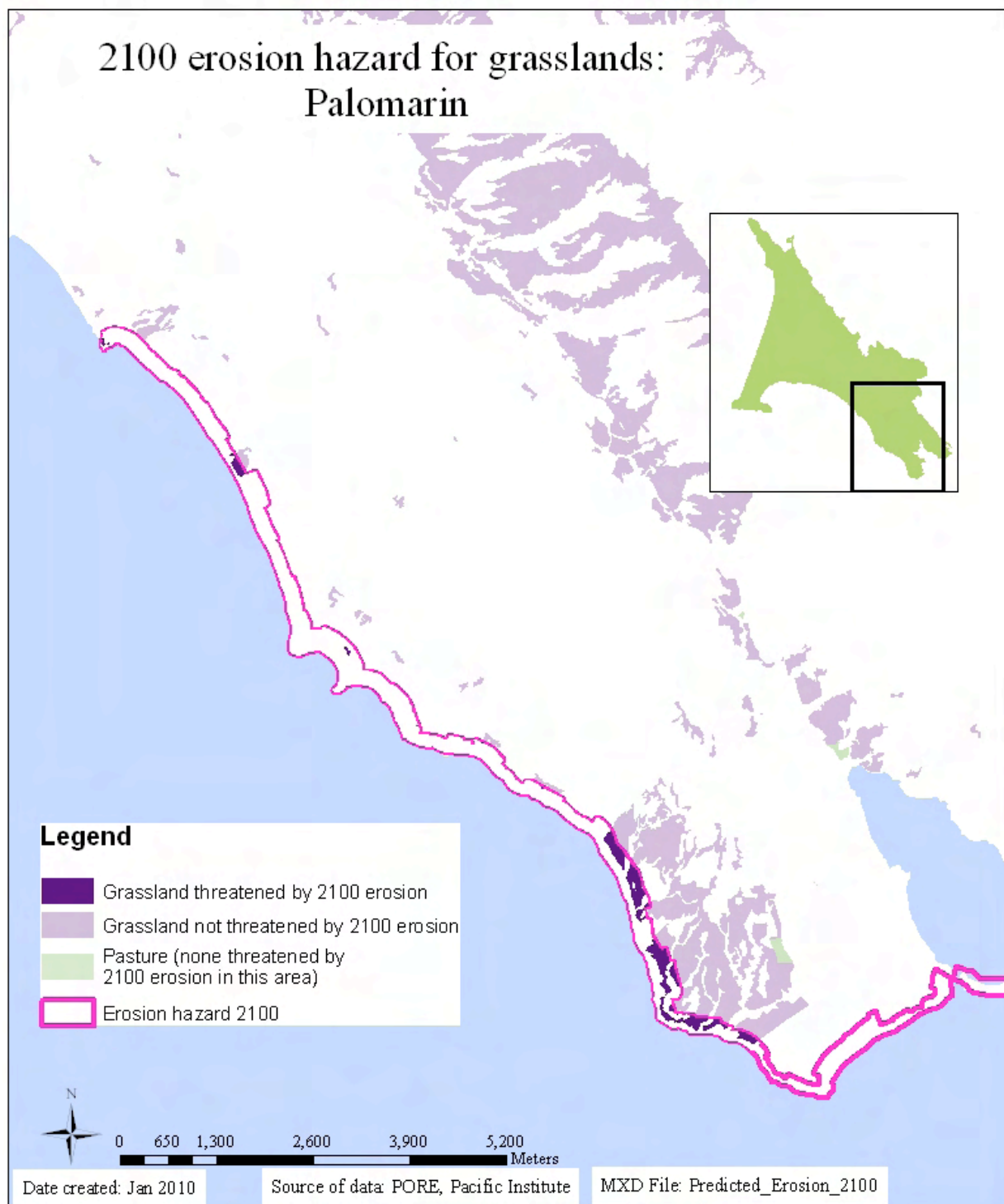


Figure GR-8

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Eelgrass beds

Introduction

Eelgrass bed communities occur within the park's estuaries, in Tomales Bay, Drake's Estero, and Estero Limantour (Figure EG-1). Eelgrass (*Zostera*) provides habitat for species that attach to the plant, protection for benthic species, and food for a number of maritime animals. It acts as a sediment trap, so it also helps to stabilize the mud substrate. Nudibranchs, sponges, tunicates, skeleton shrimp, sea cucumbers, and a wide range of other organisms live on the eelgrass blades. Native clams, feather-duster worms, and fat innkeepers are found within the roots and the surrounding soft sediments. Eelgrass beds act as extremely important nursery habitat for herring and they are feeding grounds for many bird species, so they play a significant role in the coastal food chain.

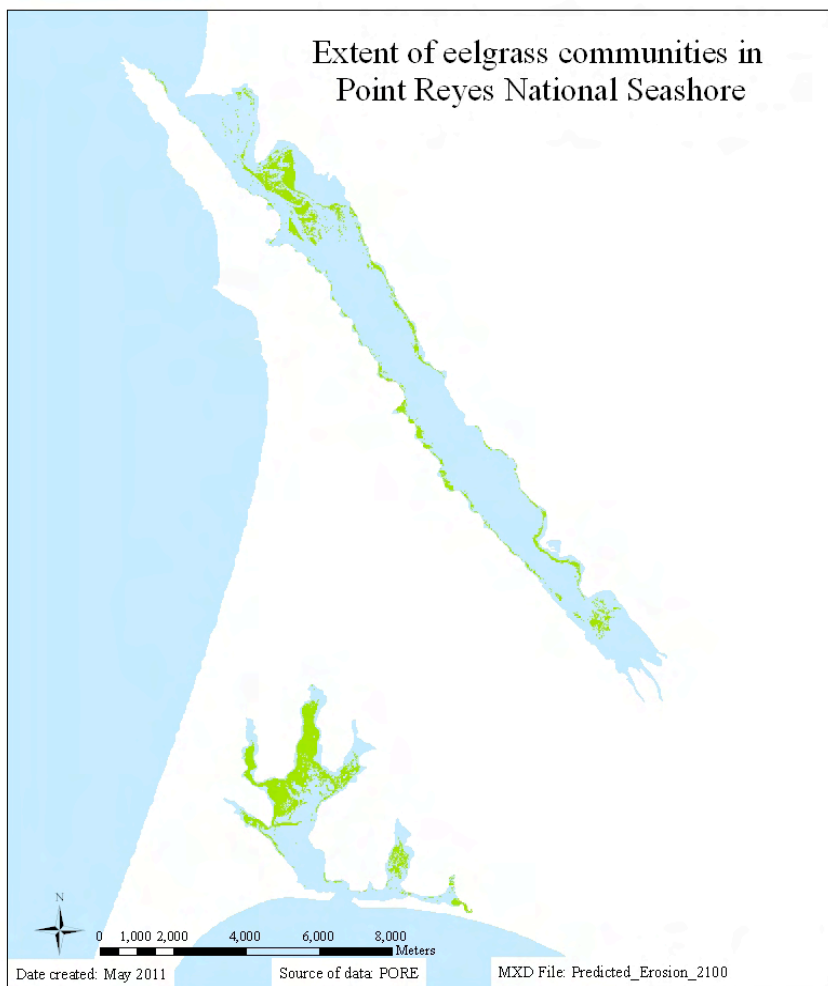


Figure EG-1

I. Expert judgment

Contributing experts

Sarah Allen, Point Reyes National Seashore

Dan Howard, Cordell Bank National Marine Sanctuary

Possible effects of a change in climate

Increase in Sea Surface Temperature

Experience with El Niño events in this region has provided some insight into what effects increased sea surface temperature (SST) would have on eelgrass communities. Studies have shown that higher SSTs have a negative causal relationship with mean eelgrass leaf lengths, and lead to a decrease in productivity (Echavarría-Heras et al. 2006).

Sea Level Rise

Increased sea level results in less light reaching eelgrass beds, thus reducing photosynthesis and overall productivity. Eelgrass beds can migrate coastward to keep pace with the rise in sea level, if room to migrate is available. Sea level rise may have a strong negative impact on eelgrass in Tomales Bay, due to steep topography on the west side and Route 1 on the east.

Changes in Seawater Chemistry & Increased Precipitation

Increased freshwater runoff due to increased precipitation may negatively impact the buffering ability of seawater, causing more acidified water in the estuaries where eelgrass communities occur. Eelgrass has actually been shown to grow faster in higher concentrations of CO₂, but many of the species associated with eelgrass may be negatively affected by more acidified water, particularly native clams and other calcifying organisms (Largier et al. 2010). There is also evidence that marine larvae are particularly sensitive to ocean acidification, which could impact the long-term persistence of several species currently common in eelgrass communities (Kroeker et al. 2010).

Increased Extreme Storm Events

A significant increase in sedimentation loads within estuaries, as a result of erosion and runoff associated with more frequent, more powerful storms, could result in sedimentation burying or covering portions of eelgrass communities.

Confounding Factors

Biotic Interactions

Eelgrass beds support a very large community of species; many of these organisms are entirely dependent on the habitat, including herring. If herring are no longer able to lay their eggs within eelgrass beds, the herring will disappear from the local area. Bolinas Lagoon, just south of Point Reyes National Seashore, had herring, historically. When it lost eelgrass, it lost herring as well. Eelgrass communities are also susceptible to invasion by non-native species. *Spartina alterniflora* and *Spartina densiflora*, invasive cordgrasses, and their hybrids with the native cordgrass *Spartina foliosa*, are a threat in similar habitats along the west coast. These introduced

cordgrasses can penetrate into deeper waters than native species and can outcompete many natives in the shallows and mudflats. *Didemnum*, a fast-growing colonial tunicate, has decimated many coastal habitats on the East Coast of the United States. Successful establishment of *Didemnum* spp in other communities has led to the overgrowth of existing marine flora and fauna, resulting in areas characterized almost exclusively by the tunicate (Bullard et al. 2007). If either of these species establishes in the park's eelgrass communities, they can be expected to negatively impact eelgrass habitat and any organisms dependent upon it.

Anthropogenic Impacts

As with most coastal habitats, eelgrass is sensitive to a large number of anthropogenic effects. Run-off from developed areas, in the form of pollution and sedimentation, can reduce the health and productivity of eelgrass. Nutrient loading, due to fertilizer runoff and sewage, enhances phytoplankton abundance and reduces the depth of sunlight and water clarity, reducing eelgrass abundance (Micheli et al. 2008). Nutrient loading may also lead to eutrophication, substantially reducing biomass and habitat for eelgrass dependent species (Anton et al. 2010). Boat propeller damage, as well as damage from fishing activities, can do considerable damage to eelgrass beds in a very short period of time (Committee on Best Practices 2009). It is also possible that oyster farming within the park impacts the health of eelgrass beds, due to the resulting suspended fine sediment that can limit the amount of sunlight reaching the eelgrass, although there is also evidence that the presence of oysters filters the waters, thus allowing sunlight to reach eelgrass at greater depths (Committee on Best Practices 2009).

II. Vegetation model predictions

Current vegetation models do not examine marine communities. It is likely that these communities will shift in the future, due to changes in the ocean and estuaries. Such changes include sea level rise and changes to sea surface temperature. Where abiotic and topographic conditions allow, eelgrass beds may migrate coastward.

III. Predicted coastline changes mapping

Although eelgrass beds are marine communities, they will still be impacted by a rise in sea level. In particular, if sea level rises and eelgrass beds do not migrate coastward, there will be less sunlight penetration at the new depth. This could negatively impact both the eelgrass and other organisms living within the community. Figures EG-2 and EG-3 show sea level rise projections for park estuaries. The red line depicts projected MHHW for 2100; these figures indicate potential room for coastward migration, although a topographic map would be necessary to make any predictions about the feasibility of shifts in distribution.

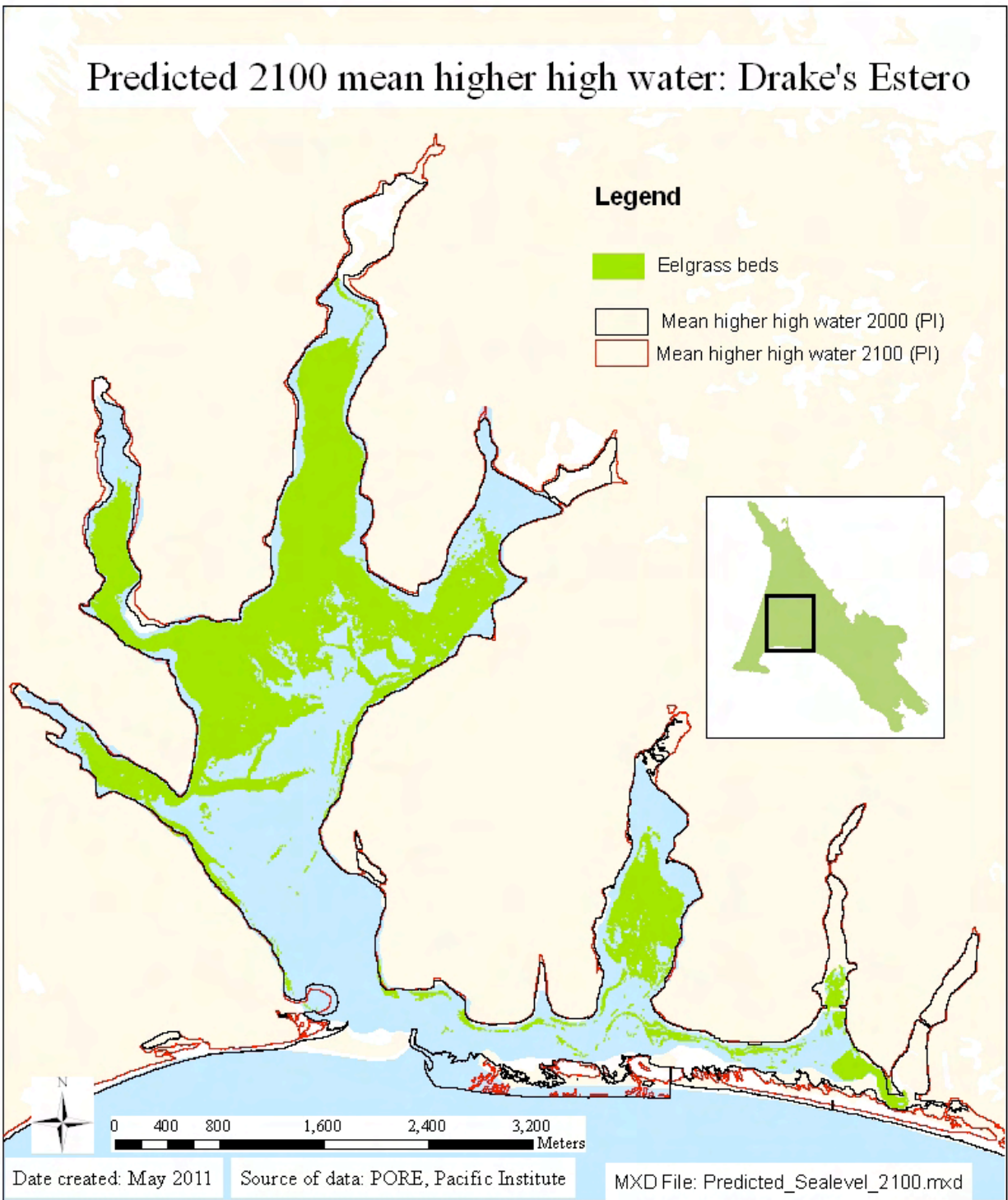


Figure EG-2

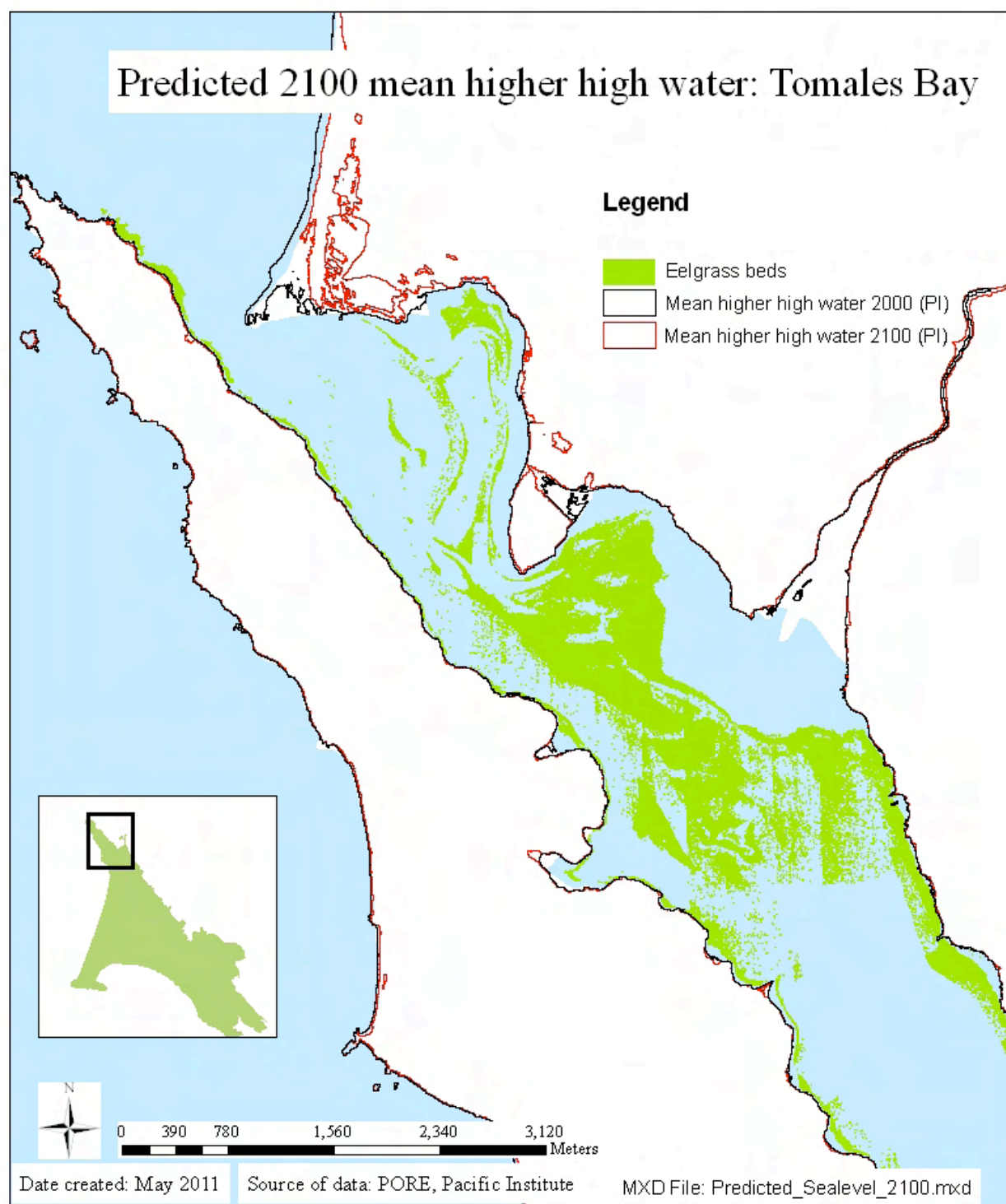


Figure EG-3

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Douglas fir and coast redwood forests

Introduction

These three forest types are found in moist environments near the west coast of North America. At Point Reyes National Seashore, these forests get much of their water from fog drip, which, annually, can be as significant as rainfall and varies independently from it. These forest types are found in the southeastern portion of the park. Douglas fir and coast redwood trees are fairly fire-resistant and tend to do well after fire disturbance. Coast redwood distribution is closely tied to the coast and this species does not penetrate very far inland. Spotted owls (*Strix occidentalis*) are federally listed as threatened and are known to nest in Douglas fir and redwood trees in the area. These forests are found in the southeastern portion of the park where there are ~18,500 acres of the forests (Figure DC-2, NPS and USGS, 2004).

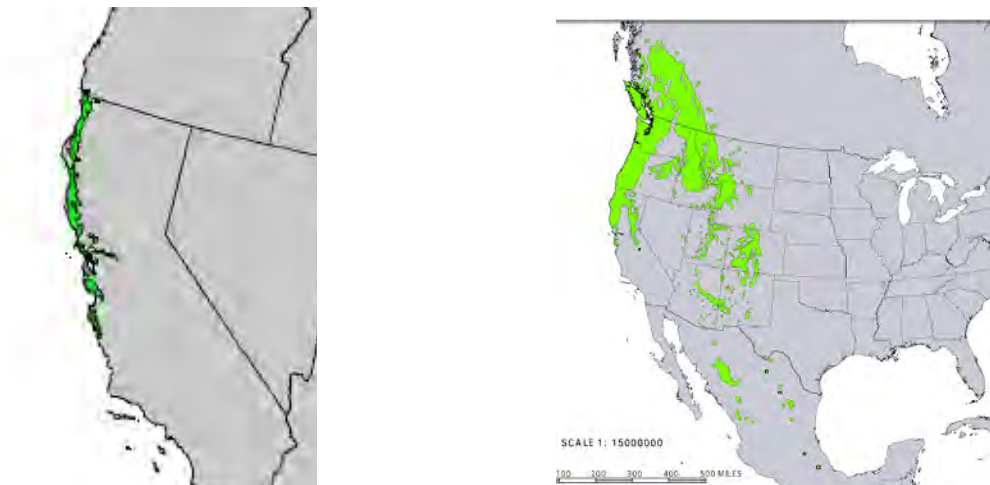
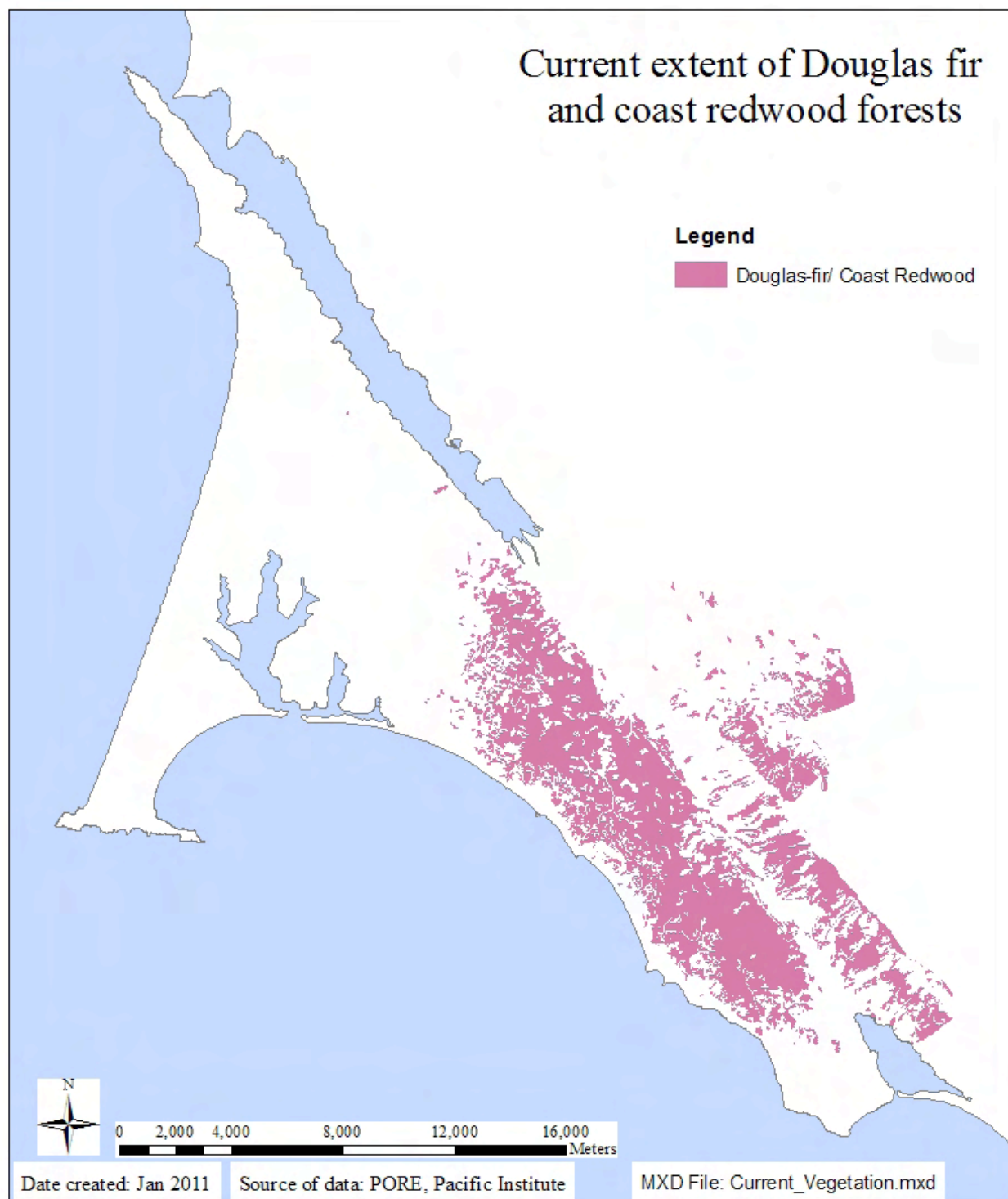


Figure DC-1 Current global range of two tree species found in Point Reyes National Seashore. Coast redwood (*Sequoia sempervirens*) is on the left and Douglas fir (*Pseudotsuga menziesii*) is on the right. [Source: USGS]



I. Expert judgment

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Chris Still, University of California, Santa Barbara

Effects of a change in climate

Changes in rainfall

Coast redwood and Douglas fir forests are easily drought-stressed and do better in areas with relatively high precipitation. Increases in precipitation would benefit these forests to a point. Douglas fir forests are found in some of the wettest parts of the continent in Washington state and British Columbia, and therefore could likely benefit from drastic increases in precipitation more than coast redwood forests. In the northern-most extent of their range, Douglas fir trees in British Columbia are shown to still be limited by precipitation, not by temperature (Griesbauer and Green 2010). Conversely, a decrease in precipitation would be detrimental to all of these forests as they may be outcompeted by species with lower water needs (see Figure CS-2).

Warmer, wetter winters or wetter springs could also lead to an increase in sudden oak death. This disease can infect several species in these forests including Douglas firs, tanoaks, black oaks, and coast live oaks. These susceptible species provide important structure to the forests and are an important food source to many forest-dwelling animals.

Increase in mean temperature

An increase in temperature would likely be detrimental to these forest types as it would increase evapotranspiration and increase water stress. Increased temperatures (especially winter temperatures) could also increase sudden oak death.

Changes in fog and cloud cover

These forests get much of their water from summer fog drip in this region. If fog increases, these forests could benefit to a point. If fog decreases, these forests will likely become water stressed and decrease growth and reproduction. Fog in this region is not correlated with rainfall, so it is possible to have increases in one and decreases in the other.

One study inferred a 33% reduction in fog from the early 20th century to 2010 (Johnstone and Dawson 2010). If this trend continues, these forests could suffer.

The amount or timing of overcast skies may also change with climate change. A study on Santa Cruz Island off the coast of California found that overcast skies can affect hydrology as much as fog drip (Fischer et al. 2009).

Increase in fires

These forests are relatively well adapted to fires. A slight increase in the frequency or intensity of fires may be beneficial as it could open up canopies, providing suitable habitat for recruitment of these tree species. However, a drastic increase in fire frequency or intensity could be detrimental. In the Big Sur region where these forests are near their southern range limits, frequent fires seem to partially dictate their range limit. An increase in fire would likely lead to less forest and more early-successional communities on the landscape. It may convert forests in to chaparral, woodland, or scrub (see CS-2).

One study in the park found that most fires in the past two centuries occurred late in the season after Douglas fir growth had stopped for the season (Brown et al. 1999). It is possible that hotter, drier summers could cause earlier-season fires, which could be detrimental to these trees. The study also found that large, stand-replacing fires were very rare on this landscape (Brown et al. 1999). This indicates that if large fires occurred more frequently due to climate shifts, the Douglas fir/coast redwood forest could change drastically in dynamics.

Fires can also increase the amount of surface runoff and erosion. A study of runoff in Point Reyes National Seashore after the 1995 fire showed that runoff potential was moderate during storms early after the fire and increased greatly during intense rain bursts later. This was due to preferential paths of water flow under the ash layer becoming clogged, causing the water to take a more destructive above-surface path (Onda et al. 2008).

Increased wind

The effects of increased wind will depend entirely on speed, direction, and timing. Higher winds increase evapotranspiration (all else being equal), but if the winds are blowing on shore, higher winds may lower temperatures enough to at least partially offset the evapotranspiration increase. Increased wind during times of fog could facilitate fog harvest by the trees and benefit the forests.

