Preparing for Climate Change Impacts to State-owned Aquatic Lands: A Climate Change Adaptation Strategy for the Washington Department of Natural Resources Aquatic Resources Program

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Abstract

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for the
Washington Department of Natural Resources Aquatic Resources Program

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This Climate Change Adaptation Strategy has been prepared to help the Washington State Department of Natural Resources (WDNR) Aquatic Resources Program develop and prioritize its climate change preparedness efforts in the coastal areas of Washington State. This Strategy provides the necessary information to transform the Aquatic Resources Program into a climate resilient institution and to increase the resiliency of the 2.6 million acres of state-owned aquatic lands under WDNR management. As the steward of aquatic lands held in public trust, WDNR has a legal obligation to proactively prepare for the direct and indirect impacts of climate change to these lands. This Strategy initiates the Aquatic Resources Program's climate change adaptation effort by articulating the next steps that the Program can take to begin preparing for climate change. This Strategy provides an overview of projected climate change impacts to Washington's coastal areas, articulates a framework for preparing for climate change, and scopes potential impacts to state-owned aquatic lands and WDNR's management activities. It also assesses the ability of the agency to continue providing a balance of public benefits from state-owned aquatic lands in the context of climate change. The

Strategy presents a vulnerability assessment of WDNR's co-management of Washington's Commercial Wild Stock Geoduck Fishery. It concludes by identifying priority planning areas for the Program, and presenting next steps for improving the resiliency of the Program and state-owned aquatic lands. The recommendations include steps to build adaptive capacity and near-term and long-term adaptive actions for the Washington Department of Natural Resources.

Key words: Climate change, Impacts, Adaptation, Washington State, Aquatic Resources Program of WDNR, State-Owned Aquatic Lands

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Dedication

To Marc J. Hershman (1942 – 2008)

Introduction

This Climate Change Adaptation Strategy (the Strategy) has been prepared to help the Washington Department of Natural Resources' (WDNR) Aquatic Resources Program (the Program) develop and prioritize its climate change preparation efforts. The Strategy establishes a climate resilient vision for the Program and Washington's state-owned aquatic lands. Through a scoping of the potential effects of projected climate change impacts to state-owned aquatic lands and to the Program itself, the Strategy identifies priority planning areas and presents recommendations for adapting to and preparing for climate change on marine state-owned aquatic lands.

WDNR manages over 2.6 million acres of state-owned aquatic lands in Washington State. The Aquatic Resources Program is statutorily mandated to manage these publicly-owned aquatic lands in a manner that ensures these lands provide specific public benefits for the citizens of Washington State in perpetuity. As the steward of these public trust lands, WDNR has a legal obligation to prepare for climate change by taking proactive steps to ensure the lands and natural resources under its management and are as resilient to climate change as possible. The WDNR Mission is "to provide forward-looking stewardship of our state lands, natural resources, and environment" (WDNR 2008). By initiating its climate change preparedness efforts today, WDNR is fulfilling its articulated mission of forward-looking stewardship.

Structure of the Climate Change Adaptation Strategy

This Strategy answers the question "what are the next steps that WDNR Aquatic Resources Division can take to begin preparing for and adapting to climate change in coastal areas?" by posing a series of follow-up questions. The Strategy is structured around answering these four basic questions:

Question 1: ***Why should the Aquatic Resources Program start preparing for climate change today?***

Question 2: ***Which state-owned aquatic lands and WDNR management areas may be most vulnerable to projected climate change impacts?***

Question 3: ***What does the Aquatic Resources Program want state-owned aquatic lands to look like in 2050?***

Question 4: ***What are the next steps that WDNR's Aquatic Resources Program can take to begin preparing for and adapting to climate change?***

To answer Question 1, the Strategy summarizes allows the latest current climate change science and information on projected impacts to Washington's coasts. A discussion of the importance of preparing for climate change through anticipatory adaptation actions and capacity building is also provided. To answer Question 2, the Strategy scopes the potential effects of climate change to state-owned aquatic lands and the Program's management activities. A pilot vulnerability assessment of the agency's co-management of Washington's Wild Stock Geoduck Fishery is also provided. Responding to Question 2 allows for Priority Planning Areas to be identified for the Aquatic Resources Program. Posing Question 3 allows WDNR to plan backward from 2050, a technique utilized by King County in the creation of their 2007 Climate Plan (King County 2007). In posing this question, the Strategy recognizes that the actions taken by the Aquatic Resources Program today will dictate the way that Washington State's aquatic lands look by mid-century. Question 4 allows for the presentation of recommended actions for creating a more climate resilient Aquatic Resources Program and for increasing the resiliency of marine state-owned aquatic lands to projected climate change impacts.