In addition, increased spring wind coinciding with rainfall could increase pathogen spread in these forests, while an increase in summer or fall could enhance fire spread.

Extremes

The dynamics of these forests are often greatly affected by extremes. Even if average temperature, rainfall, or fog remains constant, these forests can be negatively affected by long or severe droughts or hot periods.

Confounding Factors

Sudden oak death

Hardwood forest trees in the park are host to the pathogenic fungus *Phytophthora ramorum*, which causes sudden oak death. This fungus primarily kills oaks and tanoak. In 2008, centers of sudden oak death infection appeared to be Bolinas Ridge, Bear Valley/Limantour Road and Five Brooks areas. According to this study, as much as 45% of hardwood forests in the park could have been infected with the pathogen. Occurrence of the disease did not seem to be correlated with slope, aspect or elevation; infection was most likely if infected carrier trees (e.g., bay laurel)

were present (Moritz et al 2008). A less virulent relative of sudden oak death, *Phytophthora pseudosyringae* was not found in coast live oak or bay laurel trees in the park 2005 (Wickland and Rizzo 2005). Total disappearance of coast live oak, a sudden oak death worst-case-scenario, could decrease dependent bird populations by 25-68% (Monahan and Koenig 2006).

The main drivers of sudden oak death distribution are climate/microclimate and vegetation. *Phytophthora ramorum* reproduces in bay-laurels and tanoaks, but not in coast live oaks. The fungus has a high rate of infection in California bay laurels, but is not fatal to these trees. However, bay laurel is the most important species as a spreader of the pathogen. Because these drivers co-vary, it may be difficult to predict the impact of sudden oak death in the park as the climate changes, but it does tend to do better in warmer, wetter winters and wetter springs.

Sudden oak death can be brought in on infected plants, especially for restoration projects. Since sudden oak death has already been found in the park, the main concern here is introducing new genotypes or new pathogens all together. *Phytophthora ramorum* thrives under nursery conditions and the pathogen is quite common in nurseries. The disease may be detected if plants are quarantined before introduction.

Sudden oak death can also be spread by horses (transporting mud) and by moving firewood. Although there is a ban on moving firewood out of several coastal counties, people can move firewood within Marin County and possibly bring it to campgrounds at Point Reyes National Seashore. Unburned fire wood can potentially lead to the spread of the disease. The risk from these activities is low although not zero. Spread by horses or hikers would potentially be important in spreading the pathogen within the park; less so introducing it from other locations. Since the disease is established in the park, natural spread of the pathogen is the biggest issue now. But bringing in new genotypes of the pathogen via nursery stock is another big concern.

II. Predictive vegetation mapping

The current PRBO current map matches the Point Reyes National Seashore current vegetation map for these forests in the middle and southern portions of the range (Figures DC-2 and DC-3). The PRBO map shows this forest type as existing farther north up the park side of Tomales Bay than the Point Reyes National Seashore vegetation map does. This is because the PRBO vegetation community type includes hardwood forests which is a separate category in the Point Reyes National Seashore vegetation map. This should be remembered when looking at the predicted vegetation in these maps because they include Douglas fir, coast redwood, and mixed hardwood forests.

The vegetation niche models produced by PRBO for Douglas fir, coast redwood, and montane hardwood forests indicate that the current climatic niche of these forests is not predicted to be very prevalent in the park in 2100. The NCAR-CSM1.2 model predicts small patches of this niche (Figure DC-4) while the GFDL and CCSM models predict no occurrence of this niche in the park in 2100 (at least no patches large enough to dominate on pixel at the model's current resolution). Figure DC-5 shows an overlay of the current distribution of the forests in the park, the modeled current distribution, and the modeled future distribution for the NCAR-CSM1.2 model.

The data used to obtain these predictions may give some insight as to why these drastic niche shifts are predicted. The annual mean temperature, the mean temperature in the warmest quarter, and the precipitation seasonality increase similarly among all three future models. Any or all of these factors may explain the general decrease of the niche for these forests through heat or drought stress. The annual precipitation does not change from current in any of the three models within the current distribution of the species in the park, so this is unlikely to be driving the patterns. Isothermality (“evenness” of temperature as given by the average daily temperature range relative to the annual temperature range) decreases in the GFDL and CCSM models in the areas where these forests are currently found. However, isothermality does not decrease as much in the NCAR-CSM12 model in the areas where it predicts remnant niche patches for these forests. This could indicate that a decrease in isothermality may be detrimental for these forests. The precipitation in the driest quarter decreases in GFDL and CCSM models, but increases in the northern part of the range in the NCAR-CSM12 model. This could also explain the retention of some of the climatic niche for these forest species in the NCAR-CSM12 model.

Fog is very important to these forests, and the models predicting changes in fog are still very uncertain at this point. It is therefore currently difficult to predict the climatic niche of these forests.

The dominant trees in these forests (Douglas firs and coast redwoods) are long-lived, so even if recruitment slows or stops, the existing trees will likely not be gone from their current range by 2100, barring a large fire or disease outbreak. Climatic niches for trees generally affect them most at the recruitment and early growth stage, and large trees are often able to survive in a wide variety of habitats.

When examining the entire range of the two dominant tree species (Figure DC-1) we see that although Douglas fir trees are present much farther south into Mexico, they are not found much farther south on Pacific coast. This could indicate that the climatic coast niche for this tree species may move out of the park if it shifts north with climate change.

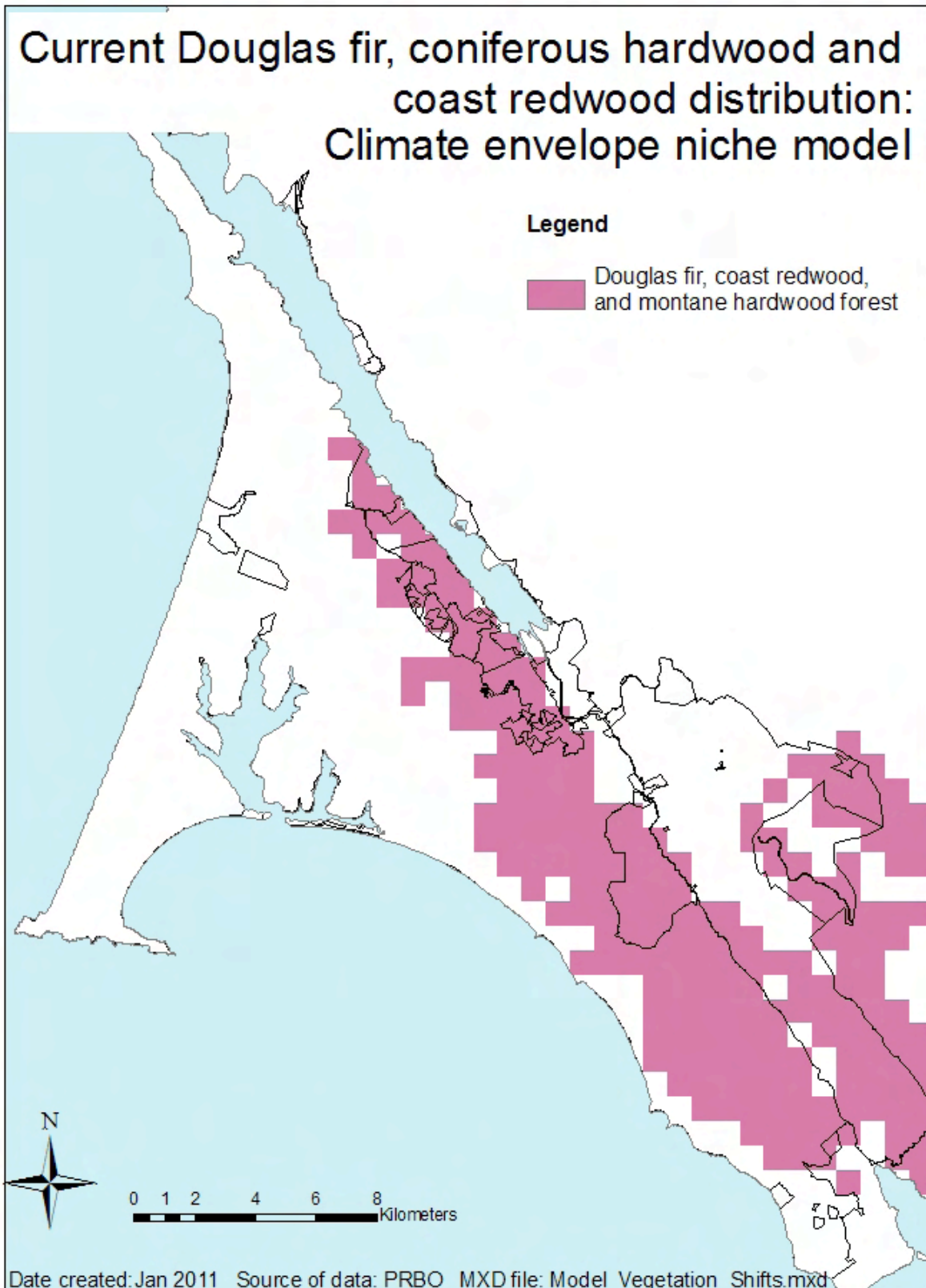


Figure DC-3

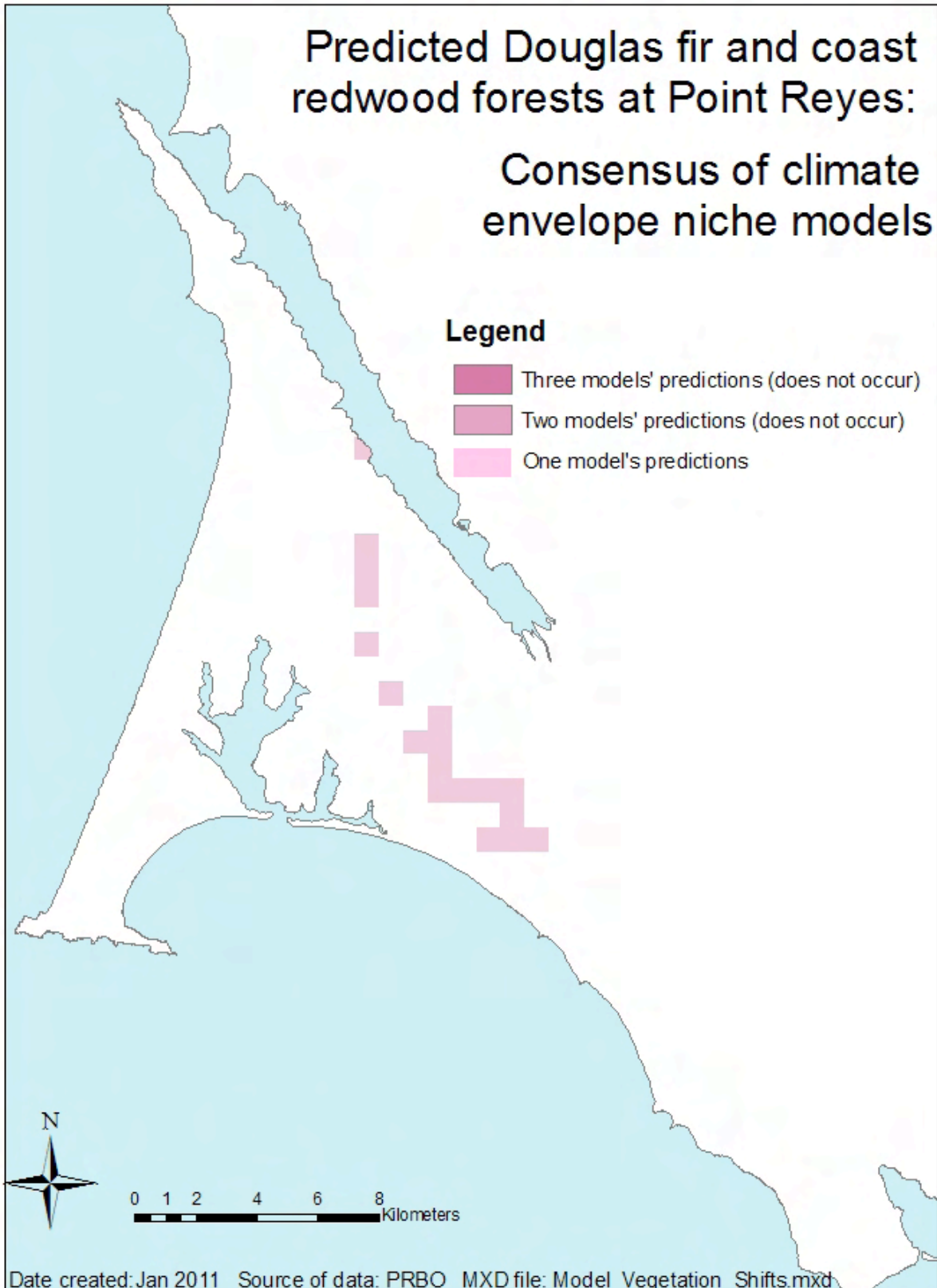


Figure DC-4

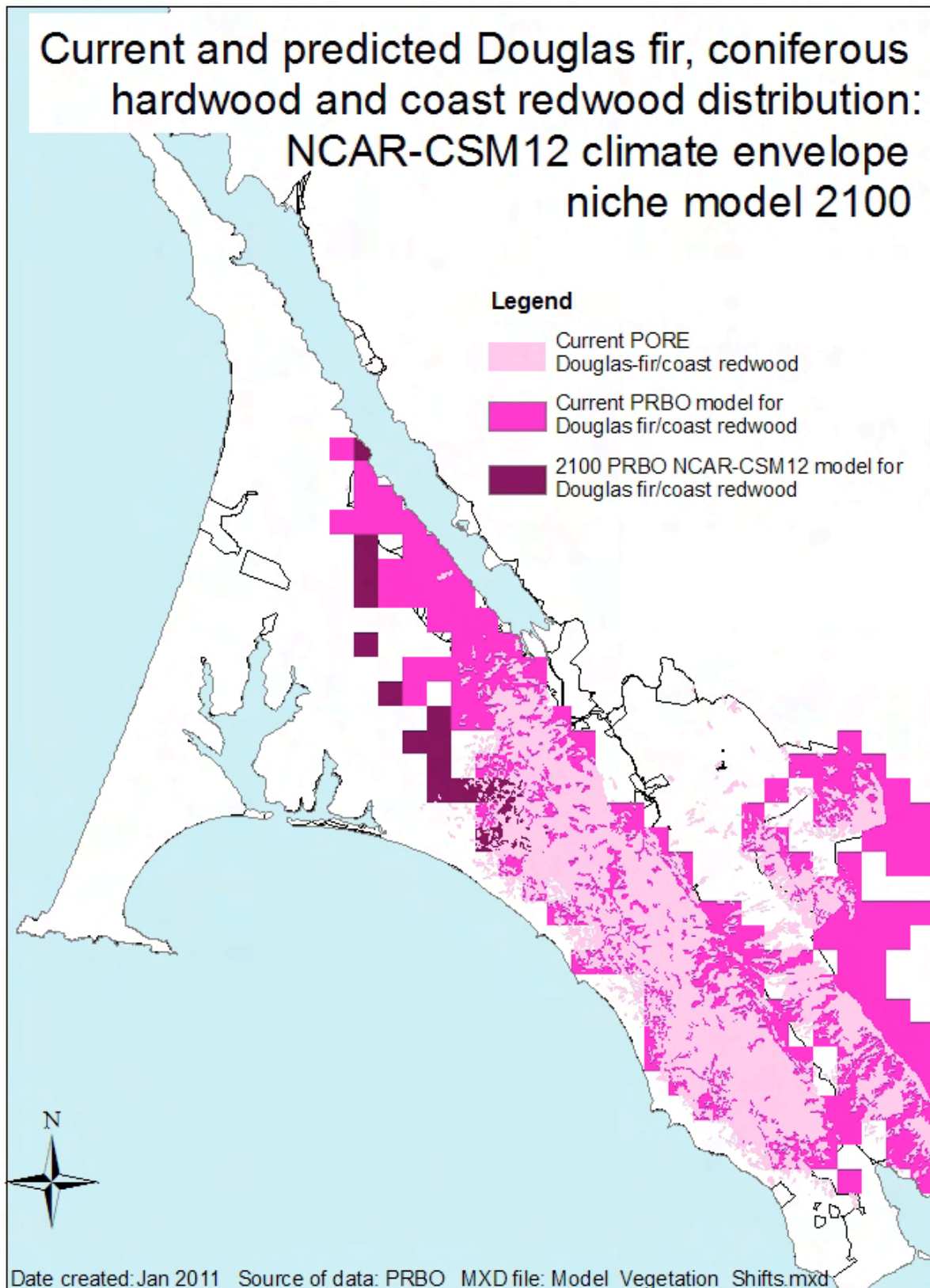


Figure DC-5

III. Predicted coastline changes mapping

Although these forest communities are associated with the coast, they are not found directly on the coast in the park. This means that they will likely experience minimal direct effects from rising sea level (Figure DC-6) or coastal erosion (DC-7) as of 2100.

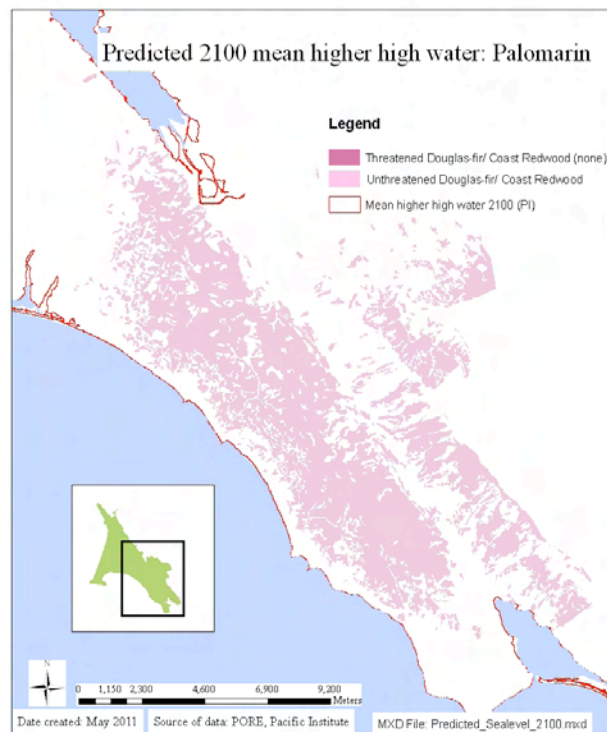


Figure DC-6

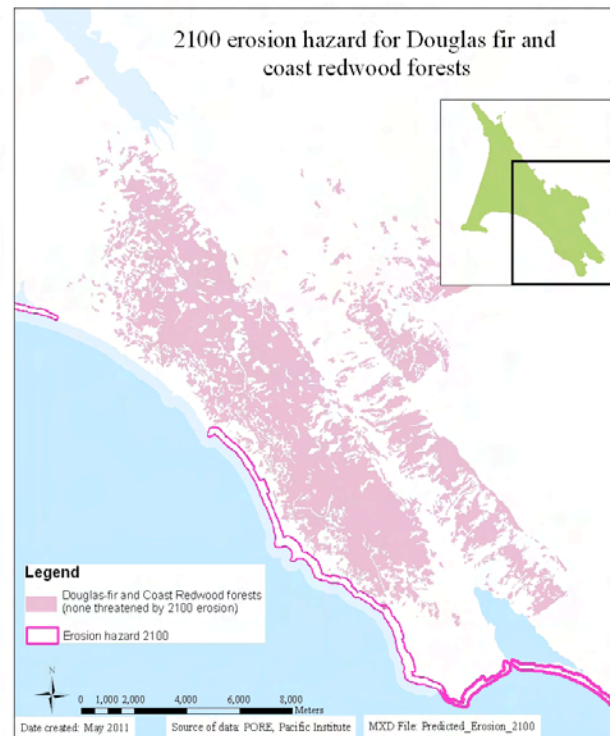


Figure DC-7

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Estuarine communities

Introduction

Estuaries are partially enclosed coastal areas where streams or rivers flow into the ocean. These areas are subject to oceanic influences such as tides and waves, as well as watershed influences such as freshwater flow and sediment, nutrient, and pollutant loads. Estuaries are some of the most productive habitats on Earth. They are found throughout the world, but species composition varies regionally and locally. The park has four estuaries: Tomales Bay, Drakes Estero, Estero Limantour, and Abbotts Lagoon, which are shown by the arrows in Figure ES-1.



Figure ES-1

Estuaries contain specific habitats including salt marshes, mudflats, and eelgrass beds. This summary addresses salt marshes and mudflats; eelgrass beds are discussed in their own summary. Salt marshes are characterized by cord grasses (*Spartina* spp.), salt grasses (*Distichlis spicata*), and pickleweed (*Salicornia* spp.) and are important for many invertebrates and the federally endangered salt marsh harvest mouse (*Reithrodontomys raviventris*). Mudflats generally lack vegetation and have abundant burrowing snails, clams, and worms just below the mud surface. Mudflats in Point Reyes National Seashore are important stopover sites and feeding grounds for many migratory shorebirds and wintering waterbirds.

Coho salmon and steelhead trout migrate through Tomales Bay to travel between their oceanic and freshwater habitats. The population of Coho salmon in the park is part of an evolutionarily significant unit that is federally listed as endangered, and the population of steelhead trout is federally listed as threatened. In addition to the natural estuarine communities in the park, commercial oyster farms exist in both Tomales Bay and Drakes Estero.

I. Expert judgment

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Daniel Howard, Cordell Bank National Marine Sanctuary
John Kelly, Audubon Canyon Ranch
Lorraine Parsons, Point Reyes National Seashore

Effects of a change in climate

Sea level rise

Increased sea level may increase the salinities and tidal influences in estuaries and drive the habitats more inland where space and topography allows. This will be detrimental for organisms that cannot survive with increased salinities, depth, and tidal influences.

Tomales Bay is bounded by steep topography and roads on some sides, so it may be difficult for the communities there to migrate. However, the greatest migration potential in Tomales Bay exists to the south: in the south portions of Giacomini and Bear/Olema Valley. Intrusion of saltwater could lead to increased abundances of some saltwater organisms that reside any estuarine area (Short and Hilary 1999).

If net deposition fails to keep up with rising sea levels, mudflats will not be able to maintain sufficient elevation (Ganju and Schoellhamer 2010). In particular, mudflats are important for shorebird foraging, and increased depth would be detrimental to the birds because of a reduction in the extent of suitable feeding areas. It has been shown in climate change models that much of the important shorebird feeding areas in California will be lost due to sea level rise (Galbraith et

al. 2002). Migrating shorebirds use mudflats in the park as stopover and wintering sites, and their populations may partially depend on the availability of mudflats at this latitude.

Increased precipitation or storm events

Increases in total precipitation or the frequency or severity of storms could increase freshwater flows into estuaries, decreasing salinity. Salinity can be very influential for many estuarine species, and changes in salinity due to climate change have the potential to have large negative impacts on these species (Jenkins et al. 2010).

These precipitation changes would also increase inputs of pollution, nutrients, and sediments (Day et al. 2008). The El Niño year of 1982 may provide a model of possible future scenarios. In that year, increased storms filled some estuarine areas, creek channels, and other areas in the park with sediments.

Shorebird densities will likely decline if there is increased total freshwater runoff or increased intensity or frequency of runoff events and sediment deposition on mudflats (Kelly 2001). These same events could decrease benthic invertebrate abundances and shift invertebrate community composition.

Increased storm frequency or intensity may also enhance wave action, increasing erosion, uprooting of plants, and turbidity in estuaries. Increased turbidity could reduce habitat suitability for visual hunters such as loons and scoters by forcing them to feed less efficiently and, possibly, lead to decreases in their abundance.

Increased freshwater inputs could also reduce the buffering ability of seawater causing changes in the pH or variation in pH of estuaries. This could intensify the effects of ocean acidification in estuarine communities. It is also possible that increased storms could increase the transport of mercury from the watershed and/or increase resuspension of mercury that has settled in Tomales Bay.

Increased temperature

Increases in average or extreme temperatures may alter the biotic community and cause desiccation or heat mortality for some individuals or species. Warmer water holds less dissolved oxygen, so it is possible that warming estuaries will hold less oxygen than they currently do. This has potential impacts for organisms in these areas that are oxygen-limited.

Coho salmon and steelhead trout are near their southern range limits and may be pushed north out of the park by increases in temperature.

A recent study of sediment in the San Francisco Bay from the last ~4000 years showed likely evidence of warming in the past 100 years that affected biota: "... [T]here is the reappearance of the *A. beccarii* - *E. gunteri* association suggesting that, once again, regional warming has taken place, oxygen availability has declined, and/or environmental conditions changed such that diatoms have become a scarce food source." (McGann 2008). This evidence of nearby warming suggests that the estuaries in the park are likely also experiencing warming and will likely have associated biotic changes.

Ocean acidification

Acidification of the Pacific Ocean caused by increases in atmospheric CO₂ concentrations may have negative impacts on organisms in the estuaries. This is especially true for crustaceans, mollusks, and echinoderms because the calcium carbonate they depend on to construct their shells and exoskeletons will become less available in acidified seawater. It has been shown that reduced pH has negative effects on Olympia oysters that persist into the juvenile phase and which have potential demographic consequences for oyster populations (Hettinger et al. 2009). However, acidification may not be as much of an issue in estuaries as in other marine habitats because estuaries are already more highly variable in pH and therefore the resident organisms may be more adapted to changes in pH.

Increase in upwelling

Increased upwelling offshore may be beneficial for some estuarine organisms because there would be a general increase in available food that could be transported into estuaries. Upwelling may also cause colder water temperatures, which can increase the amount of dissolved oxygen in the water.

Increased wind

Increases in wind may cause increased wave action that may lead to more erosion and higher turbidity in shallow waters. It may also be difficult for some organisms to withstand increased wave action and turbidity in the estuaries and more plants may be uprooted. Increased wind may also cause increased upwelling.

Confounding Factors

Giacomini Wetlands restoration

The Giacomini Wetlands Restoration project may mitigate some of the negative impacts of increased flows due to increased precipitation or storm events. In addition to sequestering carbon long term, coastal wetland communities provide important buffers against sea level rise and storm surge. The elevational gradient in the restoration area provides for southward, sea level-induced migration of tidal marshes into the next century (based on IPCC estimate of 1.4m sea level rise).

Oyster farming

Commercial oyster farming operations exist in both Drakes Estero (Drakes Oyster Company) and in Tomales Bay (Tomales Bay Oyster Company, Hog Island Oyster Company). These operations necessarily have ecological consequences in the estuarine communities where they are located due to the presence of the oysters and the activities of the culturists (Committee on Best Practices for Shellfish Mariculture and the Effects of Commercial Activities in Drakes Estero and Board 2009). It remains to be determined whether research of the impacts of various mariculture practices in other estuarine locations are relevant to the oyster farming operations in Drakes Estero and Tomales Bay.

Invasive species

Several non-native species are potentially impacting estuaries in the Park. Invasive, non-native *Spartina alterniflora* and its hybrids with the native cordgrass, *Spartina foliosa*, are a concern in Tomales Bay and Drakes Bay. Tomales Bay has also had periodic establishments by another non-native cordgrass, *Spartina densiflora*. These introduced cordgrasses can penetrate into deeper waters than native species and can out-compete many natives in the shallows and mudflats. The potential loss of intertidal mudflats caused by non-native *Spartina* could reduce the extent of suitable foraging areas for shorebirds.

The invasive tunicate, *Didemnum*, has been found on eelgrass beds in Tomales Bay and Drakes Estero.

Perennial pepperweed, *Lepidium latifolium*, is a high-marsh, upland ecotone species that has come to dominate many of these tidal marsh zones in San Francisco Bay. There are a few occurrences of this species in Tomales Bay, and the concern is that it could rapidly spread through dispersal of seed and rhizomes.

Green crabs may also be a concern as they can out-compete native rock crabs. They are currently abundant in Tomales Bay and Bolinas Lagoon and likely inhabit Drakes Estero.

The New Zealand boring isopod *Sphaeroma quoyanum* destroys marsh banks and accelerates soil loss.

Extractive use

Recreational fishing for halibut and salmon may be detrimental to these species; however, it is likely that the current decrease in salmon populations is not caused by this activity.

Kayaking and boating

Estuarine waterbirds can be negatively impacted by kayaks and other boats if their feeding in shallow coves, marshes, and mudflats is periodically disturbed (Kelly and Tappen 1998). Boating can also scar saltgrass and eelgrass, both of which tend to recover slowly.

Pollution

Pollution inputs from freshwater sources include runoff from roads and dairy farms that carry nutrients, sediment, mercury, and pathogens. Pathogen inputs into Tomales Bay are currently elevated due to faulty septic systems from nearby developments, as well as inputs from agricultural and other livestock operations. Nutrient inputs may also be elevated, although data from the National Park Service and the Tomales Bay Watershed Council suggests that nutrient inputs from the surrounding watershed are probably more episodic in nature and tied to high flow events during and after large storms.