Terms of Reference for the Climate Change Adaptation Strategy

This Climate Change Adaptation Strategy was prepared for the Washington State Department of Natural Resources' Aquatic Resources Program as the final product of a nine-month Washington Sea Grant fellowship, the Marc Hershman Marine Policy Fellowship. Table 1 lists the questions provided by WDNR at the onset of the fellowship. While all of the questions below are addressed within the Strategy, the focus is on question H: "What are the next steps that WDNR Aquatic Resources Division can take to begin preparing for and adapting to climate change in coastal areas?"

These terms of reference clearly define the scope of this Strategy to a consideration of climate change impacts in coastal and marine environments. As such, the Strategy does not examine climate change impacts to Washington's freshwater state-owned aquatic lands (shorelands, and freshwater bedlands). Much of the information provided in the Strategy, however, may be applicable to these areas.

Table 1. Terms of Reference for Marc Hershman Marine Policy Fellowship

A.	What are the expected climate change impacts to state-owned aquatic lands in coastal areas? What different adaptation measures and management strategies for state-owned aquatic lands exist?
B.	How might planning for state-owned aquatic lands provide a model for managing adjoining lands and adapting local land use policies and plans?
C.	What specific information on climate change impacts (i.e. potential levels of sea-level rise, etc) might be useful to local government planning, and how can WNDR Aquatic Resources Division and/or Washington State provide such information?
D.	How might state laws, policies, rules be revised to support adaptation to and preparation for climate change impacts?
E.	What are the legal issues associated with rising sea levels for WDNR? Specifically, how will changes in sea level impact the ownership of aquatic lands?
F.	What existing policy recommendations (e.g., Washington State Climate Change Coastal and Infrastructure Preparation and Adaptation Working Group recommendations) might be incorporated into a framework for preparing for and adapting to climate change in coastal areas?
G.	What are the next steps that Washington State can take to begin preparing for and adapting to climate change in coastal areas?
H.	**What are the next steps that WDNR Aquatic Resources Division can take to begin preparing for and adapting to climate change in coastal areas?**
I.	How might climate change adaptation and preparation in coastal areas be addressed on a regional level?

Background: An Overview of WDNR Aquatic Resources Program's Management of State-owned Aquatic Lands

This section of the Strategy provides an overview of WDNR Aquatic Resources Program's management of state-owned aquatic lands. This brief discussion of WDNR's management guidelines, activities, and authorized uses in coastal areas provides the necessary context for the Strategy's analysis of how projected climate change impacts may effect the Aquatic Resources Program.

Washington's aquatic lands were conveyed into public ownership at the time of statehood. The Washington State Constitution declares that "the state of Washington asserts it ownership to the beds and shores of all navigable waters in the state" (Washington State Constitution, art.17, sec.1). The Washington Department of Natural Resources (WDNR) is directed by statute to manage these state-owned aquatic lands, which are defined as "all tidelands, shorelands, harbor areas, the beds of navigable waters, and waterways owned by the state" (RCW 79-105-060). At the time of statehood in 1889, Washington State held some 2.8 million acres of state-owned aquatic lands in public trust. From 1889 to 1971, the State had the authority to sell tidelands and shorelands. During this period many aquatic lands were conveyed into private ownership, including 64% of the State's tidelands. Today, WDNR's Aquatic Resources Program (the Program) is the steward of over 2.6 million acres of state-owned aquatic lands (SOALs), including approximately 1,300 miles of tidelands, 6,700 acres of harbor areas and 2,000 square miles of marine bedlands. The Aquatic Resources Program manages these public trust lands for the benefit of current and future Washingtonians.

Definitions of State-owned Aquatic Lands

State-owned aquatic lands in the marine environment include tidelands, bedlands, and harbor areas. Revised Code of Washington (RCW) 79-105-060(4)(18) defines *tidelands* as those marine and estuarine waters effected by the ebb and flow of tides and located between the ordinary high tide and extreme low tide line [RCW 79.105.060(4)(18)]. *Bedlands*, or "beds of navigable waters," [RCW 79.105.060 (2)] are submerged lands that lie waterward of adjoining tidelands or shorelands and below the line of extreme low tide or the line of navigability" [RCW 79.105.060 (2)]. *Harbor areas* are defined in Article XV, Section 1 of the Washington State Constitution as those areas "…forever reserved for landings, wharves, streets, and other conveniences of navigation and commerce" [Washington State Constitution, Art. XV (1)].

Guidelines for Managing State-owned Aquatic Lands

The Aquatic Resources Program has statutorily established guidelines for the management of state-owned aquatic lands (SOAL). The Washington State Legislature established these management guidelines with the understanding that Washington's state-owned aquatic lands are "a finite natural resource of great value and an irreplaceable public heritage" (RCW 79-105-010). The legislature recognized that conflicting uses occur on SOALs (RCW 79-105-010). In an effort to address this problem of conflicting uses, the Legislature directs WDNR to manage SOALs to provide a balance of public benefits for all of Washington's citizens in perpetuity. Revised Code of Washington 79-105-030 lists four specific public benefits that WDNR's management of SOALs must provide:

> (1) Encouraging direct public uses and access;
> (2) Fostering water-dependent uses;
> (3) Ensuring environmental protection;
> (4) Utilizing renewable resources. (RCW 79-105-030)

The law further stipulates that generating revenue in a manner consistent with these four benefits is a public benefit (RCW 79-105-030). Together, these public benefits are referred to as the "Four Plus" public benefits - the "Plus" being the generation of revenue. WNDR strives to provide a balance of these "Four Plus" public benefits in its management of state-owned aquatic lands.

The Public Benefit of Direct Public Use and Access

Washington Administrative Code (WAC) 332-30-10 defines *public use* as providing for daily use by the general public "on a first-come, first-served basis" (WAC 332-30-106). WAC 332-30-131 identifies several measures to promote public access to and use of state-owned aquatic lands, including encouraging other agencies to provide for public use and access [WAC 332-30-131(1)], providing grants to state and local agencies to encourage public access on SOALs [WAC 332-30-106(2)], advertising public access [WAC 332-30-106(3)], and rent reduction for lessees of SOALs that provide public access [WAC 332-20-106(5)]. RCW 79-105-230 stipulates that the use of

SOALs for public parks or public recreation purposes be granted free of charge (RCW 79-105-230).

The Public Benefit of Fostering Water-Dependent Uses

Under RCW 79-105-060, a *water-dependent use* is defined as "a use that cannot logically exist in any location but on the water." It is recognized in statute that "water-dependent industries and activities have played a major role in the history of the state and will continue to be important in the future" (RCW 79-05-010). As such the law requires that water-dependent uses be especially encouraged on SOALs. The Program works to protect and improve water-dependent uses by collaborating with local governments to maintain harbor areas and waterways for commerce and navigation. Water-dependent uses are also encouraged through the Program's rent structure, which provides discounted lease rates for water-dependent uses on state-owned aquatic lands. When WDNR land managers are reviewing a use authorization, they are directed to favor water-dependent uses over other uses on state-owned aquatic lands [RCW 79-105-210(1)]

The Public Benefit of Ensuring Environmental Protection

RCW 79-105-210 requires that the Program consider the natural value of state-owned aquatic lands in so far as it may provide "wildlife habitat, natural area preserve, representative ecosystem, or spawning area" before issuing any leases or authorizing any use (RCW 79-105-210). It is WDNR policy to ensure environmental protection every time a new use is authorized or an existing use is reviewed on state-owned aquatic lands. The Program verifies that no net loss of ecological habitat or function occurs as a result of authorized activities on SOALs. The Program also strives to ensure that authorized uses result in a net gain of ecological function whenever possible. In addition to strictly reviewing the environmental impact of authorized uses, the agency ensures environmental protection via numerous management activities is to ensure environmental protection. These activities will be discussed in greater detail below.