Soil dumping

After mud slides affecting roads, CalTrans sometimes dumps excess soil near tidal marshes. This can contribute to leaching, the spread of invasives, and increased runoff into the marshes in the park.

Damming

Lagunitas Creek is dammed, and input of water, sediment, nutrients, and pathogens into Tomales Bay from this source is determined by the flow through the dam.

Oil Spills

Spilled oil that makes its way into estuaries can have numerous detrimental effects on all organisms residing there. Oil tankers frequent San Francisco Bay, and currents from that Bay frequently move north along the coast to the park. While the southern estuaries are more susceptible to pollution coming from San Francisco Bay, the potential also exists for currents to transport contaminants around the point to Tomales Bay.

II. Predictive vegetation mapping

The vegetation niche models produced by PRBO did not have any community types analogous to estuary communities. These communities are more defined by their location to ocean and freshwater inputs than by specific temperature or precipitation requirements. Because of this, there will very likely be estuaries in the park into the distant future, but individual species which inhabit the estuaries are likely to have climatic niches which they may track. In general, these habitats will shift inland as sea level rises where topography permits.

III. Predicted coastline changes mapping

In these figures the muted color represents habitat that is not expected to be underwater at mean higher high water in 2100. The bold colors are the areas that are expected to be underwater at mean higher high water in 2100 but are not under water according to the Pacific Institute mean higher high water 2000 data. The shoreline shown is the Pacific Institute shoreline for mean higher high water in 2000.

Abbotts Lagoon will likely experience rising water levels, but it is difficult from the Pacific Institute data where this rise will occur. Figure ES-2 shows that the predicted rise by 2100 in this area is already considered water in the vegetation map that Point Reyes National Seashore uses.

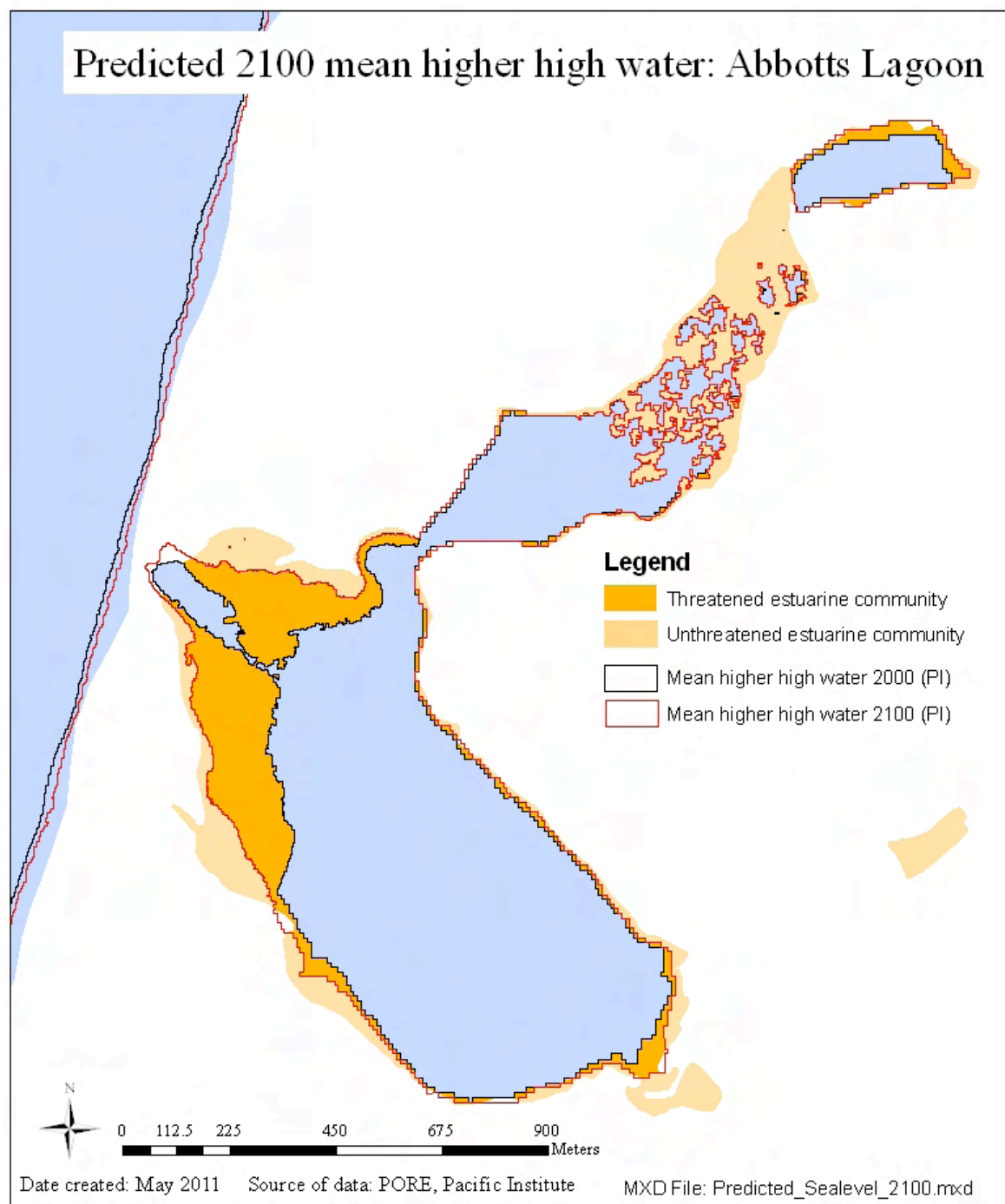


Figure ES-2

Rising sea level could have great impacts on the Giacomini Wetlands (Figure ES-3). However, the restoration of these wetlands was designed with sea level rise in mind.

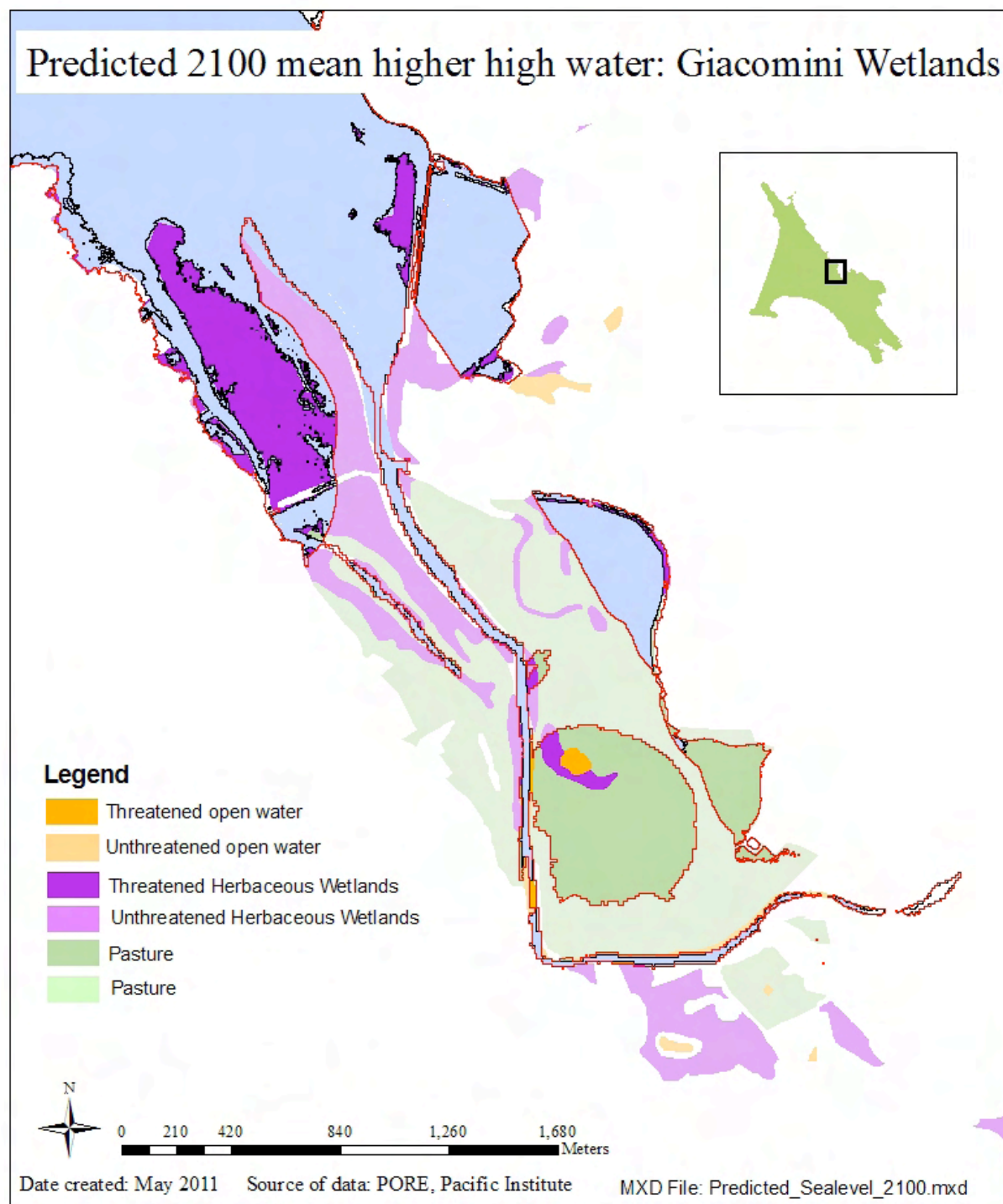


Figure ES-3

Areas of herbaceous wetlands and water near Limantour Beach, Hog Island, Drakes Beach and Drakes Estero that are not currently shown as submerged are predicted to be submerged by 2100 (Figure ES-4-ES-7).

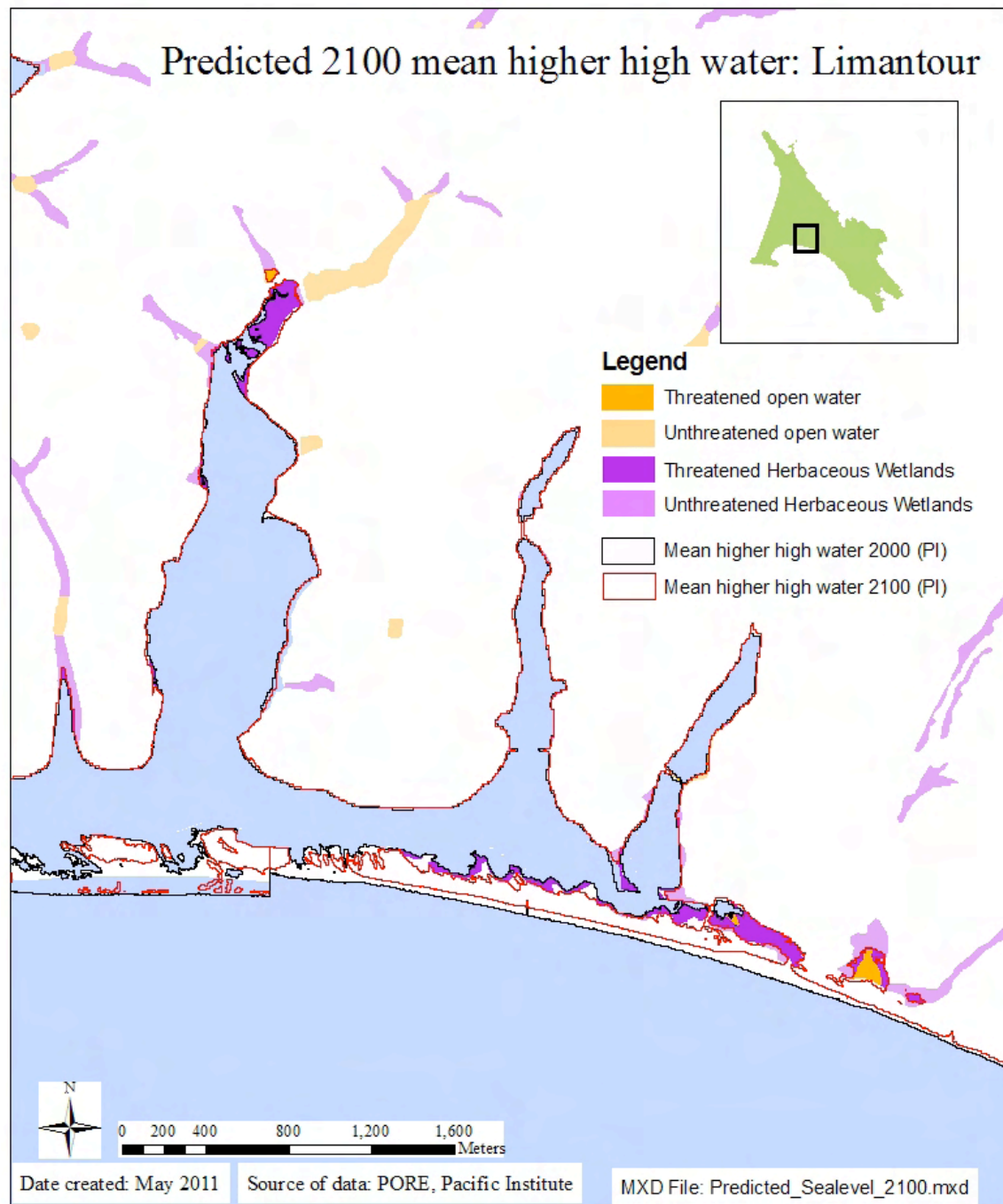


Figure ES-4

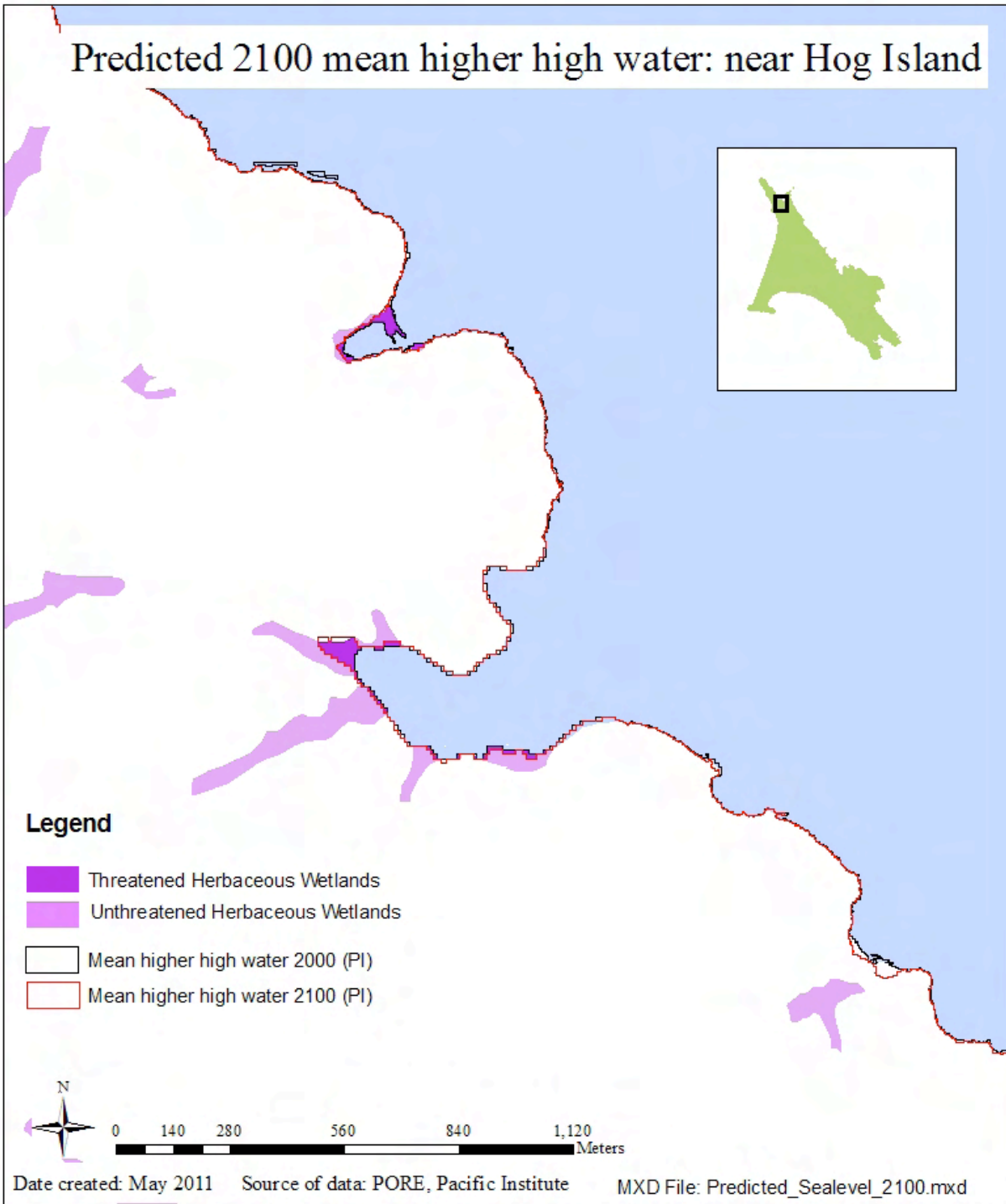


Figure ES-5

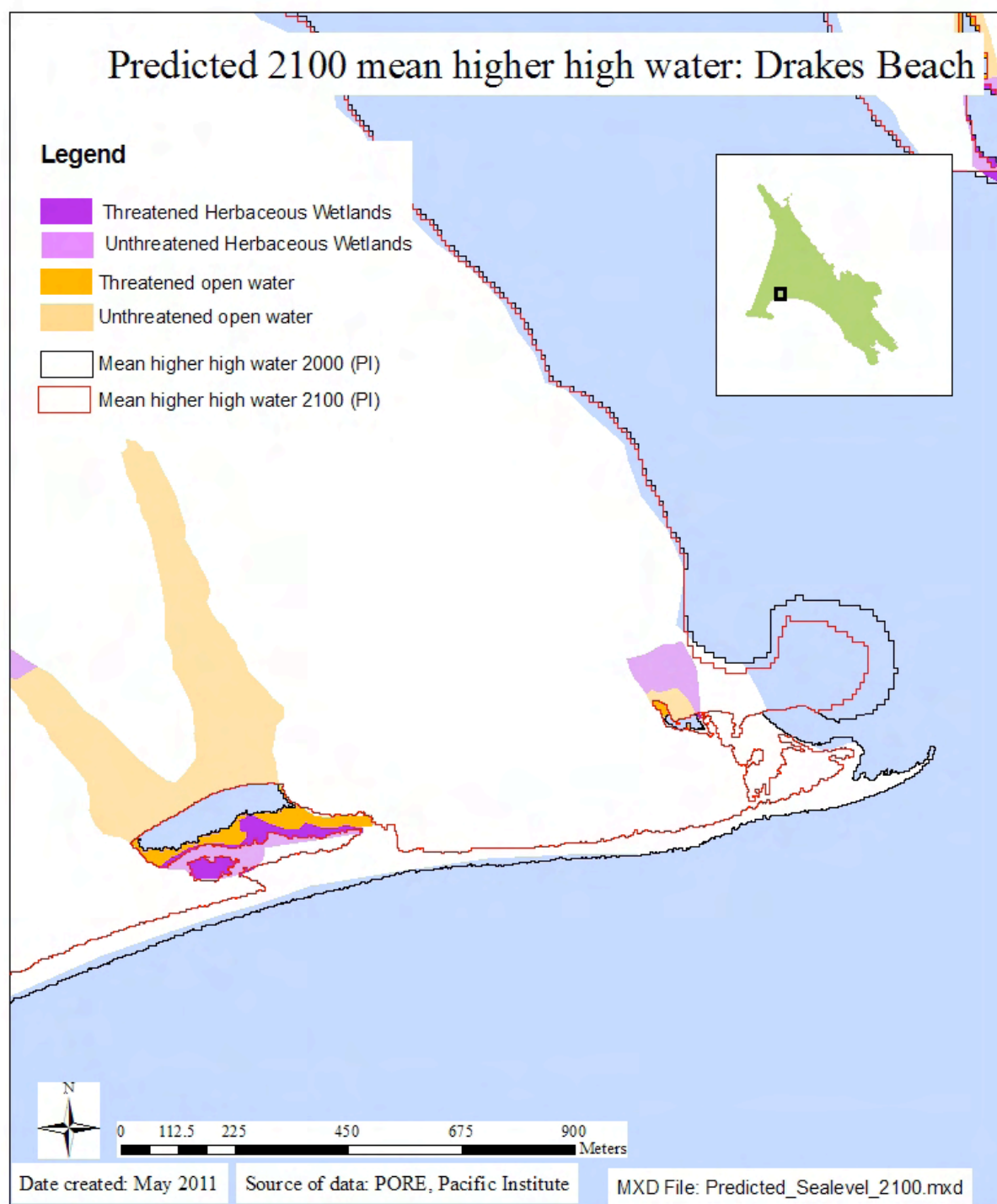


Figure ES-6

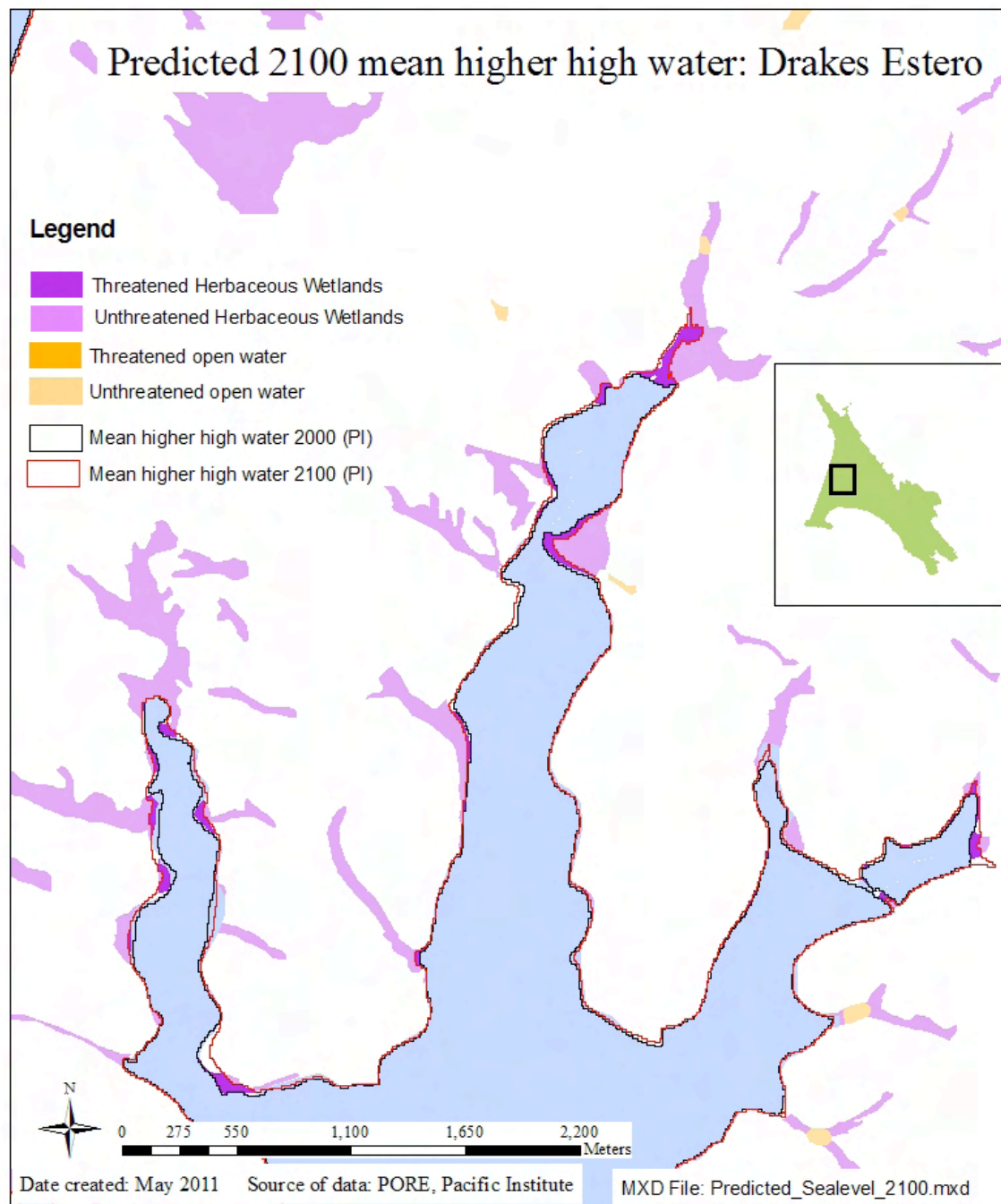


Figure ES-7

Estuaries may have high vulnerability to erosion caused by sea level rise combined with possible increases in storm frequency or intensity.

The herbaceous wetlands in the park are in general not under great erosion risk (Figures ES-8). These maps do not distinguish between salt marshes and freshwater wetlands, but neither of these wetland types are at a large erosion risk because they occur in areas that are relatively protected from storm surges.

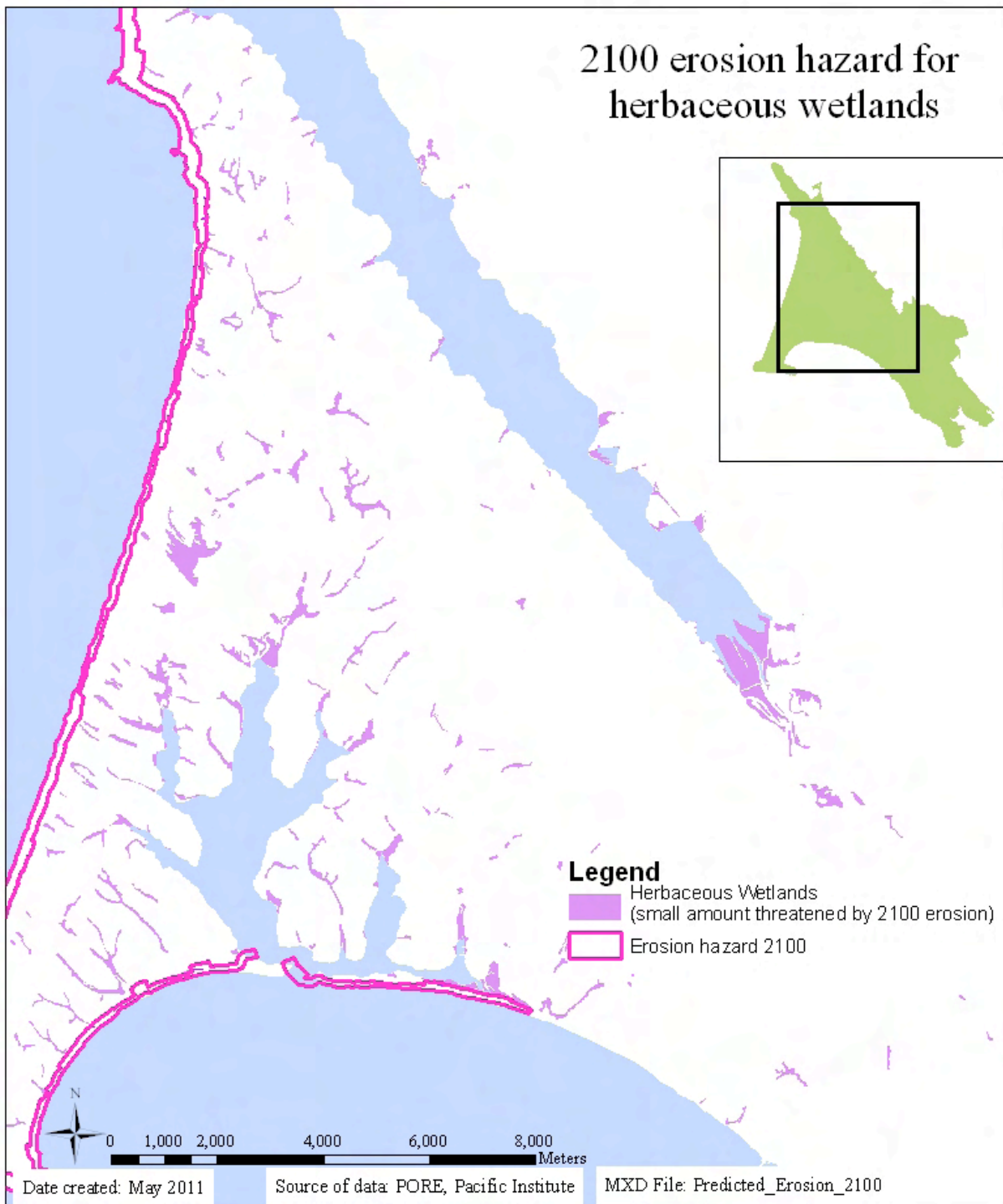


Figure ES-8

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Bay oak hardwood forests

Introduction

Hardwood forests are part of the park's undeveloped coastal environment. Like all communities at Point Reyes, hardwood forests may be susceptible to even minor changes in climatic conditions. The structure of these forests is provided largely by coast live oaks (*Quercus agrifolia*) and California bay laurel (*Umbellularia californica*). Within the Point Reyes, this forest type is found predominantly in the park's eastern portion (Figure BO-1).