The Public Benefit of Utilizing Renewable Resources

A renewable resource is defined as "a natural resource which through natural ecological processes is capable of renewing itself" (WAC 332-30-106). The renewable resources most commonly extracted from state-owned aquatic lands are shellfish, including geoducks. WDNR also views opportunities for public use and enjoyment (e.g., shellfish harvesting, swimming, walking on the beach) as renewable resources. Hydrokinetic energy projects, (capturing wave and tidal energy), are an emerging renewable resource that may provide considerable public benefit. WDNR is committed to utilizing natural resources in a sustainable manner (WDNR 2008).

Authorized Uses of State-owned Aquatic Lands

One way the Program provides a balance of the "Four Plus" public benefits on SOALs is through the types of uses authorized on state-owned aquatic lands in WDNR lease agreements. WDNR has clearly established authority to lease SOALs (RCW 79.105.210), and to determine appropriate uses on these leased lands. The Program uses its broad authority as a propriety agency to ensure that leased SOALs are utilized in a manner that benefits the public. One way that the Program works to achieve the balance of public benefits is by categorizing authorized uses as Water-Dependent, Nonwater-Dependent, or Water-Oriented.

As discussed above, a water-dependent use is one that can only logically exist on the water (RCW 79-105-060). RCW 79-105-210 stipulates that the management of SOALs "shall preserve and enhance water-dependent uses" (RCW 79-105-210) and that "water-dependent uses shall be favored over other uses in aquatic land planning and in resolving conflicts between lease applications" (RCW 79-105-210). The following water-dependent uses are specifically identified in statute (RCW 79-105-060):

- Water-borne commerce
- Terminal and transfer facilities
- Ferry terminals
- Watercraft sales in conjunction with other water-dependent uses
- Watercraft construction, repair and maintenance
- Moorage and launching facilities
- Aquaculture
- Log booming
- Public fishing piers and parks

A nonwater-dependent use is a use that can occur in a location other than the waterfront (RCW 79-105-060). If it would be merely convenient, but not necessary, to place a use on the waterfront then that use is a nonwater-dependent use. Revised Code of Washington 79-105-210(2) determines that nonwater-dependent uses of state-owned aquatic lands are low-priority uses providing minimal public benefits (RCW 79-105-210). WDNR does not be permit nonwater-dependent uses in new areas except in certain exceptional circumstances (e.g., the use is compatible with water-dependent uses in the same area) (WAC-332-30-137). RCW 79-105-060 identifies the following uses as explicitly nonwater-dependent:

- Hotels
- Condominiums
- Apartments
- Restaurants
- Retail stores
- Warehouses not part of a marine terminal or transfer facility

A water-oriented use is a use that historically has been dependent on a waterfront location, but could be located away from the waterfront today. For example, loading or unloading raw materials such as fish, wood, or petroleum between a boat and a dock is water-dependent, but processing these materials in a waterfront factory is water-oriented, since the factory could be moved to adjoining uplands. The water-oriented use classification was developed in order to "grandfather" certain existing uses of aquatic lands and to protect existing investments. The following water-oriented uses are specified in statute (RCW 79.105.060):

- Wood products manufacturing

- Watercraft sales
- Fish processing
- Petroleum refining
- Sand and gravel processing
- Log storage
- House boats

Table 2 provides a comprehensive list of Authorized Uses of state-owned aquatic lands that have been defined as Water-dependent, Nonwater-dependent, and Water-oriented.