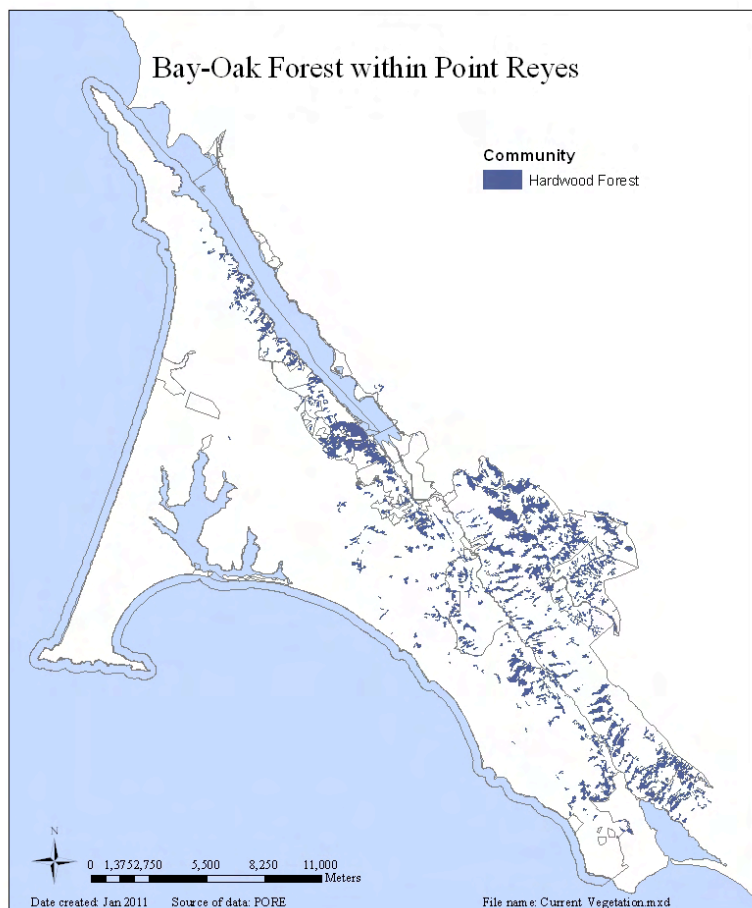


Figure BO-1

Coast live oak extends northward only through Sonoma County, but is found as far as Baja California to the south. Bay laurel's range extends northward through Washington, but only exists in patches south of Big Sur. While coast live oak and bay laurel both have broad ranges, the community defined by this association only exists from Sonoma through Monterey County. Neither species is near its elevational or inland range limit at Point Reyes.

I. Expert judgment

Effects of a change in climate

Contributing experts:

Geoffrey Geupel, PRBO Conservation Science

Joe R. McBride, University of California, Berkeley

David Rizzo, University of California, Davis

Increase in temperatures

An increase in temperature alone does not threaten coast live oaks. An increase in temperature could threaten bay laurels. This forest type could see a shift to dominance by coast live oaks with increased temperatures.

The root pathogen, *Phytophthora cinnamomi*, may be more influential under warmer conditions. Currently, this pathogen kills madrones and bay laurels in warm dry conditions. On the other hand, it can kill coast live oaks in warm wet conditions. Often, urban coast live oaks in southern California that are overwatered are susceptible to this pathogen.

At Point Reyes, hardwood forest communities are important for rare and threatened species including the northern spotted owl (*Strix occidentalis caurina*) and various lichens. Northern spotted owls choose roosting sites based on microclimate; specifically, they prefer summer roosting sites where temperatures do not exceed 29°C. Historically, temperatures at Point Reyes have not reached 29°C and have not driven the distribution of nest site selection by the owls in the park (Barrows 1981). A sufficient increase in temperatures could cause habitats in the park to be unsuitable for these birds.

Lichens, however, are quite sensitive to temperature conditions. In the Pacific Northwest, small changes in mean minimum temperature (1-2°C) and forest type strongly affect whether certain species are found (Glavich et al. 2005).

Change in precipitation

Currently coast live oaks and bay laurels compete for soil moisture at Point Reyes. A change in precipitation may shift this competitive dynamic.

Bay-oak hardwood forest communities are important for rare and threatened species including various lichens. Lichens are quite sensitive to climatic conditions. In the Pacific Northwest, moderate changes in precipitation (change in the mean of days with measurable precipitation of 25-50 days) and forest type strongly affect whether certain species are found (Glavich, Geiser et al. 2005).

Hardwood forests are also important for other more common groups. Land-birds at Point Reyes, including species found in hardwood forests, are most productive at rainfall levels at or slightly above average, with pronounced drops in years with very high or very low rainfall (DeSante and Geupel 1987). Land birds, including woodpeckers, flycatchers, swallows, sparrows, finches and warblers, are integral to the dynamics of these forests.

Tanoak (*Lithocarpus densiflorus* var. *densiflorus*) is also important in bay-oak hardwood and other forests at Point Reyes. Tanoaks produce notably large quantities of acorns, which feed insects and vertebrates at Point Reyes. Recent work on the genetics of this species suggests that two major groups are present in California, which differentiated during the Pleistocene, possibly as a result of climatic fluctuations. Coastal California populations may have diverged from southern Oregon populations during more recent climatic changes, perhaps the Last Glacial Maximum. Tanoaks thrive in more humid climates, and dry cool conditions during glacial periods could have led to bottleneck-type near extinctions in the species (Nettel, Dodd et al. 2009). Drier climates may threaten this tree.

On the other hand, tanoaks are the most susceptible species to the sudden oak death pathogen. This pathogen thrives in wetter climates, so wetter conditions may also see high tanoak mortality rates. With an increase in precipitation (especially if winters are warmer or already warm springs are wetter), sporulation of the fungus, *Phytophthora ramorum*, will increase. This fungus is responsible for the plant disease known as sudden oak death. Sudden oak death affects many tree and shrub species in addition to tanoaks. Currently, warm wet springs are followed two years later by increased mortality of coast live oaks. The oaks are then replaced by more bay laurel trees. Bay laurels carry the disease (but are not killed by it), which could feed back and lead to a dramatic decrease of coast live oaks. This could, in turn, decrease dependent bird populations by up to 25-68% (Monahan and Koenig 2006).

With a decrease in precipitation, *P. ramorum* will sporulate less and less, but will not be eliminated. Coast live oaks are killed by the pathogen, but are also a reproductive dead-end for *P. ramorum*. The fungus sporulates in bay laurel and tanoak, both of which may decrease in number with lower precipitation.

It is also possible that a decrease in precipitation could facilitate the northward movement of the gold-spotted oak borer. This beetle currently causes damage to coast live oaks in San Diego County.

Change in wind patterns

Airborne spores are important for *P. ramorum* dispersal, and the pathogen rarely moves against the wind. A change in wind patterns could bring a change in the distribution of sudden oak death at Point Reyes.

Confounding factors

Sudden oak death

Hardwood forest trees in Point Reyes are host to the pathogenic fungus *Phytophthora ramorum*, which causes sudden oak death. This fungus can kill oaks and other hardwood species. The fungus has a high rate of infection in California bay laurels, but is not often fatal to these trees. In 2008, centers of sudden oak death infection appeared to be Bolinas Ridge, Bear Valley/Limnata Road and Five Brooks areas (Moritz et al. 2008). According to this study, as much as 45% of hardwood forests in the park could have been infected with the pathogen. Occurrence of the disease did not seem to be correlated with slope, aspect or elevation; infection

was most likely if infected carrier trees were present (Moritz et al. 2008). A less virulent relative of sudden oak death, *Phytophthora pseudosyringae* was not found in coast live oak or bay laurel trees in Point Reyes 2005 (Wickland and Rizzo 2005). Total disappearance of coast live oak, a sudden oak death worst-case-scenario, could decrease dependent bird populations by 25-68% (Monahan and Koenig 2006). There is little evidence, however, that coast live oak will disappear, especially considering that a fair proportion of the population is resistant to the disease.

Phytophthora ramorum reproduces in bay-laurels, tan oaks and madrones, but not in coast live oaks. The main drivers of sudden oak death distribution are climate/microclimate and vegetation. Because these drivers co-vary, it may be difficult to predict the impact of sudden oak death in the park as the climate changes.

The largest concern with sudden oak death is infected plants being introduced to the park, especially for restoration projects. Since sudden oak death has already been found in the park, the main concern is introducing new genotypes or new pathogens all together. *Phytophthora ramorum* thrives under nursery conditions and the pathogen is quite common in nurseries. Quarantining nursery plants for a few weeks after they have been brought in to the park may help in detecting sudden oak death infection.

Sudden oak death could also be spread within the park by horses and hikers transporting mud. Since the disease is established within the park, however, natural spread may be a bigger issue.

II. Predictive vegetation mapping

The mapped current distribution of bay-oak hardwood forests shows some areas of overlap with current data provided by PRBO (Figure BO-2). Areas of mismatch are likely due to both differences in nomenclature in mapping vegetation community types, as well as the 800m scale of the climate data requiring PRBO to average the vegetation in each of those 800m cells.

Two models predict (Table BO-1) elimination of climate that is suitable to montane hardwood, conifer and coast oak vegetation communities (Figure BO-3). A third model predicts that the peninsula will be dominated by climates that are suitable to this vegetation community.

Table BO-1: Vegetation predictions are based on these GCMs , time points and conditions		
Climate Model	Time of prediction	Atmospheric CO₂
NCAR-CSM1.2	2080-2099	653-686 ppm
NCAR-CCSM 3.0	2038-2069	478-610 ppm
GFDL-CM 2.1	2038-2070	478-615 ppm

The enormous degree of disagreement between these models highlights the uncertainty surrounding this community type's future existence at Point Reyes. Many species making up montane hardwood, conifer and coast oak habitat may be dependent on wetter climates, while some, including coast live oak, thrive under conditions drier than currently found at Point Reyes. Interviews with experts highlight that dominant trees, bay laurel and coast live oak, have

contrasting climate requirements and that pathogens play an important role in the dynamics of these forests. These observations may serve to compliment the outputs of predictive vegetation models.

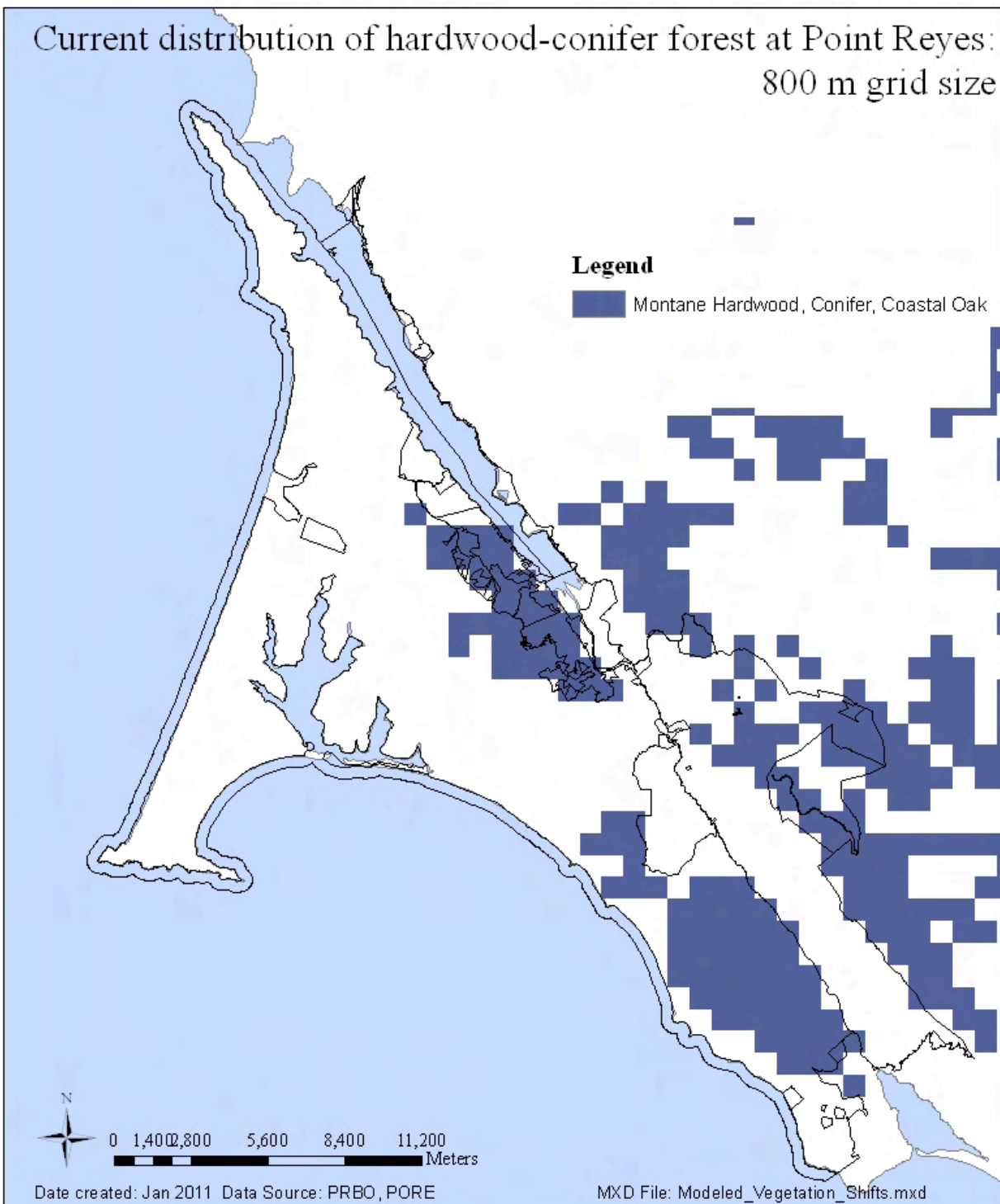


Figure BO-2

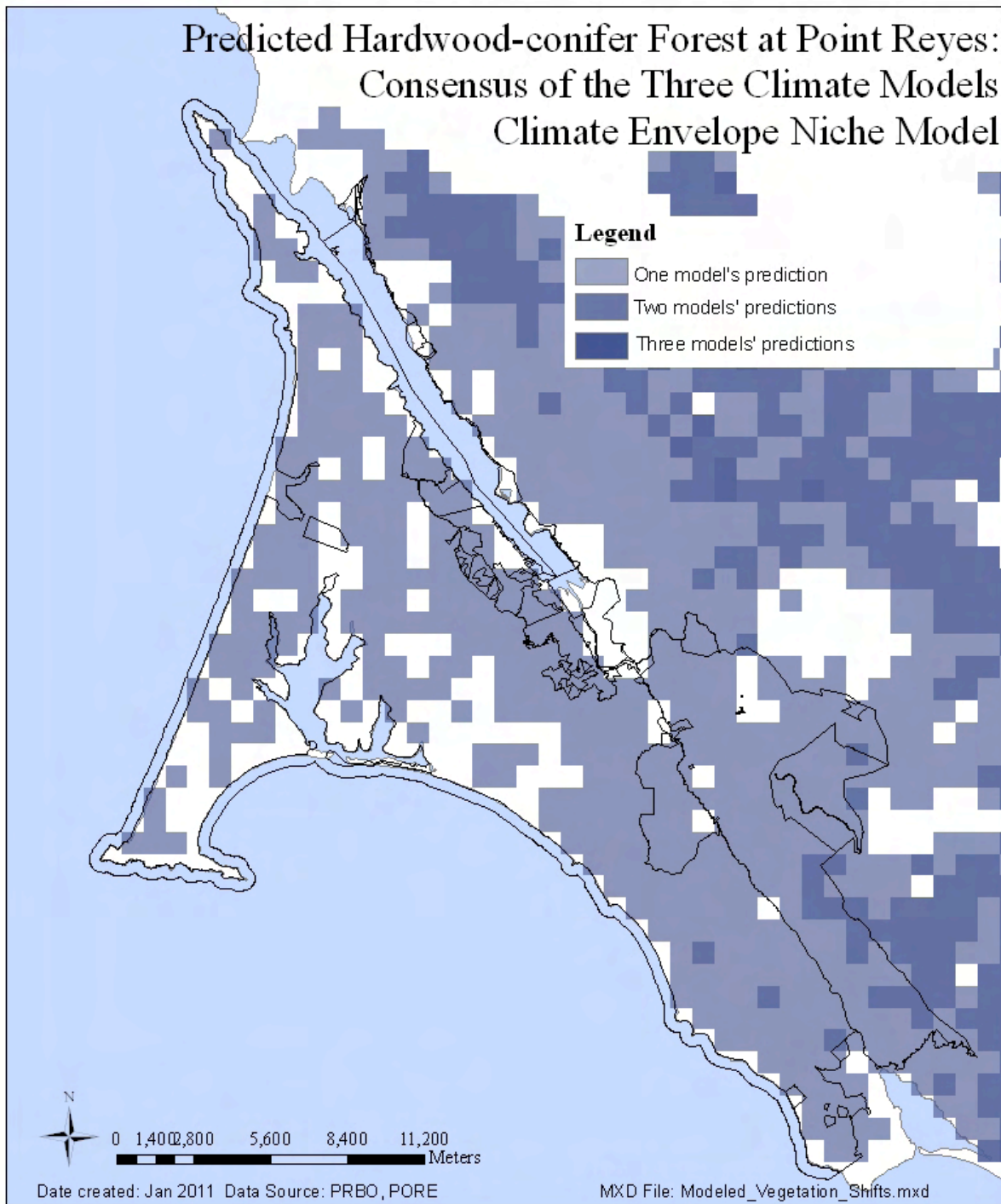


Figure BO-3

III. Predicted coastline changes mapping

Models predict a rise in the mean higher high water along the Pacific coast of approximately 1.4 meters by 2100. While these models do not include glacial melt waters, and are likely a significant underestimate of actual rises in sea level, they do highlight areas at risk of inundation. As a whole, the bay oak hardwood forests at Point Reyes are found inland and not at risk for inundation (Figure BO-4). Some bay oak forest along Tomales Bay may be directly affected by a rise in sea level. However, these areas may be highlighted only because of mapping errors and discrepancies in where the actual coast is currently located.

It is possible that a rise in sea level could force shoreline communities upslope and displace bay oak hardwood forests along Tomales Bay. It is also possible that other secondary effects of a rise in sea level could affect bay oak forests.

It is unlikely that bay oak hardwood forests will be threatened by erosion (Figure BO-5). There is a sliver of bay-oak forest located near Bolinas that may be at erosion risk, however (Figure BO-6).

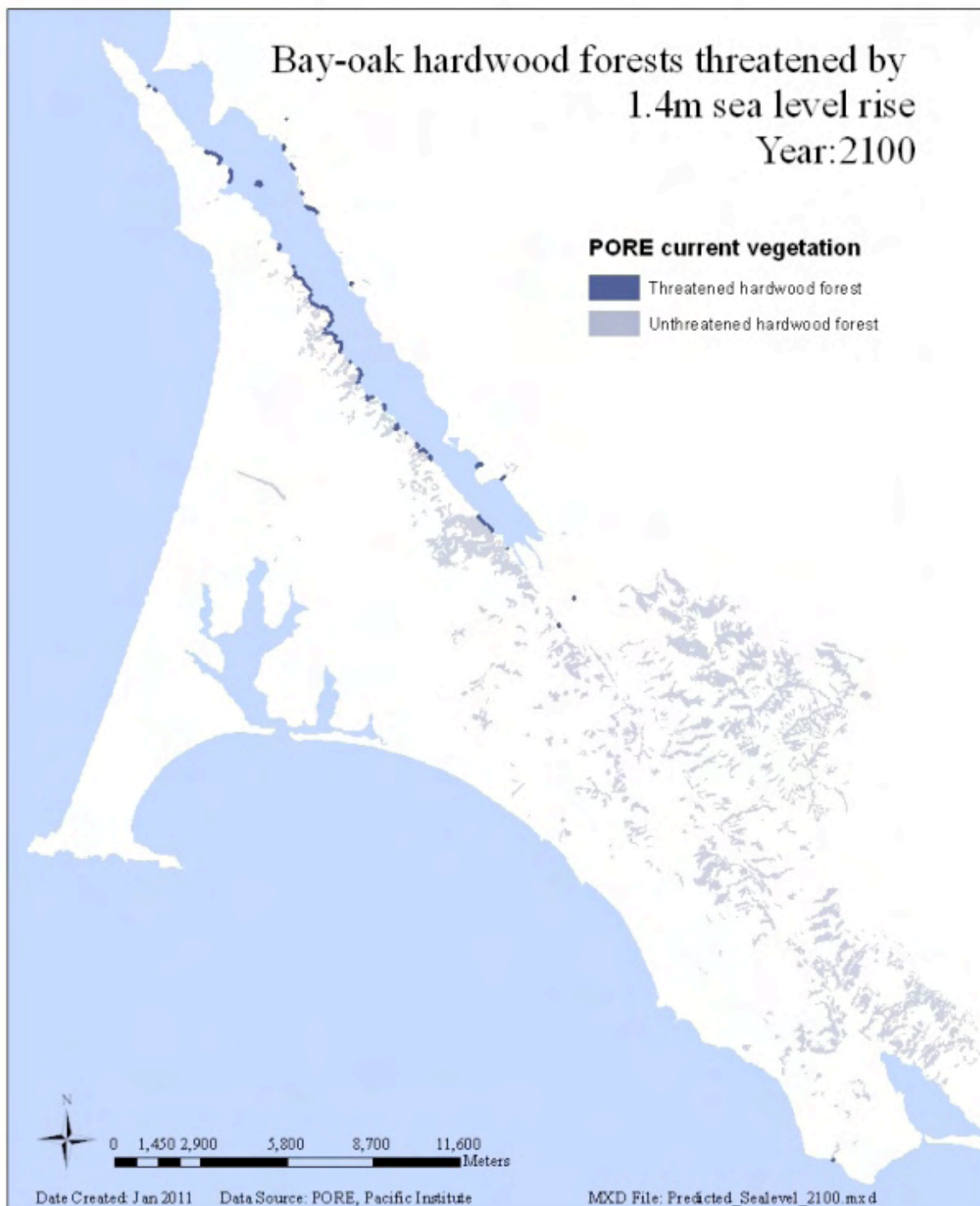


Figure BO-4



Figure BO-5

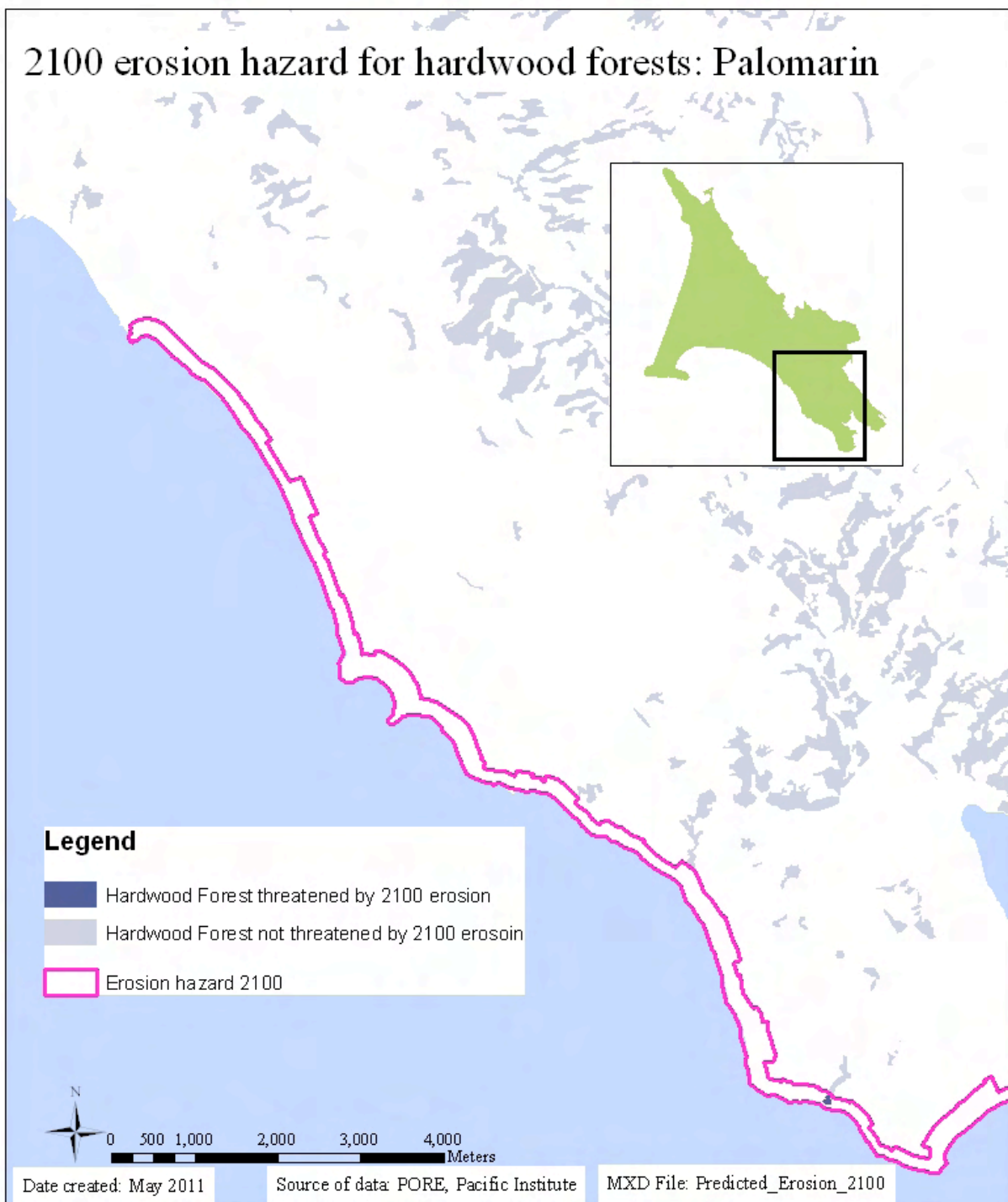


Figure BO-6

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Sandy beaches and coastal dunes

Introduction

The sandy beaches and coastal dunes in Point Reyes National Seashore are primarily located along the northwestern coast of the park – Great Beach – and along the south-facing coast – Drake’s Bay. Park GIS data lump sandy beaches and mudflats into the same category; all but the area inside Drakes Estero appears to designate sandy beach communities, however (Figure SD-1). Sandy beach and mudflat communities cover approximately 419 acres in the park (NPS and USGS 2004, see Appendix C). Park GIS data are divided into two categories of coastal dunes, named “Coastal Dunes” and “Dunes” (Figure SD-1). “Coastal Dunes” refers to the dunes of the strand line backing the sandy beaches, while “Dunes” may reflect dune communities that are not part of the strand, such as those on Point Reyes and near Double Point. Taken together, these dune communities comprise approximately 2,300 acres of the park.



Figure SD-1

Sandy beach communities are intertidal communities defined by their sand, wave and tide regimes. The morphology of sandy beaches ranges from narrow and steep – reflective – to wide and flat – dissipative (Schlacher et al. 2008). Great Beach is a more reflective beach and the beaches along Drake’s Bay are more dissipative. Beach communities are linked to both nearshore surf zones and coastal dunes trophically and through the exchange of sand (Defeo et al. 2009). Waves and local tidal cycles create habitat zones across elevation in sandy beach communities. Seaweed and plankton transported onto the beaches form the foundation of the food web in these communities (Dugan et al. 2003). Invertebrates tend to live in the beach wrack or in the sand where they can move up and down the beach to follow the tide. Gulls, sandpipers, and other shore birds feed on the invertebrates in this community as well as on the beach wrack. Sandy beaches also provide important haul-out, mating, and pupping sites for elephant seals and other pinnipeds in the park, and sandy beach surf zones serve as important nursery and foraging areas for fishes (Schlacher et al. 2008).

The coastal sand dunes that lie just above the intertidal beaches in Point Reyes are home to many plants, both native and exotic. Salt spray provides nutrients to these otherwise nutrient-poor communities (Barbour et al. 1985, as cited in Pickart 2008). The sand dunes of Point Reyes lie in a latitudinal transitional zone – they include northern species, southern species, and some California endemic species, so the community is rich in species and some of the species in this transitional zone are near their latitudinal range limits. Of particular interest is the native dune grass, *Leymus mollis*. Beach layia (*Layia carnosa*) and Tidestrom’s lupine (*Lupinus tidestromii*) are federally endangered plant species found along dunes in Point Reyes National Seashore. Shore birds congregate in the dunes – one of these is the Western snowy plover (*Charadrius nivosus*), a federally threatened species that nests in the coastal dunes. The federally endangered Myrtle’s silverspot butterfly (*Speyeria zerene myrtleae*) uses some of the dune plants as nectar sources.

I. Expert judgment

Contributing experts:

Sarah Allen, Point Reyes National Seashore
Michael Barbour, University of California, Davis
Dan Howard, Cordell Bank National Marine Sanctuary
Joe McBride, University of California, Berkeley
Lorraine Parsons, Point Reyes National Seashore

Effect of a change in climate

Temperature & Precipitation Changes

Disagreement exists on the likely responses of sandy beach and coastal dune communities to temperature changes. Species composition may change due to temperature changes (Jones et al. 2007). Sand dune communities could remain largely unchanged, however, because vegetation along the strand (sandy beaches and dunes) is thought to be determined more by local stresses than by regional climate. Warmer temperatures might result in the reduced presence of some species in the park that are generally near the southern extent of their latitudinal ranges (e.g. deerweed – *Lotus scoparius* and yellow bush lupine – *Lupinus arboreus*), and increased abundance of the plant species closer to their northern range limit (e.g. California sagebrush – *Artemisia californica* and native sand verbena – *Atriplex leucophylla*). However, coastal dunes are thought to be “azonal” – determined more by the presence of loose sand, salt spray and salt water tides, sand blast, and the local fog regime rather than regional climate. Relatively small temperature changes may therefore not have much of an impact on these communities.

Migratory birds that spend part of the year on sandy beaches and coastal dunes in Point Reyes may exhibit different migration patterns due to changes in temperature across a broad latitudinal gradient. For example, if temperatures are warmer further north, then some birds may not migrate as far south as Point Reyes to breed, changing the seasonal structure of the dune’s avian community.

Seawater temperature changes could impact sandy beach and dune communities in Point Reyes by changing the plankton that are transported onto sandy beaches and form the foundation of the food web. Small increases in temperature ($\sim 0.6^{\circ}\text{C}$) have been associated with large changes in planktonic communities in the North Atlantic (Richardson and Schoeman 2004, Richardson 2008). Changes to the planktonic communities in the region around the park could result in changes to the food web of the strand.

Sea Level Rise

Where sandy beach and coastal dune communities are able to migrate inland with sea level rise, they will likely do so (Zhang et al. 2004). Where they can not migrate inland, the communities may be lost (Dugan et al. 2008). The ability to migrate not only depends on the availability of undeveloped area and substrate inland, but also on whether coastal dunes have been stabilized by invasive species such as European beachgrass. Once established, European beachgrass limits the ability of the dunes to move. Sea level rise may also result in increased rates of erosion, which could change beach morphology and cause increased loss of dune communities if they are not able to move inland due to development or the presence of stabilizing invasive species.

Dissipative beaches, such as those on Drake's Bay, are thought to be the most sensitive to sea level rise because they tend to be more erosive and will experience greater swash run-up on their gentle gradients (Defeo et al. 2009).

Any losses of beach and coastal dune habitats in the park will have important ramifications for the seabirds and marine mammals that rely on these habitats for reproduction, food, and rest.

Increased Extreme Storm Events

Storm events have important implications for beach building and beach erosion – such storms will likely change the morphology of Point Reyes' beaches. Larger waves associated with severe storm events are predicted to increase, and are likely to increase coastal erosion rates. However, the increased precipitation associated with such storms would also lead to increased sediment loads coming from rivers and streams that could reach outer coastal areas and contribute to onshore beach building. This increased sedimentation may result in the beaches being built up further offsetting beach erosion from larger waves.

Increased wind could have a major impact on dune morphology due to its ability to both erode and form sand dunes. Additionally, snowy plover nests are often lost during storm events, so an increase in severe storm events could threaten the snowy plover populations in Point Reyes National Seashore.

If increased storm events have a strong negative effect on nearby kelp forests, less drift kelp may wash up onto the park's beaches, reducing a primary facet of the sandy beach community food web.

Changes in Ocean Chemistry

Since Point Reyes lies in an upwelling cell, its marine communities are exposed to the more acidified waters that are transported onto the continental shelf (Feely et al. 2008). Increasingly acidified seawater will directly affect all organisms that form calcium carbonate structures and

indirectly affect the rest of the community through trophic and other inter-special interactions (Jones et al. 2007). On sandy beaches, mole crabs, beach hoppers, and other amphipods – organisms that comprise much of the lower levels of the food chain on sandy beaches – form calcium carbonate structures. The larval stage of these invertebrates may be most sensitive to ocean acidification (Doney et al. 2009), which means that more acidified seawater may result in less recruitment of these organisms.

Confounding factors

Invasive Species

Coastal dunes have been heavily impacted by exotic species such as European beachgrass (*Ammophila arenaria*) and ice plant (*Carpobrotus edulis*). These species displace native plants and native wildlife species. Ice plant has been shown to have negative residual effects on the germination, survival, growth, and reproduction of the rare dune annual *Gilia millefoliata* due to its impacts on the soil (Conser and Connor 2009). European beachgrass builds a steep continuous foredune ridge that slows the flow of sand to the region behind the foredune, reducing an abiotic stress that keeps the environment patchy and increases species diversity, according to research in Australia (Webb et al. 2000). It reduces the amount of sparsely vegetated habitat that western snowy plovers prefer (USFWS 2007). Invasive species indirectly impact rare species by increasing habitat for plover predators and for predators of Tidestrom's lupine seeds (deer mice).

Trampling

Sandy beach and coastal dune communities are very sensitive to trampling. Trampling opens up more of the sand surface in coastal dunes to winds that can erode the dunes – only the most tolerant plants can survive trampling (Defeo et al. 2009). Trampling is likely to increase with the likely increase in park visitation associated with rising temperatures in interior valleys and the area's increasing population.

Oil Spills

Point Reyes is positioned to potentially feel the impacts from any major oil spill in or around San Francisco Bay, due to coastal oceanographic patterns. Sandy beaches on the south side of Point Reyes are particularly susceptible to the degrading effects of oil spills in the bay because coastal currents that flow from San Francisco Bay up to the south side of Point Reyes, and because they are more sheltered beaches, less well flushed by wave action (Sindermann 1996, as cited in Defeo et al. 2009). Oil has sometimes been found on the west-facing Great Beach following an oil spill in San Francisco Bay, however. Oil spills affect all trophic levels on sandy beaches (Suderman and Thistle 2003) and may have acute as well as long-lasting impacts in these communities (Irvine et al. 2006).

Marine Debris

In addition to seaweed, sea grass, and the carcasses of marine organisms, the beach wrack on the beaches of Point Reyes also frequently contains plastic. Some of this plastic enters the sandy beach food web and has deleterious effects on the community.

II. Predictive vegetation mapping

The climate envelop models created by PRBO (Stralberg et al. 2009) do not include predictions for sandy beach or coastal dune communities.

III. Predicted coastline change mapping

Sea level rise and the potential increase in wave action will necessarily affect sandy beach and coastal dune communities in Point Reyes, as discussed by the experts on these community types (Sandy beaches and coastal dunes, I. Expert Judgment). The exact patterns of sea level rise and wave activity sandy beaches and coastal dunes in the park will experience are unknown, as is the responses these communities will have to changing conditions. We can, however, quantify and spatially identify the areas that may be most impacted according to the Pacific Institute's models for mean higher high water and erosion hazard areas for the year 2100.

By laying the spatial data of the Pacific Institute's model for 2100 erosion hazard areas over Point Reyes National Seashore's spatial community type data, we were able to calculate estimates of the area and proportion of each community type that falls within erosion hazard areas (see Appendix C). Approximately 73% of the parks sandy beach and coastal dune communities (2000 acres) fall within the 2100 erosion hazard area (Figures SD-2, SD-3, SD-4, and SD-5). This is not surprising since sandy beach communities are largely intertidal and much of the coastal dunes communities lie on the strand, just above the current high tide.

Important to note is that the 2100 erosion hazard area maps can not predict the degree to which sandy beaches and dunes may be built up or may migrate inland from their current locations.

2100 erosion hazard for sandy beaches and coastal dunes: Great Beach south and Pt. Reyes Headlands

Legend

-  Beaches or Mudflats threatened by 2100 erosion
-  Beaches or Mudflats not threatened by 2100 erosion
-  Coastal Dunes threatened by 2100 erosion
-  Coastal Dunes not threatened by 2100 erosion
-  Dunes threatened by 2100 erosion
-  Dunes not threatened by 2100 erosion
-  Erosion hazard 2100



Date created: May 2011

Source of data: PORE, Pacific Institute

MXD File: Predicted_Erosion_2100

Figure SD-2

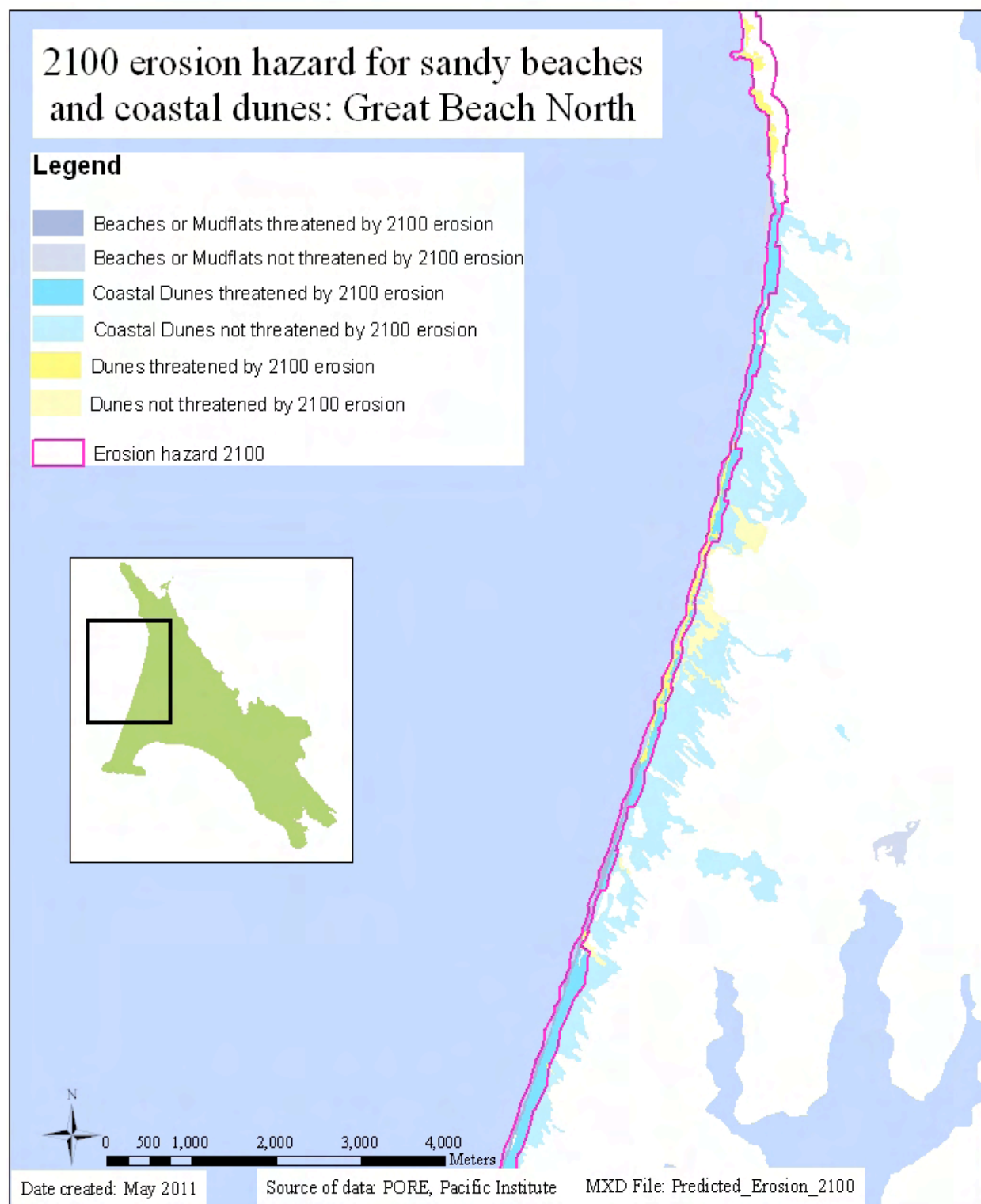


Figure SD-3

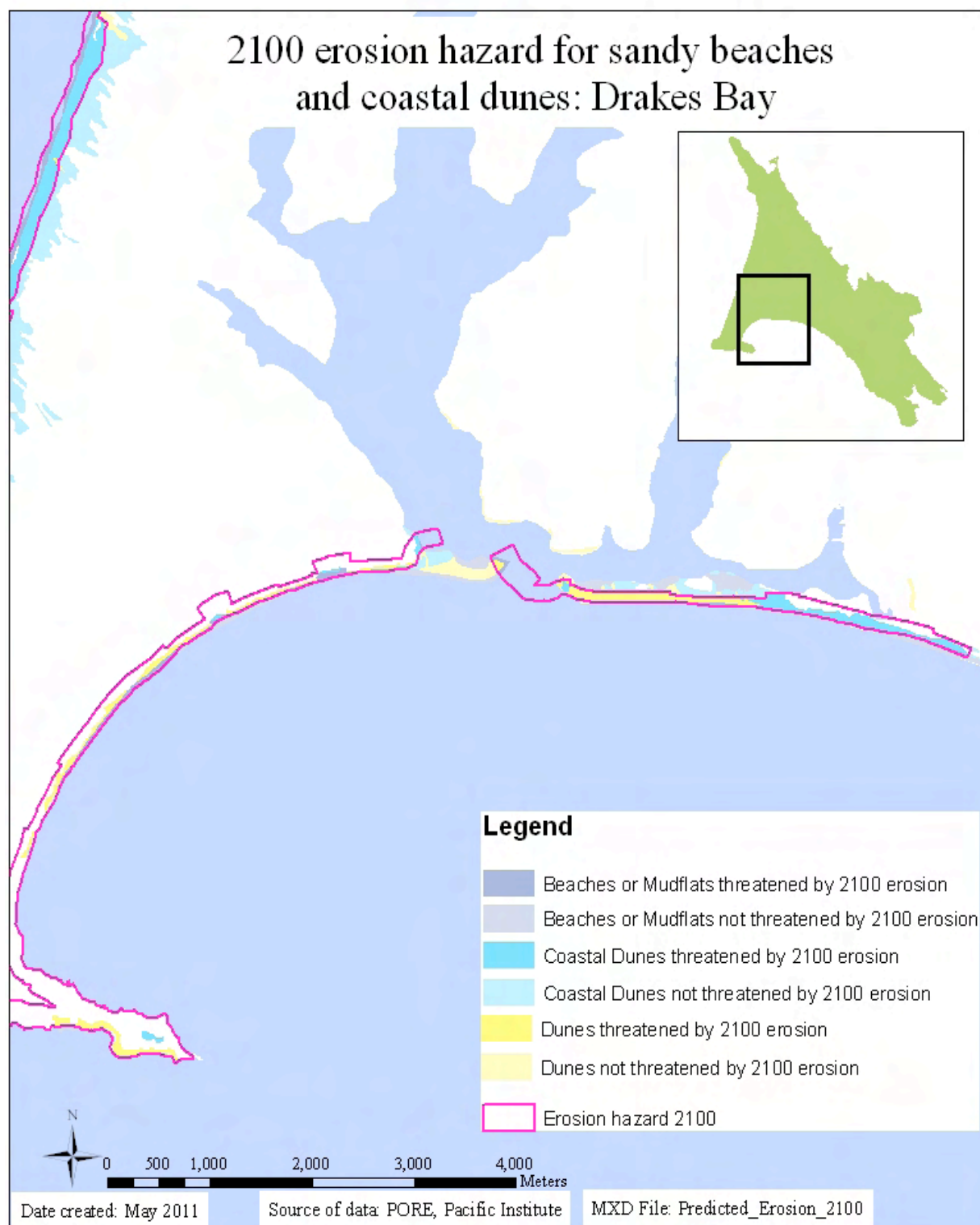


Figure SD-4

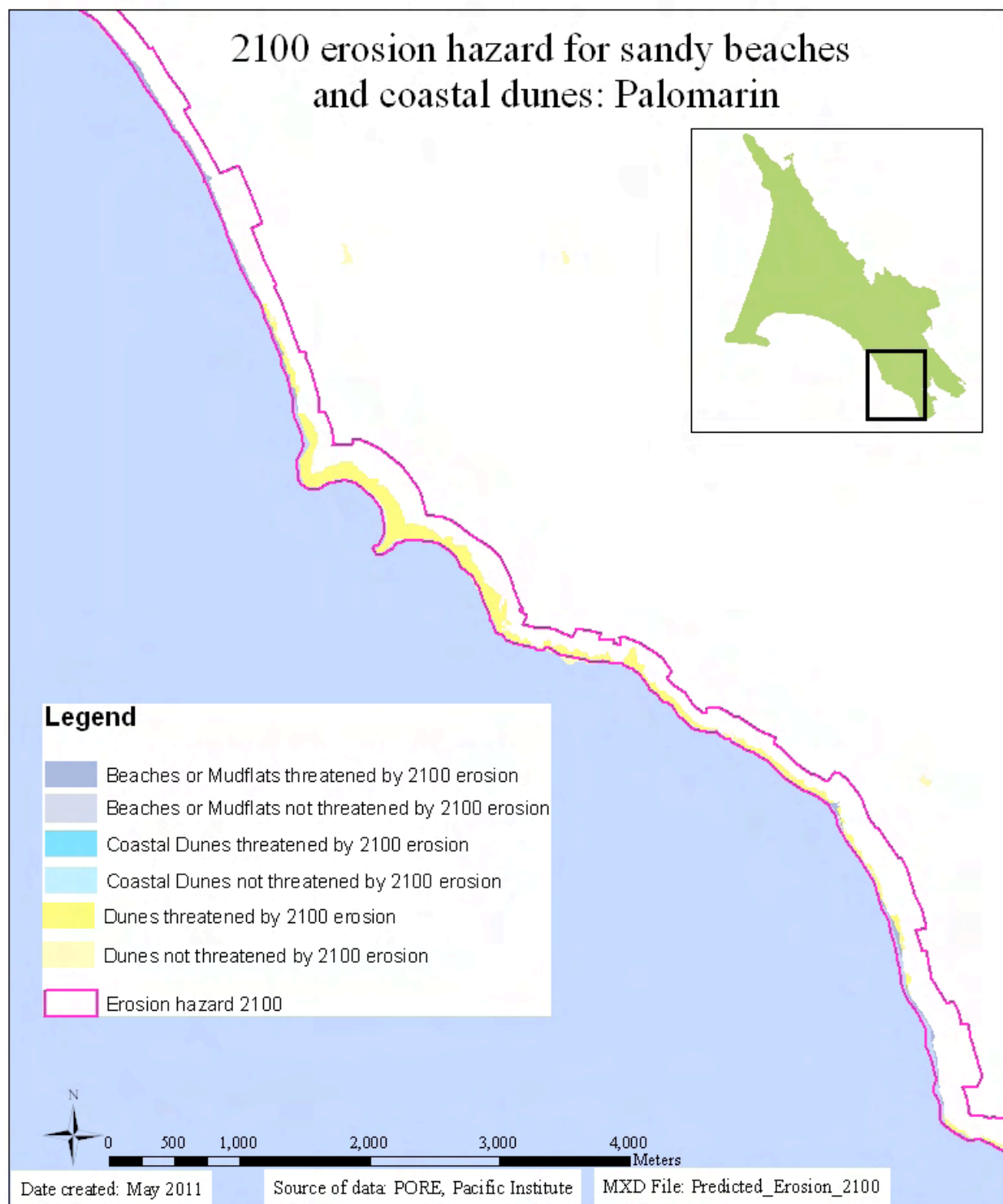


Figure SD-5

A particular management concern with respect to both sandy beaches and rocky intertidal areas are the pinniped haul-out sites in the park. The park's spatial data for pinniped haul-outs may be incomplete, but maps of Tomales Point and Point Reyes/Drakes Bay (Figures SD-6 and SD-7) show that some of the park's pinniped haul-out sites are within the 2100 erosion hazard area.

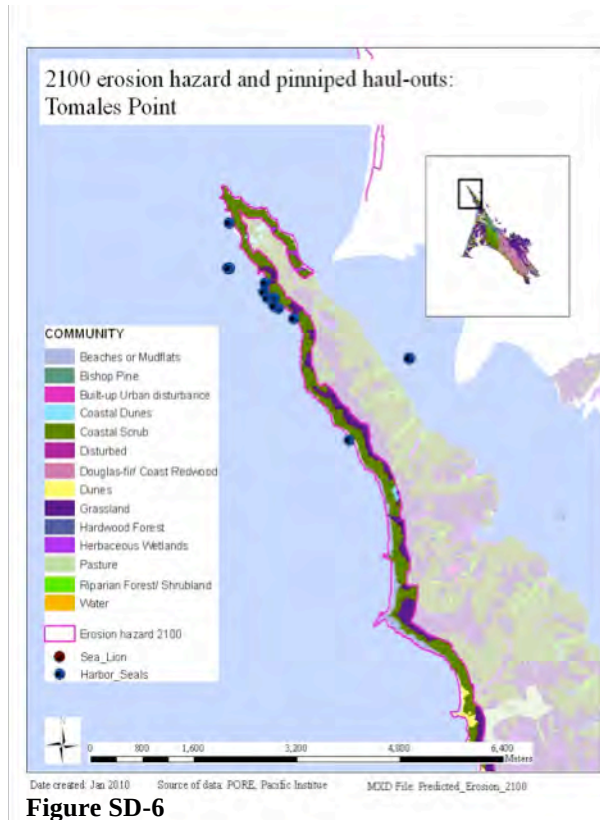


Figure SD-6

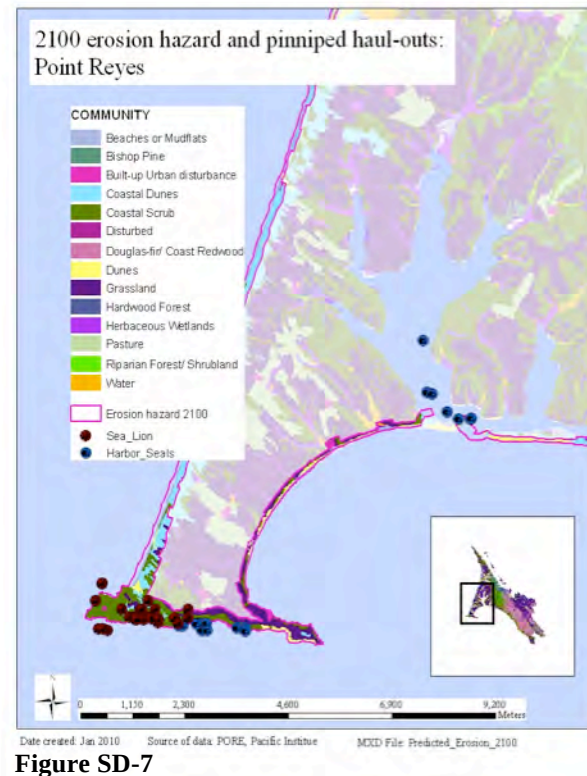


Figure SD-7

The Pacific Institute's projected 2100 mean higher high water data generally shows mean higher high water lines that run up existing beaches in the park. Figures SD-8 and SD-9 show the projected 2100 mean higher high water line (in red) on Drakes and Limantour beaches. These dissipative beaches are likely to experience more run-up during high tides as the sea level rises. Figures SD-10 and SD-11 show areas where the predicted 2100 mean higher high water line indicates more inland incursion over and sandy beach area near Elephant Rock and a dune area near Bolinas Point, respectively.

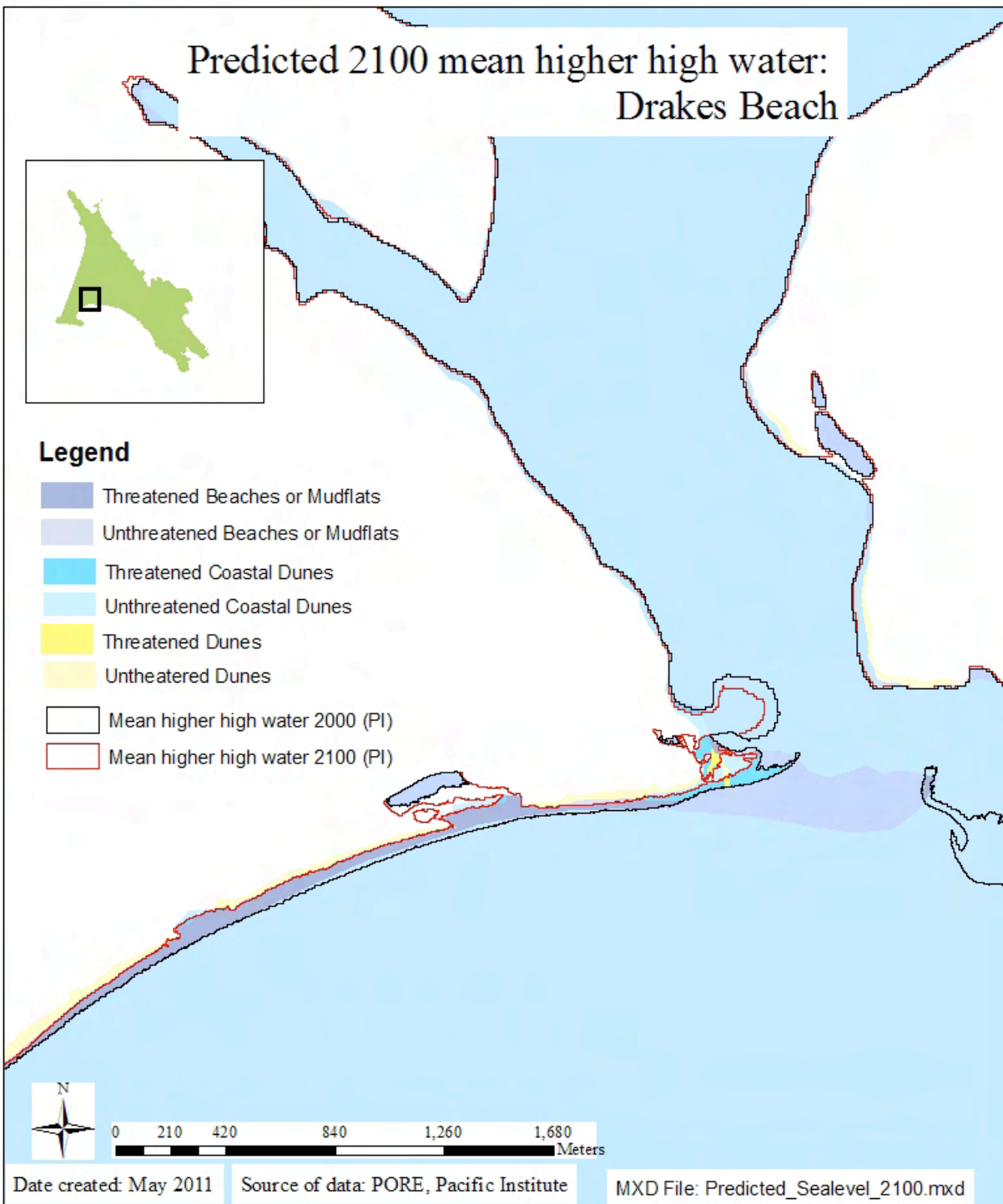


Figure SD-8

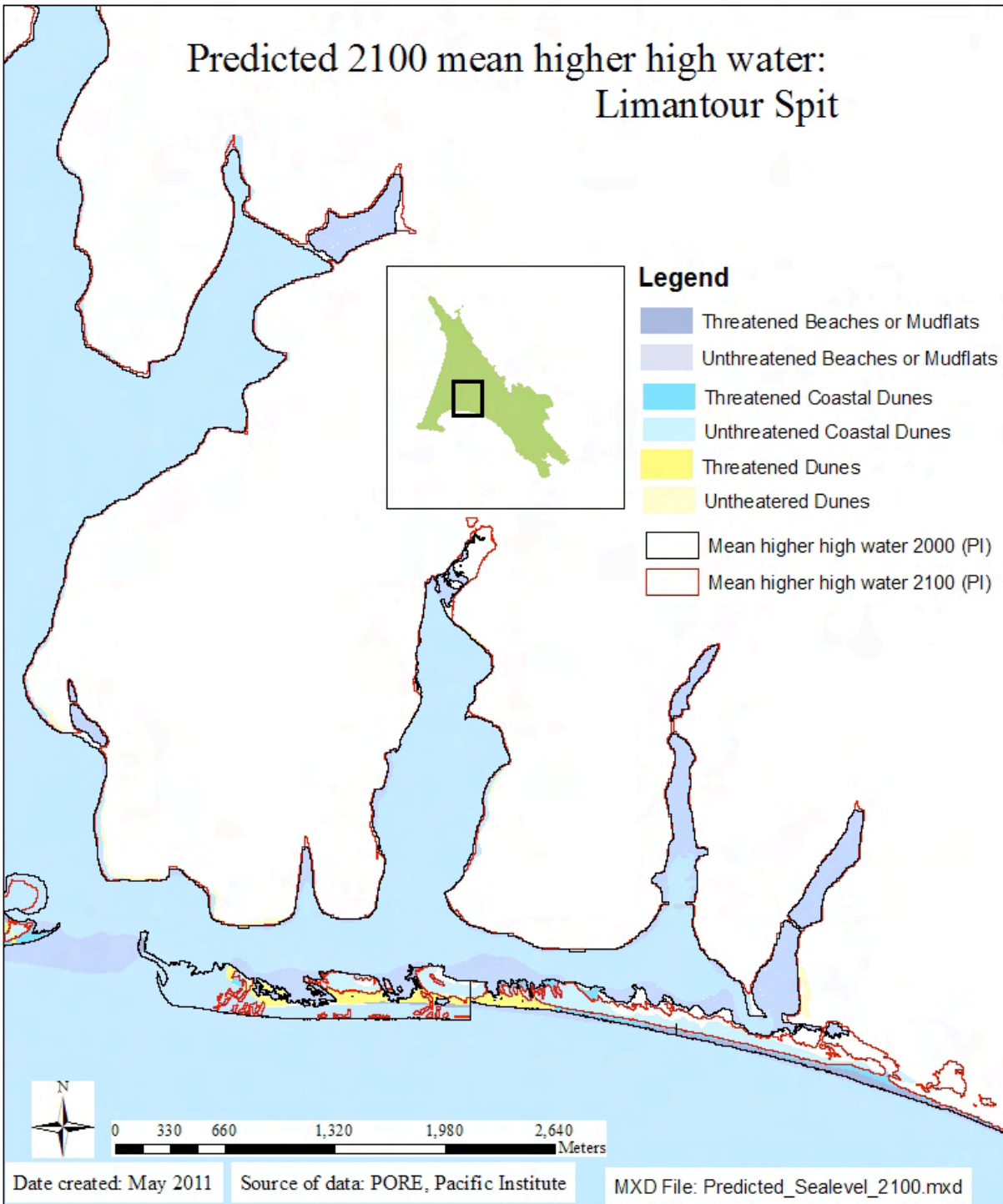


Figure SD-9

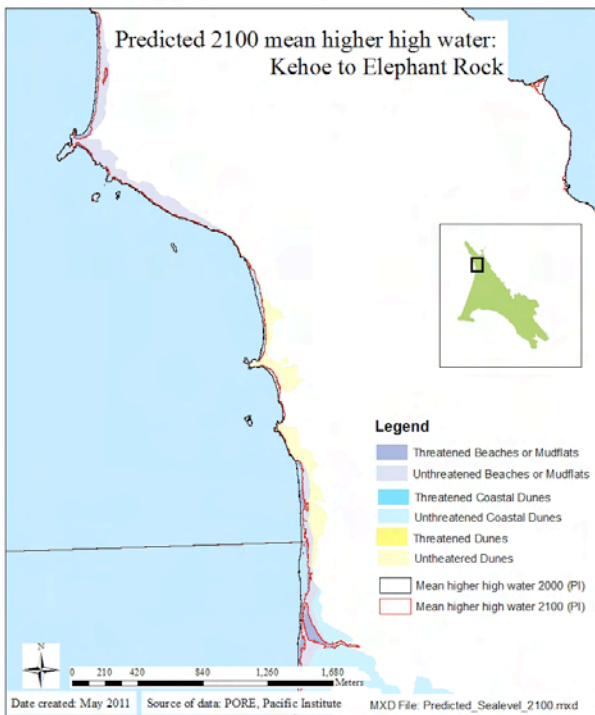


Figure SD-10

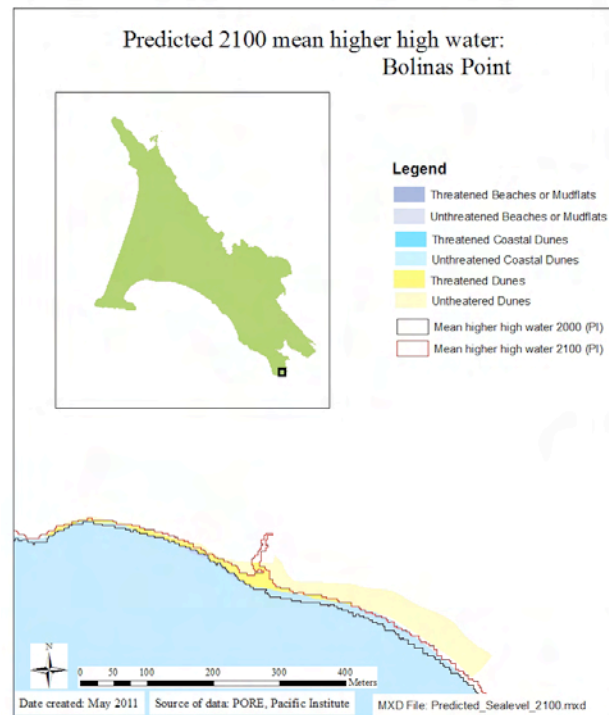


Figure SD-11

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Maritime chaparral

Introduction

Maritime chaparral at Point Reyes is part of the park's undeveloped coastal environment. Like all communities at Point Reyes, chaparral may be susceptible to even minor changes in climatic conditions. Within the park, chaparral is largely found along the southwest facing slopes of Bolinas Ridge, covering approximately 400 acres (Figure 1-CH).

Common plant species that provide structure to this community include manzanita (*Arctostaphylos spp.*), chamise (*Adenostoma fasciculatum*), giant chinquapin (*Chrysolepis chrysophylla*), buckbrush (*Ceanothus cuneatus*), and chaparral pea (*Pickeringia montana*). Rare plant species include Bolinas manzanita (*Arctostaphylos virgata*), Point Reyes ceanothus (*Ceanothus gloriosus* var. *exaltatus*), and Mason's ceanothus (*Ceanothus masonii*).

At Point Reyes, maritime chaparral is near its northern limit. It can only be found in isolated patches in Sonoma and Humboldt Counties. In elevation, maritime chaparral can be found between 100 and 2,000 feet.

Climate and geological (uplift) changes of the past have altered fire return intervals and the boundary of forest-chaparral communities. As the climate dried in the Pleistocene, forest receded and what had been understory shrubs were left to dominate. With the elimination of summer rain, coastal sage and chaparral spread widely (Ford and Hayes 2007).

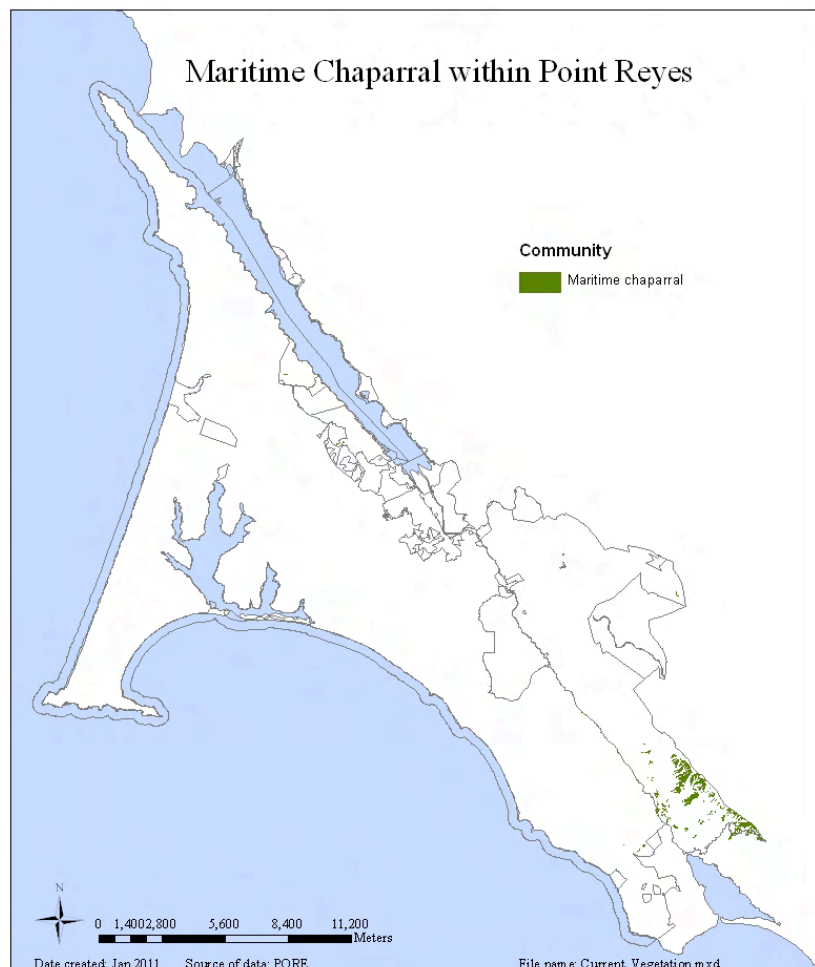


Figure CH-1

I. Expert judgment

Effects of a change in climate

Contributing experts:

Geoff Geupel, PRBO Conservation Science

Joe R. McBride, University of California, Berkeley

Temperature increase

Plant species in the maritime chaparral community are adapted to high temperatures, making it unlikely that any increase in temperature would change the distribution of this community at Point Reyes. Due to the edaphic restrictions on the plants in this community type, it is unlikely to invade adjacent plant community types. Under a warmer climate, plants that are more heat tolerant will out-compete other plants.

A change in temperatures could change the fire regime in maritime chaparral. An increase in the fire frequency could result in a permanent loss of the slow-growing coastal sage.

An extension of the breeding season can drive double brooding in many species of birds. Bird breeding seasons may increase with increasing temperatures if the length of time with suitable weather increases. Although wrentits in Chaparral do double brood irregularly, this behavior does not seem to be driven by the length of the brooding season in wrentits. Research has demonstrated that pairs breeding early in the season were more likely to double brood than those that bred later in the season (Geupel and DeSante 1990). Presumably the timing and duration of spring weather will affect the success but not the frequency of double brooding wrentits and other birds in Point Reyes chaparral communities.

Change in precipitation

An increase in precipitation could cause conifers to encroach on maritime chaparral. An increase in precipitation could also increase the dominance of annual plants in the chaparral, decreasing fire intensities.

A decrease in precipitation could increase fire frequency in maritime chaparral. Net primary production is unlikely to be affected by drier conditions in maritime chaparral. With no loss of fuels and drier conditions, fires will be more likely to ignite and burn in chaparral. A decrease in precipitation could open adjacent forested areas to chaparral expansion. These dynamics remain unclear.

A loss of fog may limit the future distribution of maritime chaparral. It may also change the composition of the shrub community.

Some chaparral shrubs (chaparral pea, manzanita species) have important fungal or bacterial associations in the soil. It is unclear how these sorts of symbioses will be affected by a change in precipitation.

Wind

A decrease in wind intensity could allow conifers to encroach on maritime chaparral communities. The effects of increased wind will depend entirely on speed, direction, and timing. Higher winds increase evapotranspiration (all else being equal), but if the winds are blowing on shore, higher winds may lower temperatures enough to at least partially offset the evapotranspiration increase. Increased wind during times of fog could facilitate fog harvest by trees and benefit the forests.

In addition, an increase in summer or fall winds could increase fire spread.

Secondary effects

A change in the area and distribution of maritime chaparral at Point Reyes could affect species that use this community as habitat, including white-crowned sparrows.

Nuttall's white-crowned sparrow breeds in maritime chaparral at Point Reyes. In some areas of Point Reyes, Nuttall's white-crowned sparrow nests are parasitized by brown-headed cowbirds. Cowbirds were most abundant in pastureland and other short grassland habitats (Trail and Baptista 1993). If climate change alters the interface of grassland and chaparral, it is possible that the relationship between Nuttall's white-crowned sparrow and brown-headed cowbirds at Point Reyes could also change.

Confounding factors

Loss and fragmentation

This habitat has historically been fragmented and lost to urbanization, grazing and fire suppression. Chaparral may be removed because it is difficult to navigate and because it may have a high cover of poison oak (*Toxicodendron diversilobum*) which can cause severe dermatitis. These factors may continue to cause loss of chaparral in the future, although this will likely happen to a far lesser extent within Point Reyes National Seashore than in areas with more human use.

Fire suppression

Lack of fire may cause conifers to encroach on maritime chaparral and shade it out.

II. Predictive vegetation mapping

In the predictive climate envelope niche models created by Point Reyes, maritime chaparral is not differentiated from coastal scrub. These community types are distinct, both in terms of vegetation composition and in terms of management and the lack of distinction between Northern coastal scrub and maritime chaparral should be kept in mind when interpreting the results of the predictive maps. The map comprising current vegetation distributions provided by PRBO are based on a grid of cells 800m to a side because this is the size of climate data used to inform the predictions. This required the modelers to average the vegetation community within each of the cells, and is likely the reason that the distribution of current shrubland provided by PRBO does not overlap with the current distribution of maritime chaparral.

As compared with the current distribution (Figure CH-2) of shrubland in the park, CCSM and GFDL (Table CH-1) models predict a decrease in areas that are climatically suitable for shrublands in the future (Figure CH-3). These models agree that suitable climates will be located along the western coast of the park, along the central ridge, and in the area close to Bolinas. The NCAR-CCSM model predicts a dramatic decrease in shrubland-suited climate, which may be located in a few square kilometers on Point Reyes. Models predict that area currently described as shrubland will become grassland or forested. Drivers of successional dynamics in the grassland-shrubland-forest systems at Point Reyes are described in more detail in the Expert Opinion section below.

While these niche models may not capture the future of maritime chaparral well, they can serve as a broad-scale compliment to the threats experts imagine for this community type and its key species at Point Reyes.

Table CH-1: Vegetation predictions are based on these GCMs , time points and conditions		
Climate Model	Time of prediction	Atmospheric CO₂
NCAR-CSM1.2	2080-2099	653-686 ppm
NCAR-CCSM 3.0	2038-2069	478-610 ppm
GFDL-CM 2.1	2038-2070	478-615 ppm

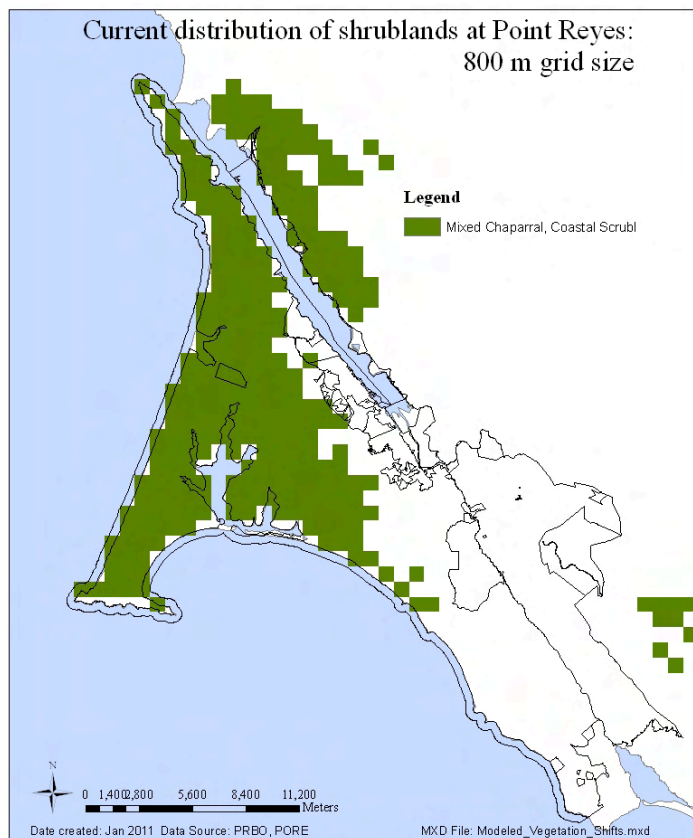


Figure CH-2

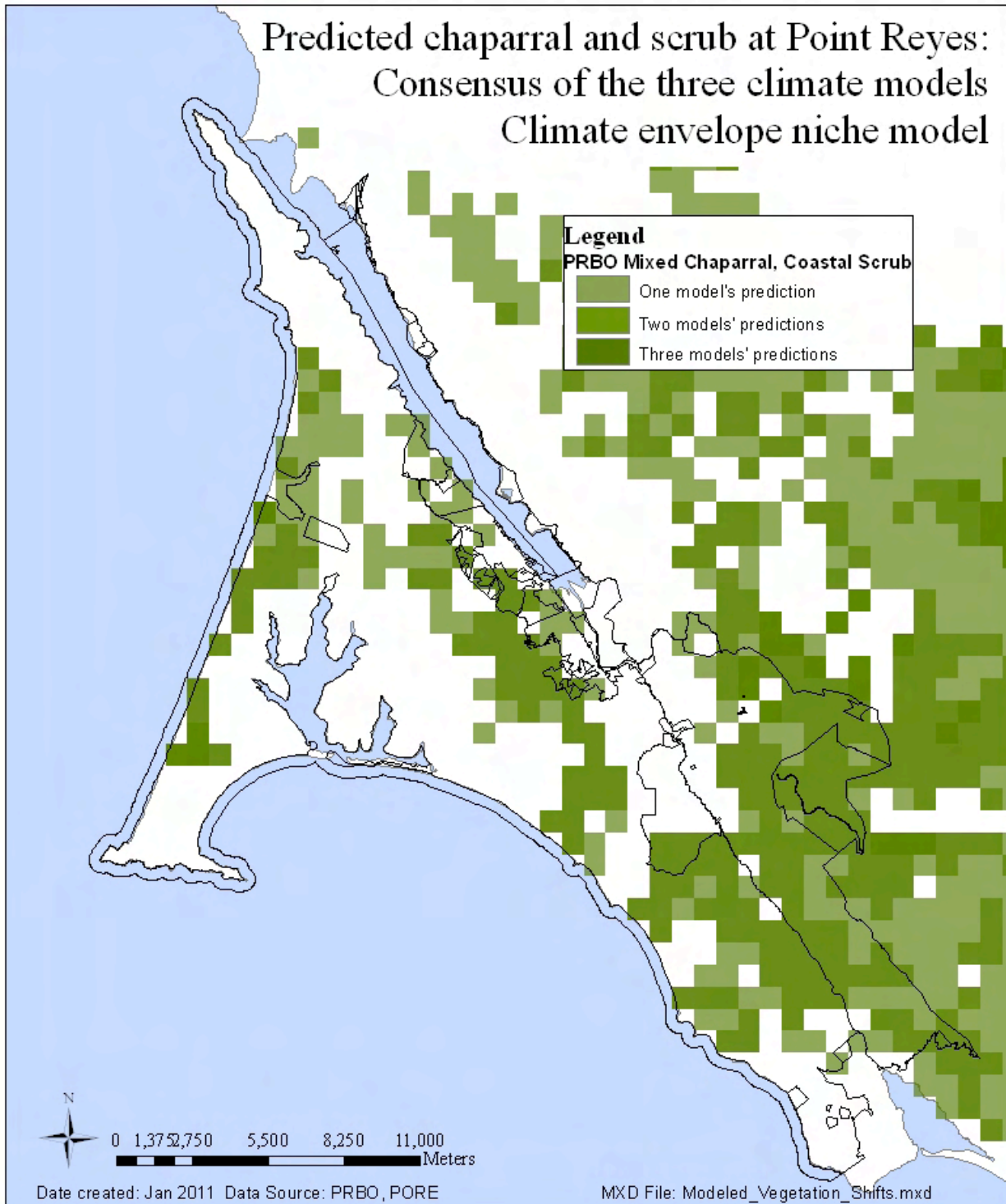


Figure CH-3

III. Predicted coastline changes mapping

Maritime chaparral in Point Reyes is located far from the coast and is directly threatened by neither predicted rises in the mean higher high water or by predicted coastal erosion (Figure CH-4, Figure CH-5). However, it is possible that secondary effects of these changes could influence the integrity of maritime chaparral.



Figure CH-4



Figure CH-5

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Rocky intertidal communities

Introduction

Rocky intertidal habitat covers a small area of the coastline in Point Reyes National Seashore. These communities inhabit relatively narrow areas near Tomales Point, Point Reyes, Point Resistance, Double Point, and Bolinas Point (rocky intertidal communities are shown in yellow and marked as “High diversity in the intertidal zone” in Figure RI-1). Because intertidal communities are uniquely situated at the interface between marine and terrestrial environments, they will experience more exposure to environmental changes associated with climate change than most communities.

The rocky intertidal communities in Point Reyes are very diverse. Various species of algae are the most abundant primary producers in the community. California mussels (*Mytilus californianus*) are competitively dominant in these communities and provide habitat for a wide variety of invertebrates. Ochre sea star (*Pisaster ochraceus*) predation determines the mussels’ lower extent in the intertidal (Menge et al. 2004). Of particular management concern is the federally endangered black abalone (*Haliotis cracherodii*) that lives in the lower intertidal. The habitat also provides important pinniped haulout sites as well as seabird nesting sites.



Figure RI-1: from Denn et al. (2010).

I. Expert judgment

Contributing experts:

Sarah Allen, Point Reyes National Seashore
Ben Becker, Point Reyes National Seashore
Dan Howard, Cordell Bank National Marine Sanctuary

Effect of a change in climate

Changes in Temperature

Temperatures fluctuate swiftly over the tidal cycle in rocky intertidal communities. These communities are exposed to both seawater temperatures and air temperatures. Most rocky intertidal organisms are ectothermic, making them particularly sensitive to temperature changes – thermal stress is thought to be one of the important determinants of both latitudinal and vertical species distribution patterns in rocky intertidal communities (Helmuth et al. 2002, Helmuth et al. 2006). Intertidal community composition has been shown to be highly correlated with long-term mean sea surface temperature along the coast of North America (Blanchette et al. 2008). Many intertidal species live near their thermal tolerance limits (Stillman and Somero 2000), and therefore may be more sensitive to temperature increases. The exposure of intertidal communities to temperature changes depends on seawater temperatures during high tides, air temperatures and sun exposure during low tides, wave height, fog, and wind, making it difficult to predict changes in thermal exposure as well as the community responses to temperature change (Largier et al. 2010). Temperature changes in this community will necessarily be affected by sea level rise. Studies have documented some increases in rocky intertidal temperatures in California – one study conducted in Pacific Grove, CA, approximately 100 miles southeast of Point Reyes National Seashore, found an increase in the average temperature of shoreline seawater of 0.79 degrees C between 1933 and 1993, corresponding to changes in the abundances of 46 invertebrate species over that same time period (Sagarin et al. 1999). Rocky intertidal communities may be most at risk of exposure to high temperatures during the spring, when low tides coincide with the hottest parts of the day (Helmuth et al. 2002).

Organisms could respond to increased temperatures by moving lower in the intertidal zone or shifting poleward, though conflicting evidence makes biological response predictions difficult. Fossil evidence shows that marine organisms shifted poleward as sea surface temperatures rose, as in the Pleistocene-Holocene transition (see Blanchette et al. 2008). The study conducted in Pacific Grove between 1933 and 1993 documented an increase in most southern species abundance (10 of 11) and a decrease in most northern species abundance (5 of 7) associated with an average temperature increase of 0.79 degrees C (Sagarin et al. 1999). An 18-year study documenting the rocky intertidal and subtidal community changes on the exposed coast between Morrow Bay and Pismo, Ca (approximately 215 mi. south southeast of Point Reyes) found significant community-wide changes associated with a 3.5 degree C rise in average seawater temperature induced by a power stations thermal pollution (Schiel et al. 2004). The study found no trend toward warmer-water species replacing colder water species, however. Rather, the researchers found cascading responses to changes in abundance of key taxa, such as intertidal foliose red algae. Point Reyes' rocky intertidal communities lie at the intersection between northern algal populations and southern algal populations, so any poleward range shift might change the algal composition of these communities in the park (PISCO 2009).

Some evidence suggests that the most warm-adapted species in intertidal communities are likely to be the most threatened by increasing temperatures because these species tend to live closer to their upper thermal tolerance limits (Somero 2010). Mass mortality events in rocky intertidal communities have been observed, but rarely documented. Two documented cases of mass mortality events occurred on the Bodega peninsula, 22 miles north of Point Reyes in the spring

of 2004. Extreme heat events caused mass mortality for limpets (*Lottia scabra*) in mid-March and California mussels in late April (Harley 2008). In addition to the direct impacts of thermal stress, increased temperatures may negatively impact particular species through the spread of disease. Warmer seawater temperatures have been associated with an accelerated development of the fatal disease withering foot syndrome in endangered black abalone (Raimondi et al. 2002).

Relatively few studies have examined the indirect effects of temperature changes in rocky intertidal communities due to changed species interactions. Research indicates that increased seawater temperatures have a positive effect on the growth of California mussels (*Mytilus californianus*) (Blanchette et al. 2008, Menge et al. 2008), but it has also been shown to increase sea star (*Pisaster ocraceus*) consumption of mussels (Sanford 1999). It is unclear how temperature changes will ultimately effect this important community interaction. If increases in emersion temperatures cause mussels to shift lower in the intertidal while their primary predators remain unaffected or shift upward due to warming seawater temperatures, California mussels could be “squeezed” out of the intertidal (Harley and Helmuth 2003). One recent study indicates that the interaction between California mussels and *Pisaster* changes differently with chronic exposure to warmer temperatures as opposed to acute exposure – *Pisaster* respond to acute exposure with increased foraging, and they respond to chronic exposure with decreased foraging (Pincebourde et al. 2008). Seawater temperature changes could also impact rocky intertidal communities in Point Reyes by changing the plankton communities that form the foundation of the food web. Small increases in temperature ($\sim 0.6^{\circ}\text{C}$) have been associated with large changes in planktonic ecosystems in the North Atlantic (Richardson and Schoeman 2004, Richardson 2008).

Changes in Ocean Chemistry

Acidified seawater due to increased carbon inputs into the ocean is delivered to near shore coastal environments through upwelling (Feely et al. 2008). Ocean acidification is predicted to have negative biological impacts in marine communities, but differences in the sensitivity to ocean acidification across taxa is likely to have important, and as yet unknown, implications for community responses (Kroeker et al. 2010). Increasingly acidified seawater will negatively impact rocky intertidal organisms that form calcium carbonate structures (Doney et al. 2009), though recent meta-analysis of ocean acidification research indicates that there is significant variation in the sensitivity of different taxa to ocean acidification (Kroeker et al. 2010). Among calcifying organisms, those that used more soluble forms of calcium carbonate (high-magnesium calcite) were more resilient to ocean acidification than those that use less soluble forms (calcite and aragonite), while crustaceans do not seem to be negatively affected by ocean acidification. Coralline algae, in particular, appear to recruit less and grow more slowly in acidic conditions (Kuffner et al. 2008). Additionally, the larval stages of rocky intertidal community members may be most sensitive to ocean acidification (Doney et al. 2009), which means that more acidified seawater may result in higher larval mortality rates and lower recruitment rates. One species of particular concern, black abalone, is likely to be negatively impacted by ocean acidification.

Sea Level Rise

Intertidal communities will migrate up-shore in response to sea level rise where available substrate permits. A problem for these communities will arise where there is not appropriate

substrate to which organisms can move as the sea level rises. If intertidal communities are squeezed due to a lack of accommodating topography, it is also likely that important pinniped haulout sites will be lost, though erosion and sediment transport processes could also result in increased sandy beach habitats that might provide alternative haulout sites (see “Sandy Beaches and Dunes”). It is also possible that if intertidal communities are successful in migrating up-shore, they could squeeze out supertidal communities lacking space or substrate to which to migrate.

Changes in upwelling intensity and duration

Increased coastal upwelling due to an increase in the duration of seasonal southward winds would likely provide more nutrients to intertidal communities. If this more intensive upwelling has fewer or shorter periods of relaxation, however, it may have a negative impact on larval recruitment. The strong currents associated with upwelling could push larvae offshore, preventing them from migrating back to shore (Largier et al. 2010). Because upwelling is responsible for delivering cold nutrient-rich bottom waters to the ocean surface, it drives the phytoplankton blooms that make the marine ecosystem around Point Reyes National Seashore so productive. Reductions in coastal upwelling would likely have a negative impact on all of the marine communities in the park.

Increased Extreme Storm Events

Increased wave heights will likely result in increased erosion for the sedimentary rock along parts of Point Reyes’ coast. Increased sediment, either from shoreline erosions, or from erosion that occurs inland and is carried to the nearshore environment by rivers and streams, could endanger rocky intertidal communities by burying the rocky substrate that provides their habitat. In addition to sediment, increased runoff associated with storm events could carry more pollution into nearshore waters, negatively impacting intertidal communities.

Confounding factors

Oil Spills

Point Reyes is positioned to feel the impacts from major oil spills in or around San Francisco Bay. Communities on the south side of Point Reyes are particularly susceptible to the degrading effects of oil spills in the bay. Oil tankers frequent San Francisco Bay and nearshore ocean currents flow up the coast to the south side of Point Reyes. Protected coastlines are also more vulnerable to oil spills because they are less frequently flushed by wave action. While the communities on the south side of Point Reyes are more vulnerable to oil spills, oil from such spills has been found on the north side of Point Reyes on occasion.

Harvesting

It is not clear how much abalone is taken from rocky intertidal communities in Point Reyes. It is possible that overharvest of red abalone could hurt the populations in the park. It is also possible that endangered black abalone are sometimes mistaken for red abalone and harvested illegally. Reduced numbers would make these populations more sensitive to negative impacts associated with climate change.

Trampling

Point Reyes' rocky intertidal areas are less frequented than its sandy beaches, but an increase in visitation could result in increased trampling of rocky intertidal communities.

II. Predictive vegetation mapping

The climate envelope models created by PRBO (Stralberg et al. 2009) do not include predictions for kelp forest communities.

III. Predicted coastline change mapping

Sea level rise and coastal erosion will directly impact rocky intertidal communities in Point Reyes National Seashore. While the degree to which these communities may be able to migrate inland onto suitable substrate is unknown, we can identify the areas in which these communities are most vulnerable to erosion risk according to the Pacific Institute's 2100 erosion hazard predictions.

Although we were not able to access any spatial data for rocky intertidal communities in the park, Figure RI-1 indicates the coastal areas with rocky intertidal communities in yellow. All of the rocky intertidal areas on Tomales Point and on Point Reyes fall within the 2100 erosion hazard zone (Figures RI-2 and RI-3). The rocky intertidal communities near Point Resistance do not appear to be in erosion hazard zones, according to the Pacific Institute's predictions (Figure RI-4). Those near Double Point and Bolinas Point do fall within the 2100 erosion hazard zones (Figure RI-4).

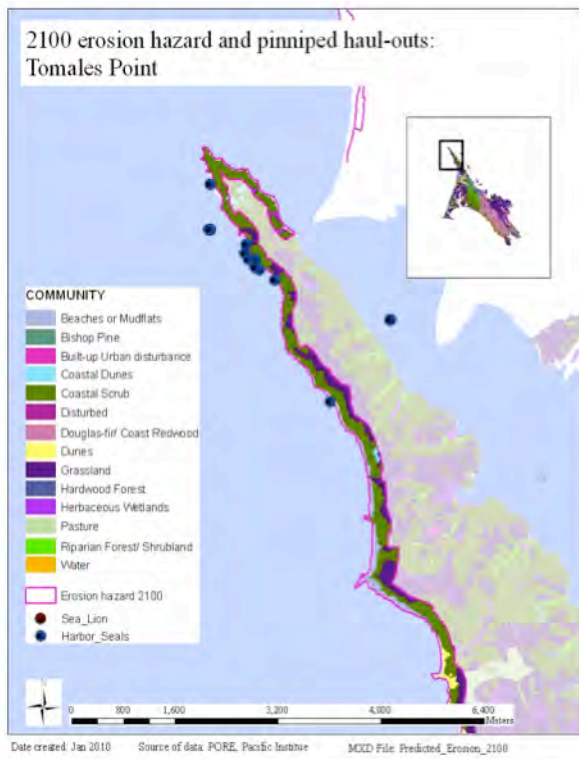


Figure RI-2

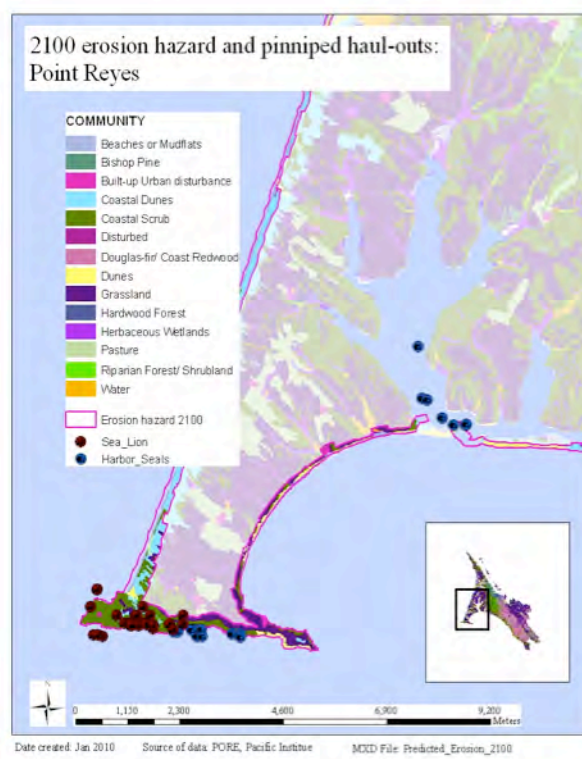


Figure RI-3



Figure RI-4

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Bishop Pine Forests

Introduction

Bishop pine forests are found scattered along the coast of California, with one of the most extensive stands found within Point Reyes National Seashore. Bishop pines grow predominately in areas with granitic quartz-diorite soils. Although the pine is the determining species within this vegetation type, several other trees and shrubs are found in Bishop pine communities. Bay laurels, madrone, California buckeye, coast live oak, California wax myrtle, and huckleberry all provide important structure and resources in Bishop pine communities. Additionally, there are two varieties of ceanothus and three species of Manzanita that are located only within Bishop pine communities (Evens et al. 2010)

Distribution and range limits

Currently, Bishop pine forests cover just over 3600 acres within Point Reyes National Seashore (Figure BP-1). The forests grow along the northern portion of Inverness Ridge on the Point Reyes Peninsula, and there are smaller groupings of trees found scattered along the ridge toward Drakes Bay (Holzman & Folger 2005).

Although Bishop pines are not near any latitudinal range limits, they do have very specific climatic requirements. Bishop pine is a maritime tree species, and populations are found between sea level and about 400 m elevation. These forests grow along the coast and are not found very far inland. Bishop pines can persist in a variety of microclimates and soil types, but are very reliant on a specific temperature range and fog level, especially during dry summer months. Bishop pine forests within the park may be able to establish closer to the coast, but will be limited in their ability to move away from the ocean due to this reliance on coastal fog. Their current range is highly discontinuous, and different stands are often genetically distinct (Hong et al. 1993).

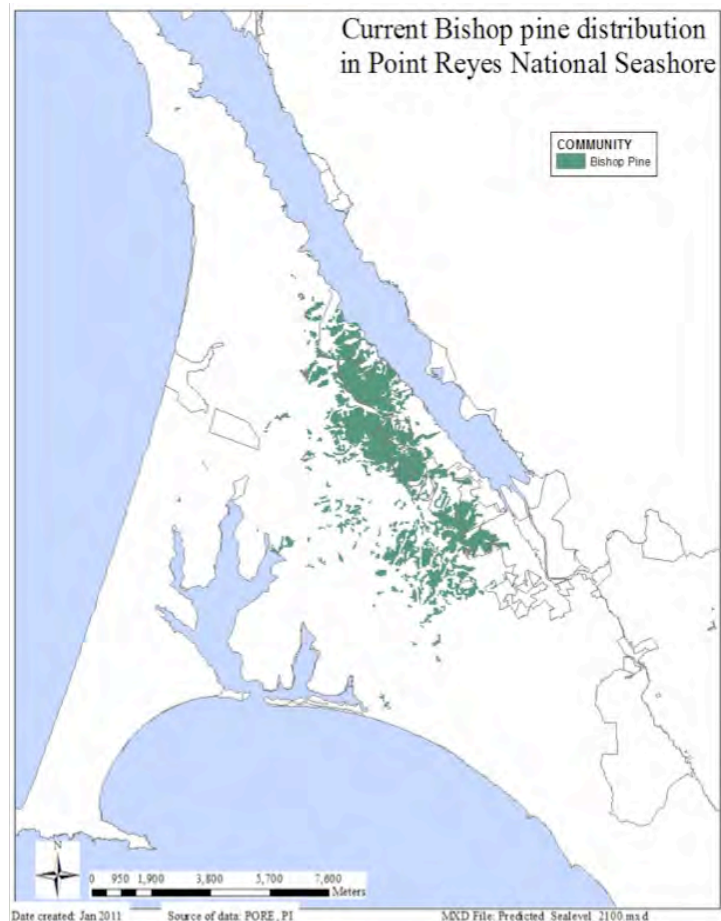


Figure BP-1

I. Expert judgment

Effects of a change in climate

Contributing experts

Tom Bruns, University of California, Berkeley

Michael Barbour, University of California, Davis

Douglas Fischer, ARCADIS Environmental Consulting

Christopher Still, University of California, Santa Barbara

Change in fog levels

It is likely that changes to current fog and overcast levels and timing will have the single largest impact on the viability of Bishop pines (Williams et al. 2008). Cold currents along the coast at Point Reyes create a fog layer that is present throughout the summer. Changes in the current, or a drying of the air, would have a significant impact on the presence of this fog layer, and thus Bishop pines. If fog and overcast were significantly reduced, local reduction of forest cover or even extirpation of Bishop pine stands could be expected to occur. While Bishop pines can withstand a dry year or two, prolonged or repeated drought events can lead to mass die-offs of seedlings and established trees (Fischer et al. 2009 and references therein).

Temperature changes

Although changes in temperature will have less of an impact on Bishop pines than changes in fog and overcast levels, increases in temperature are likely to be correlated with decreases in fog levels. Warmer, drier temperatures are a potential result of climate change, and these temperatures may lead to a contraction or migration of Bishop pine forests. However, if warmer temperatures did not result in reduced fog and precipitation, the temperatures could have a positive impact on the forest. Bishop Pine cones are both xeriscent and pyriscent, which means they open due to aridity and heat (including fire). It is possible that hotter summers could lead to increased recruitment, although this would imply that Bishop Pines are currently seed-limited in recruitment with Point Reyes National Seashore and there is no current evidence of this. It is also possible that hotter temperatures could result in the opening of more cones in conditions not favorable to seedling growth, thus reducing seed availability in ideal conditions.

Extremes

Extremes events, such as droughts, may impact the distribution of Bishop pine within Point Reyes. Bishop pine is a highly drought sensitive species and will likely not be able to withstand prolonged drought events. In addition to their dependence on moisture, drought events make forests more susceptible to pathogens and parasites, which would also have a negative impact on Bishop pines.

Confounding Factors

Biotic

Drought stressed Bishop pines have been found to be more susceptible to bark beetles. When drought stressed, Bishop pines are not able to produce enough pitch to keep the beetles out. As

more trees become weakened by the drought, the population of bark beetles increases, and eventually the density of the beetles becomes great enough to damage or kill healthy trees as well as the weakened ones. Such beetle epidemics may last longer than the drought itself, and have much more serious consequences.

Within Point Reyes, pitch canker is also affecting younger Bishop pines. Pitch canker, a fungal disease caused by *Fusarium circinatum*, seems to predominately affect younger, faster growing trees. It was brought into the park by Monterey pines, and the effects of climate change on the fungus are unknown. It is possible that pitch canker is the most serious threat facing the continuous health and recruitment of Bishop pine forests within the park.

Fire Regime

Bishop pines are reliant on fires or extremely hot temperatures in order for the cones to open, but seedlings, saplings, and adult trees may be sensitive to hot and highly recurrent fires. Hot fires, such as the type that commonly occur in chaparral and on mountain slopes, are able to kill live pines as well as seeds and cones, particularly if there are other tree species, such as Douglas fir, growing within and underneath the Bishop pine. There is evidence that “low burning surface [fires]” lead to the opening of cones, which can cause wide-scale seed release and regeneration (Walter and Taha 1999). However, the regeneration process may rely on grazing by animals to reduce resource competition for the seedlings, and therefore may not function effectively in areas where grazing is limited. Additionally, very hot, dry temperatures can lead to cones opening and releasing their seeds, although this is a slower process, as it requires desiccation of the cones. While fires can be very beneficial for Bishop pines, management plans that attempt to limit fires are more likely to result in forests with a wide range of tree ages; such forests may be better able to withstand negative biotic interactions, such as the spread of pitch canker and bark beetles.

Anthropogenic Impacts

It is likely that the combination of increased temperatures, reduced precipitation or moisture, and an increase in visitation to the park will result in more frequent fires. Fires in Bishop pine communities have the propensity to spread quickly and become extremely hot. Bishop pine’s structure enables surface fires to climb the trunk to the canopy. This creates the potential for any fires within Bishop pine forests to quickly become catastrophic crown fires.

II. Vegetation model predictions

In PRBO’s climate envelop niche models, redwoods, closed-cone pines (e.g. Bishop pine), and cypress forests are mapped together (NPS and USGS 2004). This leads to some level of uncertainty regarding future predicted distributions of Bishop pine within the park. In addition, due to the climatic projections used to create the predictive vegetation GIS data, there is very little of these forest types expected to persist into the future (Figure BP-2). Of the three GCMs used by PRBO, only one predicts any amount of Bishop pine forest to exist in the park in 2100. However, these climate models are not currently able to account for fog, which will likely be a more significant driver in Bishop pine persistence than precipitation or temperature.

The NCAR-CSM12 model predicts small patches of these forest types (Figure BP-2), while the GFDL and CCSM models predict no occurrence of Bishop pine’s required niche in the park in

2100. Small stands of Bishop pine may still persist in the park, but not at a significant enough scale to be reflected in the models projections. Figure BP-2 shows an overlay of the current distribution of the forests in the park, the PRBO modeled current distribution, and the modeled future distribution for the NCAR-CSM12 model.

However, it is necessary to further examine the data used to obtain these predictions to understand why climate characteristics are expected to change so substantially, and why Bishop pine is predicted to have such a limited presence in the park. The annual mean temperature, the mean temperature in the warmest quarter, and the precipitation seasonality increase similarly among all three future models. Any or all of these factors may explain the general decrease of the in suitable habitat for these forests, due to heat or drought stress. The annual precipitation does not change substantially from current levels in any of the three models, so this is unlikely to be driving the patterns. Isothermality (“evenness” of temperature as given by the average daily temperature range relative to the annual temperature range) decreases in the GFDL and CCSM models in the areas where these forests are currently found. However, isothermality does not decrease as much in the NCAR-CSM12 model in the areas where it predicts remnant niche patches for these forests. This could indicate that a decrease in isothermality may be detrimental for these forests. The precipitation in the driest quarter decreases in GFDL and CCSM models, but increases in the northern part of the range in the NCAR-CSM12 model. This could also explain the retention of some of the climatic niche for these forest species in the NCAR-CSM12 model.

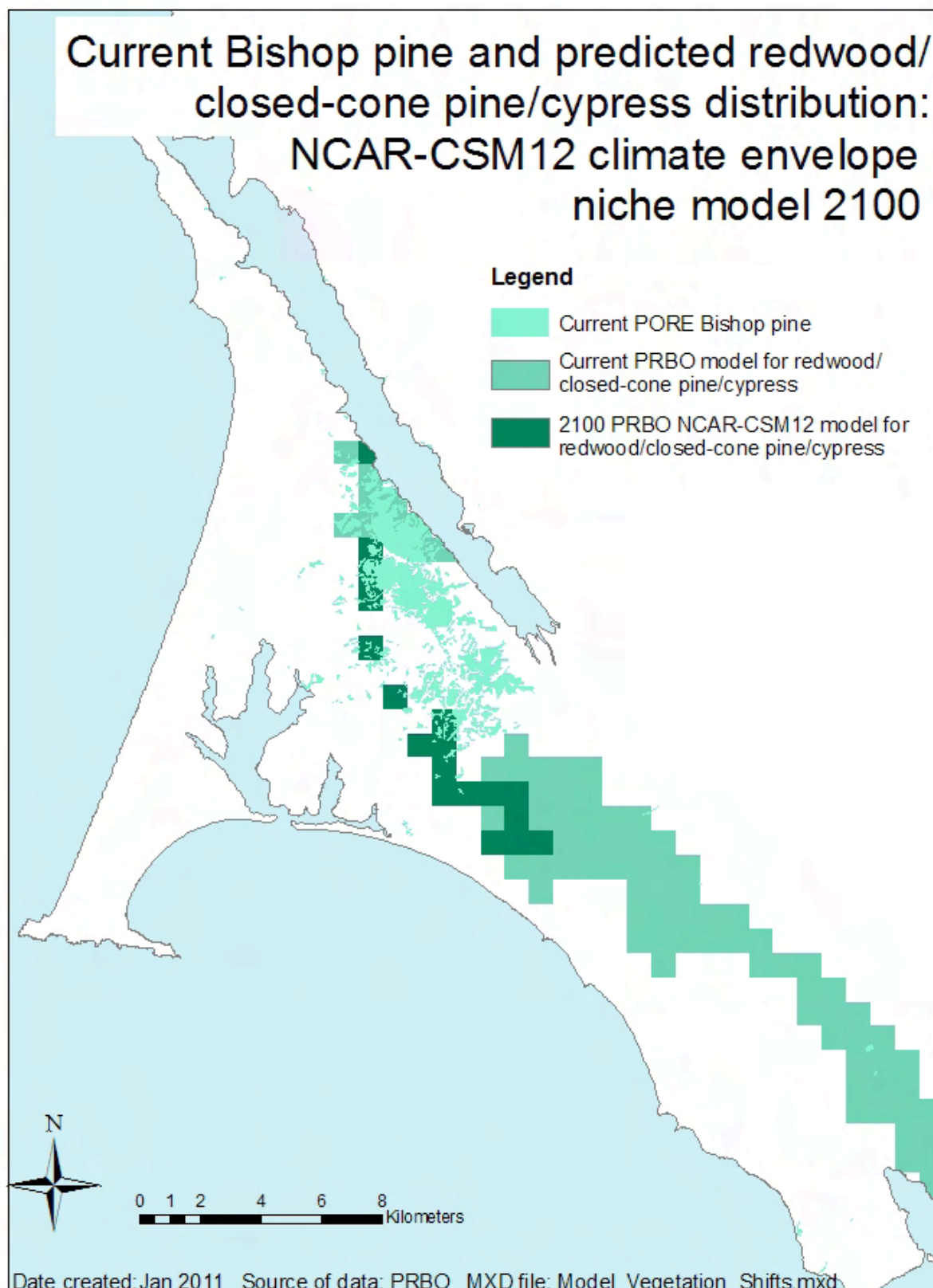


Figure BP-2

The current distribution of Bishop pine also fails to align completely with the current distribution of this forest niche in PRBO's models. This is likely due to the fact that PRBO used a 800m grid, and the vegetation type represented within each grid is the dominant vegetation type. That means that smaller stands of Bishop pine located amongst other communities would not be reflected in PRBO's vegetation models.

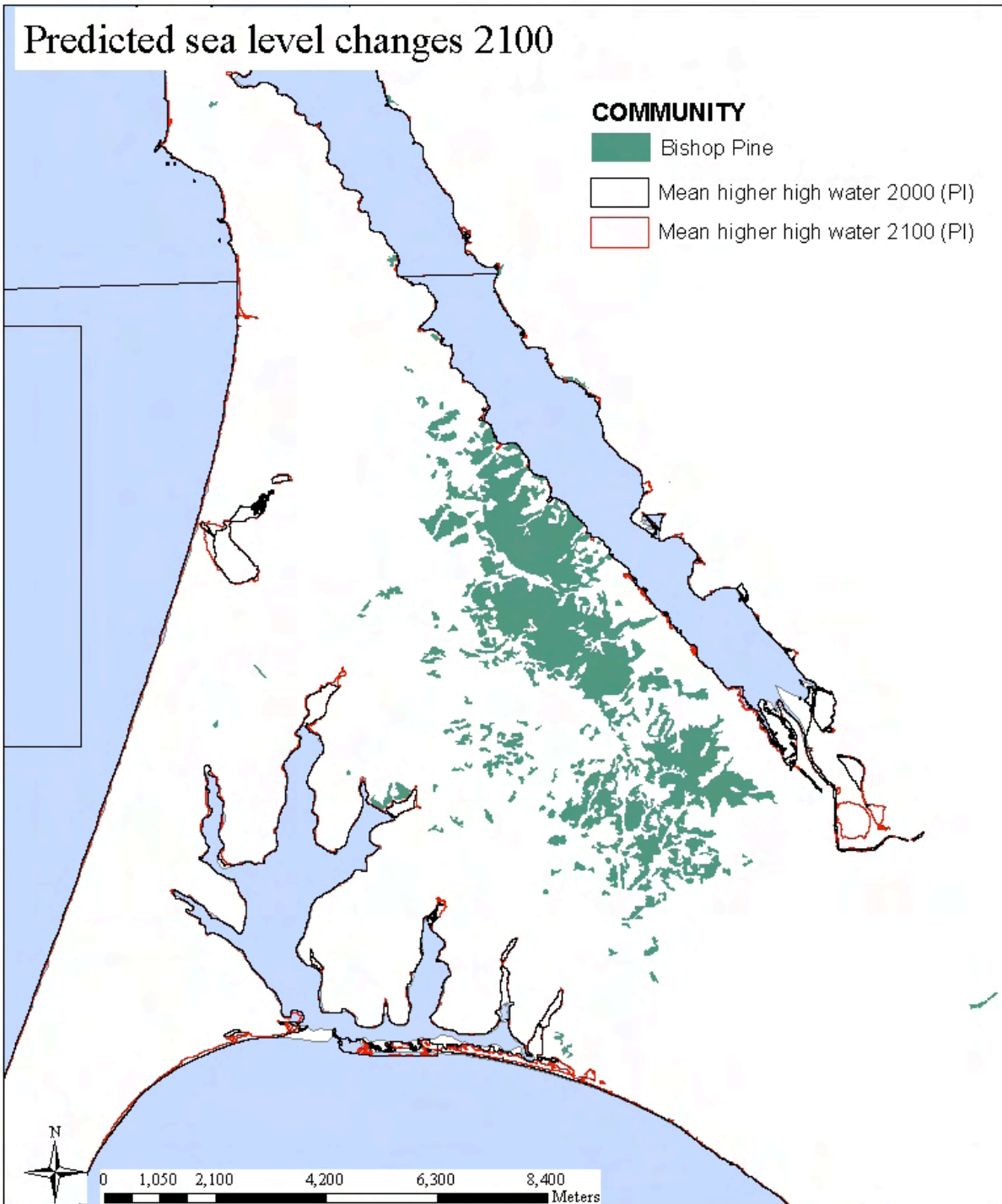
Three global circulation models (GCMs) were used by PRBO to predict future vegetation distributions: NCAR-CSM12, CCSM, and GFDL. The associated timeframes and atmospheric CO² predicted by these models is provided in Table BP-1.

Climate Model	Time of prediction	Atmospheric CO ₂
NCAR-CSM1.2	2080-2099	653-686 ppm
NCAR-CCSM 3.0	2038-2069	478-610 ppm
GFDL-CM 2.1	2038-2070	478-615 ppm

Table BP-1

III. Effects of a rise in sea level

Although Bishop pine is a maritime species, and strands are located near to the coast, it is generally found at higher elevations and therefore will not be immediately impacted by predicted changes in sea level (Figure BP-3). However, many of the communities located between the coastline and Bishop pine strands will be affected, and it is possible that a rising sea level will cause an inland migration of these communities, which could potentially affect Bishop pine forests. In addition, oceanic changes could result in changes in soil salinity along the coast as MHHW levels increase, and erosion is a potential threat in many coastal areas. Currently, only a small amount of Bishop pine forest—just over eighteen acres—is considered at risk due to erosion, but the combination of factors associated with rises in sea level, to include changes in communities located between Bishop pine and the coastline, may impact strands located within park boundaries (Figure BP-4).



Date created: Feb 2011

Source of data: PORE, Pacific Institute

MXD File: Predicted_Sealevel_2100.mxd

Figure BP-3

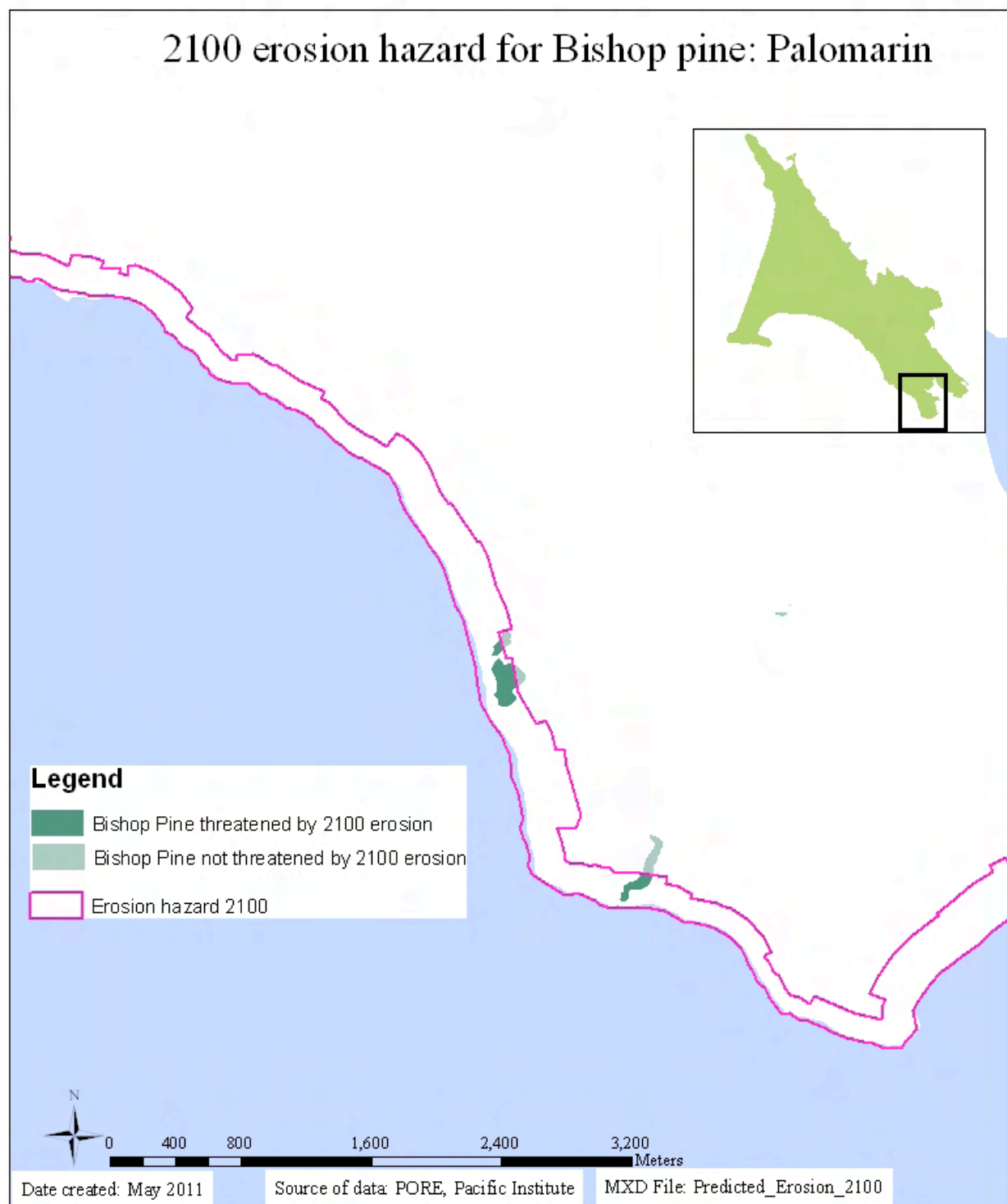


Figure BP-4

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Kelp forests

Introduction

Canopy-forming kelps provide habitat for rich subtidal communities along the southern rocky coast of Point Reyes National Seashore. Kelp forest communities are some of the most biologically productive in the world. The kelp forest communities in the park fall within a range of kelp forests that include both *Macrocystis pyrifera*— a species found from Baja California to Southeast Alaska – and *Nereocystis luetkeana*— a species found largely to the north of the park.

Kelp forests are home to many invertebrates as well as many fish. Of particular management concern are the various species of rockfish that live in the kelp forests.

The kelp forests in Point Reyes National Seashore occur on the south side of the park, near Palomarin and Bolinas Point (Figure KF-1).



Figure KF-1: from Denn et al. (2010).

I. Expert judgment

Contributing experts:

Sarah Allen, Point Reyes National Seashore

Dan Howard, Cordell Bank National Marine Sanctuary

Effect of a change in climate

Increases in Seawater Temperature

The kelp species that act as primary producers and form habitat for many kelp forest-associated species may be particularly sensitive to increases in water temperature. A small increase in seawater temperatures could result in a shift towards *Macrocystis* dominated kelp forests, since this species is better adapted to warmer water. An 18-year study was conducted documenting the rocky intertidal and subtidal community changes on the exposed coast between Morrow Bay and Pismo, Ca (approximately 215 mi. south southeast of Point Reyes). It found significant community-wide changes associated with a 3.5 degree C rise in average seawater temperature induced by a power stations thermal pollution (Schiel et al. 2004). The study concluded that most of the community changes observed resulted from cascading responses to changes in abundance of key taxa, such as habitat-forming kelps. A persistent increase in seawater temperatures could be devastating to the kelp forests in the park. During the 1997-1998 El Nino event, persistent seawater temperatures above 16 degrees C, in conjunction with increased wave height, significantly reduced giant kelp populations in southern California. The El Nino event had only mild impacts to giant kelp populations in central California (Edwards and Estes 2006). Any significant decrease in the kelp populations in the park would have negative impacts both on the species for whom the kelp forests provide habitat, as well as species that do not live in the kelp forest, but that consume drift kelp (Harrold et al. 1998, Largier et al. 2010).

Warmer seawater temperatures have also been associated with reduced reproductive capacity in red abalone (*Haliotis rufescens*) and an accelerated development of the fatal disease, withering foot syndrome (Rogers-Bennett et al. 2010).

One recent study has focused on the synergistic effects of temperature increase and increased atmospheric CO₂ (and the resulting ocean acidification) on kelps (Connell and Russell 2010). The lab experiment found that increased atmospheric CO₂ and seawater temperatures have a positive impact on the abundance of algal turfs, which inhibit kelp recruitment.

Increased Extreme Storm Events

Increased wave heights associated with more extreme storm events would negatively impact kelp forests by dislodging kelp. Any decline in the kelp communities of the park would also result in the loss of kelp-associated species. Changes in the timing of severe storm events will also change the timing and distribution of drift kelp (Largier et al. 2010), which will have ramifications for communities outside of kelp forests where drift kelp plays an important role in the food web (e.g. sandy beach communities and rocky intertidal communities).

The increased turbidity in the water that will occur with storms due to increased terrestrial runoff and higher sediment resuspension may limit the amount of light that kelps are able to absorb in deeper water, negatively impacting kelp growth. While *Macrocystis* is likely to be negatively impacted by increased turbidity, *Nereocystis* may be positively impacted by increased turbidity (Largier et al. 2010).

Increased nutrient levels due to terrestrial runoff could positively impact kelp growth. Depending on how sediment transport is affected by storm patterns and oceanographic changes,

increased wave action around the park's kelp forests could negatively impact kelp forests if sediment accumulates over the rocky substrate that kelps require.

Changes in Ocean Chemistry

Since Point Reyes lies in an upwelling cell, its marine communities are exposed to the more acidified waters that are transported onto the continental shelf (Feely et al. 2008). Ocean acidification is predicted to have negative biological impacts in marine communities, but differences in the sensitivity to ocean acidification across taxa is likely to have important, and as yet unknown, implications for community responses (Kroeker et al. 2010). Increasingly acidified seawater will negatively impact kelp forest organisms that form calcium carbonate structures (Doney et al. 2009), though recent meta-analysis of ocean acidification research indicates that there is significant variation in the sensitivity of different taxa to ocean acidification (Kroeker et al. 2010). Among calcifying organisms, those that used more soluble forms of calcium carbonate (high-magnesium calcite) were more resilient to ocean acidification than those that use less soluble forms (calcite and aragonite), while the data suggest that crustaceans are not negatively affected by ocean acidification. Larval stages of kelp forest community members may be most sensitive to ocean acidification (Doney et al. 2009), which means that more acidified seawater may result in higher larval mortality rates and lower recruitment rates.

Sea Level Rise

Sea level rise is likely to result in a shoreward movement of kelp forests if the requisite available rocky substrate exists closer to shore, since the kelps will not fair as well in deeper water where they have less access to light. If suitable substrate does not exist for a shoreward migration, kelp forests may be 'squeezed out' and become locally extinct.

Changes in upwelling intensity or duration

Upwelling intensity will directly affect the health, distribution, and abundance of kelps. Increased upwelling would likely benefit both kelp species in the park since it would deliver cold nutrient-rich seawater. Decreased upwelling would likely have a negative impact on both species of kelp due to warmer seawater temperatures and the reduction in nutrients. Intensive upwelling with fewer or shorter periods of relaxation may be bad for kelp-associated species if these changes in upwelling patterns prove detrimental to larval recruitment of kelp-associated fauna as some experts expect (Largier et al. 2010).

Confounding factors

Invasive Species

The invasive kelp *Undaria pinnatifida* has been documented in wave protected habitats in California, including Monterey Bay (Silva et al. 2002).

Invasive *Didemnum* has turned offshore reefs into monocultures off the eastern coast of the United States (Bullard et al. 2007). This colonial tunicate has been found growing on eelgrass in Tomales Bay and Drakes Estero. While it has not yet been documented in kelp forests in this region, the invasion of *Didemnum* along the East Coast suggests that if conditions are favorable, this species has the capacity to invade and negatively impact kelp forests.

Oil Spills

Point Reyes is positioned to potentially feel the impacts from any major oil spill in or around San Francisco Bay, due to coastal oceanographic patterns. Communities on the south side of Point Reyes are particularly susceptible to the degrading effects of oil spills in the bay. Oil tankers frequent San Francisco Bay and nearshore ocean currents flow up the coast to the south side of Point Reyes. Protected coastlines are also more vulnerable to oil spills because they are less frequently flushed by wave action. While the communities on the south side of Point Reyes are more vulnerable to oil spills, oil from such spills has also been found on the north side of Point Reyes on occasion.

Species Interactions

Purple sea urchin (*Strongylocentrotus purpuratus*) populations, when unchecked, can effectively clear-cut kelp forests, forming urchin barrens devoid of the organisms that depend on kelp forest habitat. While there is no indication that the environmental changes associated with climate change would increase purple sea urchin populations in the park, if they did, it would endanger the relatively small kelp forest communities in the park. Ocean acidification may have a negative impact on purple sea urchin populations, given the calcium carbonate structures these organisms produce (Dupont et al. 2010).

Harvesting

It is not clear how much abalone is taken from kelp forests in Point Reyes National Seashore. It is possible that overharvest of red abalone could hurt the populations in the park's kelp forests. Reduced numbers might make these populations more sensitive to negative impacts associated with climate change.

II. Predictive vegetation mapping

The climate envelope models created by PRBO (Stralberg et al. 2009) do not include predictions for rocky intertidal communities.

III. Predicted coastline change mapping

The Pacific Institute's spatial predictions of 2100 sea level rise and erosion hazard (Heberger et al. 2009) are only directly relevant to intertidal and terrestrial communities in the park.

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Conclusion

Next steps and adaptive management

This Climate Change Vulnerability Assessment has compiled and attempted to interpret available information evaluating how 12 key communities at Point Reyes National Seashore may respond to a change in climate. Several sources of information were used in this assessment: scientific knowledge, expert judgment, modeled changes to the coastline and modeled changes to the distributions of vegetation communities. These data specifically address the communities at Point Reyes National Seashore.

Our intention is that this information be used for several purposes. First, this information should inform the scenario planning exercise that the park staff undergoes before writing a climate change action plan. Second, this information should be revisited and updated. As the climate changes over the next century and as computer models become more sophisticated, it will be critical for park managers to remain informed of new developments to best manage the natural communities at Point Reyes National Seashore. Due to all of the uncertainties related to climate change, taking an adaptive management approach in the future will be essential (as outlined in Fig AM-1, reproduced from the NPS). Third, this vulnerability assessment highlights areas of further research needs.

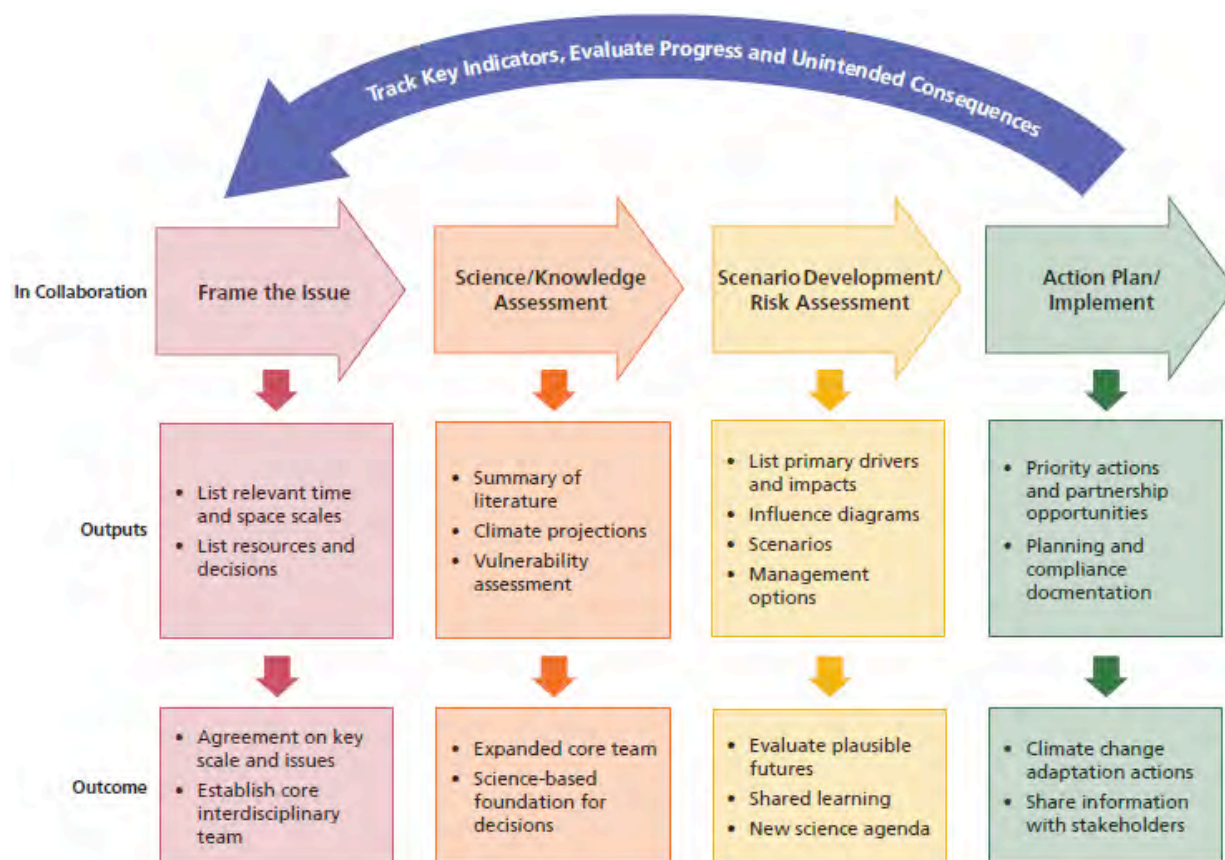


Figure AM-1: Conceptual diagram of adaptive management. From National Park Service Climate Change Response Strategy 2010.

Identifying research priorities

One of the aims of this report is to help park managers identify research needs. Throughout the course of this vulnerability assessment we have identified several information gaps. Research in these areas would be helpful in further evaluations of the impacts of climate change. These are mostly general needs and not specific to communities or species.

More research in general is needed concerning the future of fog in this area. Many of the species at Point Reyes National Seashore are dependent on specific fog regimes and there currently are not clear predictions of how fog regimes will change. While the scope of modeling fog responses to climate change may be outside the scope of management at Point Reyes National Seashore, we would encourage park staff to support partners who engage in this type of research.

It would be helpful to investigate models of how important ecological processes may respond to climate change. These processes include nutrient cycling, hydrology, succession, and adaptation. It will be especially important to understand how invasives with abilities to alter nutrient cycling, hydrology, succession, adaptation and species interactions will interact with climate change to

alter natural communities in the park. Plant species of particular concern include the various species of gorse and broom found in Marin County.

Fire is a driver of vegetation state changes in many communities in the park. Understanding how fire frequencies and intensities will react to climate change will be very important for understanding what the vegetation in the park may look like in the future. Specifically, it will be helpful to understand how increases or decreases in fuel loads (in response to climate conditions) will interact with weather conditions that favor or disfavor fire.

Although computer models can generally deal with many abiotic influences of predicted climate change (albeit with uncertainty), it is even more difficult to include biotic interactions in future models. It will be increasingly important to understand the biotic interactions which maintain the park's communities in their current states, as well as how these interacting species may be vulnerable to climate change.

Predictive models of individual species' ranges are becoming more common in the scientific literature. Some such models for key species of management concern may provide useful complement to NatureServe's Climate Change Vulnerability Index.

Understanding the status of emergent diseases (such as the amphibian chytrid fungus and sudden oak death) at Point Reyes National Seashore may become increasingly important. It may be useful to understand the status of disease-resistance in the local gene pool of affected plants and animals.

Method III of this report looked mostly at direct influences of rising sea level such as inundation and erosion. It will important to understand the secondary effects of rising sea level on vegetation community distributions in the park. These secondary effects can include changes in deposition of salt spray and increased tidal influences on streams.

Lastly, good baseline information on the physical and biological aspects of the park will provide a ruler by which future managers will be able to measure the effects of a change in climate. For example, the discrepancy between the shoreline of the park's vegetation map and Pacific Institute's modeled current shoreline is generally larger than predictions of sea level rise over the next 90 years. These lines crisscross throughout the park. The first step in conducting a good analysis of the threats of sea level rise to the coast will be to create an accurate map of current sea level at high and low tide, along with associated vegetation communities.

By answering key research questions with regards to how Point Reyes National Seashore's natural communities will respond to a changing climate, future managers at the park will be better able to manage natural communities and respond to these changes. It is critical that the information in this document, the results of the scenario-planning project, and the results of further climate-oriented research feed back to guide management in the future.

Appendix A

The experts that contributed to the expert judgment portion of this report

Community	Expert	Affiliation
Freshwater wetlands, streams & riparian areas	Lorraine Parsons	Point Reyes National Seashore
	Sarah Allen	Point Reyes National Seashore
	Tom Gardali	PRBO Conservation Science
	Gary Fellers	United States Geological Survey
Coastal scrub	Michael Barbour	University of California, Davis
	Lawrence D. Ford	University of California, Santa Cruz
Grasslands	Thomas Bruns	University of California, Berkeley
	James Bartolome	University of California, Berkeley
	Michael Barbour	University of California, Davis
	Judd Howell	H. T. Harvey & Associates
	Joe McBride	University of California, Berkeley
Eelgrass beds	Sarah Allen	Point Reyes National Seashore
	Dan Howard	Cordell Bank National Marine Sanctuary
Douglas fir & coast redwood forests	Michael Barbour	University of California, Davis
	Dave Rizzo	University of California, Davis
	Chris Still	University of California, Santa Barbara
	Douglas Fischer	ARCADIS Environmental Consulting
Estuarine communities	Lorraine Parsons	Point Reyes National Seashore
	Sarah Allen	Point Reyes National Seashore
	Roger Byrne	University of California, Berkeley
	John Kelly	Audubon Canyon Ranch
	Dan Howard	Cordell Bank National Marine Sanctuary
	Ted Grosholz	University of California, Davis
Bay oak hardwood forests	Geoff Geupel	PRBO Conservation Science
	David Rizzo	University of California, Davis
	Joe McBride	University of California, Berkeley
Sandy beaches & coastal dunes	Michael Barbour	University of California, Davis
	Lorraine Parsons	Point Reyes National Seashore
	Sarah Allen	Point Reyes National Seashore
	Dan Howard	Cordell Bank National Marine Sanctuary
	Joe McBride	University of California, Berkeley
Maritime chaparral	Geoff Geupel	PRBO Conservation Science
	Joe McBride	University of California, Berkeley
Rocky intertidal communities	Sarah Allen	Point Reyes National Seashore
	Ben Becker	Point Reyes National Seashore
	Dan Howard	Cordell Bank National Marine Sanctuary

Bishop pine forests	Michael Barbour	University of California, Davis
	Thomas Bruns	University of California, Berkeley
	Douglas Fischer	ARCADIS Environmental Consulting
Kelp forests	Sarah Allen	Point Reyes National Seashore
	Dan Howard	Cordell Bank National Marine Sanctuary

Appendix B

General information for maps generated in ARC-GIS

The current Point Reyes National Seashore vector vegetation map uses the UTM zone 10N projection with a NAD83 datum.

The PRBO raster maps are in Teale-Albers projection with a NAD27 datum.

PORE community name on 2004 vegetation map	Color used in GIS maps
Beaches or Mudflats	Violet dust
Bishop Pine	Deep forest
Built-up Urban disturbance	Peony pink
Coastal Dunes	Apatite blue
Coastal Scrub	Spruce green
Disturbed	Cattleya orchid
Douglas-fir/Coast Redwood	Protea pink
Dunes	Autunite yellow
Grassland	Ultramarine
Hardwood Forest	Glacier blue
Herbaceous Wetlands	Anemone purple
Pasture	Sage dust
Riparian Forest/Shrubland	Queztal green
Water	Electron gold

PRBO community name	Color(s) used in GIS maps
Annual Grasslands, Perennial Grasslands	Ultramarine
Mixed Chaparral, Chamise-Redshank Chaparral, Coastal Scrub	Spruce green
Montane Hardwood-Conifer, Douglas Fir	Protea pink
Montane Hardwood, Coastal Oak Woodland	Glacier blue
Redwood, Closed-Cone Pine, Cypress	Protea pink or deep forest

Appendix C

Area of community types in Point Reyes National Seashore & in erosion hazard zone

Community	Total Acres in PORE ¹	Acres in PI Erosion Hazard Zone ²	% of Acres in PI Erosion Hazard Area
Douglas-fir/ Coast Redwood	19000	18	0.1
Hardwood Forest	7900	25	0.3
Bishop Pine	3700	18	0.5
Riparian Forest/ Shrubland	2300	55	2
Built-up Urban disturbance	820	31	4
Pasture	3900	270	7
Herbaceous Wetlands	2200	160	7
Coastal Scrub	19000	2300	12
Water	530	70	13
Grassland	20000	2800	14
Coastal Dunes	1900	1200	67
Beaches or Mudflats	420	350	84
Dunes	470	425	91
Sandy beaches and dunes (Sum of Coastal Dunes, Beaches or Mudflats, and Dunes)	2700	2000	73

¹ National Park Service (NPS) and United States Geological Survey (USGS). 2004. Shapefile name: vegmap_2004_fpaupdate_pore.

² Areas generated by clipping NPS and USGS (2004) spatial data of park's communities by Pacific Institute's (PI) protected erosion hazard zone using Arc GIS.

Appendix D

Full inputs for NatureServe's Climate Change Vulnerability Index

California red-legged frog: *Rana draytonii*:

The NatureServe Climate Change Vulnerability Index																																										
Release 2.01 10 May 2010; Bruce Young, Elizabeth Byers, Kelly Gravier, Kim Hall, Geoff Hammerson, Alan Redder With input from: Jay Cordeiro, Kristin Szabo Funding for Release 2.0 generously provided by the Duke Energy Corporation.																																										
																																										
* = Required field																																										
Geographic Area Assessed:	Point Reyes National Seashore *																																									
Assessor:	Katie Holzer																																									
Species Scientific Name:	<i>Rana draytonii</i> *																																									
English Name:	California red-legged frog																																									
Major Taxonomic Group:	Amphibian *																																									
Relation of Species' Range to Assessment Area:	Center of range *																																									
G-Rank:	G2G3																																									
S-Rank:	S2S3																																									
Check if species is an obligate of caves or groundwater aquatic systems:	☐ (Must be marked with an "X" for accurate scoring of these species.)																																									
Assessment Notes (to document special methods and data sources)																																										
Section A: Exposure to Local Climate Change (Calculate for species' range within assessment area)																																										
Temperature *																																										
Severity	Scope (percent of range)																																									
>5.5° F (3.1° C) warmer																																										
5.1-5.5° F (2.8-3.1° C) warmer																																										
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3.9-4.4° F (2.2-2.4° C) warmer																																										
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Total:	100 (Must sum to 100)																																									
Hamon AET:PET Moisture Metric *																																										
Severity	Scope (percent of range)																																									
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-0.051 - -0.073																																										
-0.028 - -0.050	100																																									
>-0.028																																										
Total:	100 (Must sum to 100)																																									
Section B: Indirect Exposure to Climate Change (Evaluate for specific geographical area under consideration)																																										
Mark an "X" in all boxes that apply.																																										
<table border="1"><thead><tr><th colspan="6">Effect on Vulnerability</th></tr><tr><th>Greatly increase</th><th>Increase</th><th>Somewhat increase</th><th>Neutral</th><th>Somewhat decrease</th><th>Decrease</th><th>Unknown</th></tr></thead><tbody><tr><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td></tr><tr><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td>X</td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td></tr></tbody></table>		Effect on Vulnerability						Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown				X					X								X								X			
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2) Distribution relative to barriers																																										
a) Natural barriers																																										
b) Anthropogenic barriers																																										
3) Predicted impact of land use changes resulting from human responses to climate change																																										

Section C: Sensitivity

Mark an "X" in all boxes that apply.

Effect on Vulnerability						
Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown
			X			
	X	X				
	X	X				
				X		
X						
			X			
			X			
			X			
			X			
			X			
			X			
			X			
						X
						X
						X

Factors that influence vulnerability (* at least 10 required)

- 1) Dispersal and movements
- 2) Predicted sensitivity to temperature and moisture changes
 - a) Predicted sensitivity to changes in temperature
 - i) historical thermal niche
 - ii) physiological thermal niche
 - b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime
 - i) historical hydrological niche
 - ii) physiological hydrological niche
- c) Dependence on a specific disturbance regime likely to be impacted by climate change
- d) Dependence on ice, ice-edge, or snow-cover habitats
- 3) Restriction to uncommon geological features or derivatives
- 4) Reliance on interspecific interactions
 - a) Dependence on other species to generate habitat
 - b) Dietary versatility (animals only)
 - c) Pollinator versatility (plants only)
 - d) Dependence on other species for propagule dispersal
 - e) Forms part of an interspecific interaction not covered by 4a-d
- 5) Genetic factors
 - a) Measured genetic variation
 - b) Occurrence of bottlenecks in recent evolutionary history (use only if 5a is "unknown")
- 6) Phenological response to changing seasonal temperature and precipitation dynamics

Section D: Documented or Modeled Response to Climate Change (Optional; May apply across the range of a species)

Mark an "X" in all boxes that apply.

Effect on Vulnerability						
Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown
						X
						X
						X
						X

(Optional)

- 1) Documented response to recent climate change
- 2) Modeled future (2050) change in population or range size
- 3) Overlap of modeled future (2050) range with current range
- 4) Occurrence of protected areas in modeled future (2050) distribution

Climate Change Vulnerability Index

for *Rana draytonii* in Point Reyes National Seashore

Moderately Vulnerable

Notes:

Confidence in Species Information
Moderate

* Histogram below

Copy Data to Results Table

Definitions of Index Values

Extremely Vulnerable (EV): Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

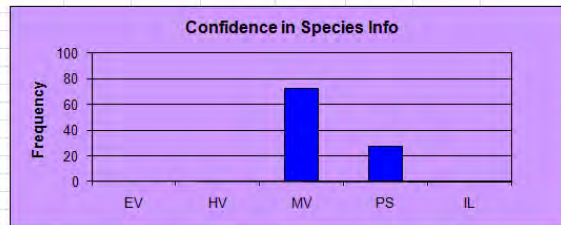
Highly Vulnerable (HV): Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

Moderately Vulnerable (MV): Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

Not Vulnerable/Presumed Stable (PS): Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

Not Vulnerable/Increase Likely (IL): Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

Insufficient Evidence (IE): Available information about a species' vulnerability is inadequate to calculate an Index score.



American Bullfrog: *Rana catesbeiana*

The NatureServe Climate Change Vulnerability Index

Release 2.01 10 May 2010; Bruce Young, Elizabeth Byers, Kelly Gravuer, Kim Hall, Geoff Hammerson, Alan Redder
With input from: Jay Cordeiro, Kristin Szabo
Funding for Release 2.0 generously provided by the Duke Energy Corporation.

** = Required field*



Geographic Area Assessed: Point Reyes National Seashore *

Assessor: Katie Holzer

Species Scientific Name: Rana catesbeiana *

Major Taxonomic Group: Amphibian *

Relation of Species' Range to Assessment Area: Center of range *

English Name: American Bullfrog

G-Rank: G5

S-Rank: SNA

Check if species is an obligate of caves or groundwater aquatic systems: ☐

(Must be marked with an "X" for accurate scoring of these species.)

Assessment Notes (to document special methods and data sources)

Section A: Exposure to Local Climate Change (Calculate for species' range within assessment area)

Temperature *

Severity

>5.5° F (3.1° C) warmer

5.1-5.5° F (2.8-3.1° C) warmer

4.5-5.0° F (2.5-2.7° C) warmer

3.9-4.4° F (2.2-2.4° C) warmer

< 3.9° F (2.2° C) warmer

Scope (percent of range)

100

Total: 100 (Must sum to 100)

Hamon AET:PET Moisture Metric *

Severity

< -0.119

-0.097 - -0.119

-0.074 - -0.096

-0.051 - -0.073

-0.028 - -0.050

> -0.028

Scope (percent of range)

100

Total: 100 (Must sum to 100)

Section B: Indirect Exposure to Climate Change (Evaluate for specific geographical area under consideration)

Mark an "X" in all boxes that apply.

Effect on Vulnerability

Greatly increase

Increase

Somewhat increase

Neutral

Somewhat decrease

Decrease

Unknown

Factors that influence vulnerability (* at least three required)

1) Exposure to sea level rise

2) Distribution relative to barriers

a) Natural barriers

b) Anthropogenic barriers

3) Predicted impact of land use changes resulting from human responses to climate change

Section C: Sensitivity

Mark an "X" in all boxes that apply.

Effect on Vulnerability

Greatly increase

Increase

Somewhat increase

Neutral

Somewhat decrease

Decrease

Unknown

Factors that influence vulnerability (* at least 10 required)

1) Dispersal and movements

2) Predicted sensitivity to temperature and moisture changes

a) Predicted sensitivity to changes in temperature

i) historical thermal niche

ii) physiological thermal niche

b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime

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e) Forms part of an interspecific interaction not covered by 4a-d

5) Genetic factors

a) Measured genetic variation

b) Occurrence of bottlenecks in recent evolutionary history (use only if 5a is "unknown")

6) Phenological response to changing seasonal temperature and precipitation dynamics

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Section D: Documented or Modeled Response to Climate Change (Optional; May apply across the range of a species)

Mark an "X" in all boxes that apply.

Effect on Vulnerability						
Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown
						X
						X
						X
						X

(Optional)

- 1) Documented response to recent climate change
- 2) Modeled future (2050) change in population or range size
- 3) Overlap of modeled future (2050) range with current range
- 4) Occurrence of protected areas in modeled future (2050) distribution

Climate Change Vulnerability Index

for *Rana catesbeiana* in Point Reyes National Seashore

Not Vulnerable/Presumed Stable

Notes:

Confidence in Species Information
Moderate

* Histogram below

Copy Data to Results Table

Definitions of Index Values

Extremely Vulnerable (EV): Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

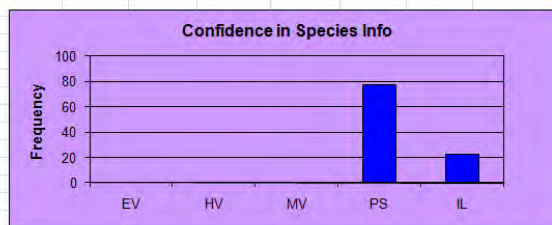
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Not Vulnerable/Increase Likely (IL): Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

Insufficient Evidence (IE): Available information about a species' vulnerability is inadequate to calculate an Index score.



Results of a Monte Carlo simulation (1000 runs) of the data entered in the Index.