Table 2. Authorized Water-dependent, Water-oriented, and Nonwater-dependent Uses on State-Owned Aquatic Lands

Water-dependent Uses:	Water-oriented Uses:	Nonwater-dependent Uses:
Overwater structures		
Boat ramps, launches & hoists	Fish processing facilities	Nearshore buildings, (airports, apartments and condominiums, aquariums, retail stores, restaurants, hotels, warehouses/ storage NOT part of a marine terminal
Docks & wharves	Floating homes	
Rafts & floats		
Terminal & transfer facilities, tug & barge facilities, warehouses & storage (part of a marine terminal)		Sewage treatment facilities
Watercraft construction, repair, maintenance		Boat lifts, boat or vessel storage
Watercraft sales in conjunction with water-dependent uses		
Marinas		
Miscellaneous nearshore		
Geoduck harvesting	Log storage	
Log booming	Petroleum refining	
Sediment removal (use for public purposes)		
Public access		
Sand shrimp harvesting		

Water-dependent Uses:	Water-oriented Uses:	Nonwater-dependent Uses:
Aquaculture		
Finfish Aquaculture		
Shellfish Aquaculture		
Geoduck Aquaculture		
Flood, wave, and erosion control		
Breakwaters		Bank armoring
Fill		
Dams		
Utilities		
Desalinization intake		Utility lines
Water intake lines, not desalinization plants		Desalinization outfalls
Oil & gas pipelines		Outfalls
water pipelines		
Power & cable lines		
Sewer & water lines		
Mitigation and enhancement		
Artificial habitat		
Conservation/ preservation		
Remediation of contamination		
Compensatory mitigation		
Restoration		
Transportation		
Ferries		Bridges and trestles
Waterbourne commerce		Highways and roads
Cargo & bulk products		Parking lots

The Program strives to balance the "Four Plus" benefits in many ways beyond the designation of uses as water-dependent, water-oriented, and nonwater-dependent when authorizing uses and leasing state-owned aquatic lands. For example, the program authorizes the use of overwater structures, which can foster water-dependent uses, provide public access, and promote the utilization of renewable resources. To encourage environmental protection of state-owned aquatic lands, the Program has developed a conservation leasing program. To encourage the utilization of renewable resources, WDNR leases state-owned tidelands for shellfish and fin-fish aquaculture. And most all leasing of SOALs generates revenue in a manner consistent with the other four public benefits. Table 3 illustrates how different authorized uses and leasing of state-owned aquatic lands foster the public benefits articulated in RCW 79-105-030.

Table 3: Public Benefits Provided by WDNR Authorized Uses of SOALs

	Public Benefits				
WDNR Authorized Uses of SOALs	Encourage direct public use and access	Foster water-dependent uses	Ensure environ-mental protection	Utilize renewable resources	Generate revenue in manner consistent with other four benefits
Aquaculture leases (Shellfish & Fin-fish)		X	X	X	X
Discounts for water-dependent leases that offer public access	X	X	X	X	X
Fair market values for nonwater-dependent Uses			X		X

Authorizing overwater structures	X	X	X	X	X
Conserva-tion leasing	X	X	X		X

Management Activities of the Aquatic Resources Program

Use authorizations are only one way that the Program manages SOALs for the public's benefit. WDNR also manages the State's aquatic lands through a number of specific management activities. Table 4 lists these activities, and indicates those public benefits that each of these management activities promotes. Below is a very brief description of some of the Program's primary management activities.

Operation of Commercial Wild Stock Geoduck Fishery

WDNR and the Washington Department of Fish and Wildlife (WDFW) co-manage the wild stock geoduck fishery on SOALs with the Puget Sound Treaty Tribes as mandated under treaty and interpreted under the Rafeedie decision (*U.S. v. Washington,* 898 F. Supp 1453, 1995). The state and tribes are each entitled to 50 % of the annual total allowable catch, which is determined by WDFW. WDNR markets the state's quota through three to four public auctions annually. Only fishermen that are licensed by WDFW and working for companies with valid harvest agreements may harvest geoduck.

WDNR compliance divers assure the terms of the harvest agreements are being met and that there is no theft of valuable state resources.

Aquaculture Leases (Shellfish & Fin-fish)

As the utilization of renewable resources is one of the "Four Plus" public benefits, the Program actively fosters aquaculture activity on SOALs. Aquaculture includes the harvesting of existing shellfish, the cultivation of shellfish in artificial beds and floating rafts, and the raising of fin-fish in floating pens. It does not include harvesting of the wild stock geoduck fishery. WDNR currently leases approximately 2,100 acres of SOALs for commercial shellfish aquaculture activities. Approximately 80% of WDNR's commercial aquaculture leases are for oyster culture. Most state-owned aquatic lands leased for aquaculture are located in the two large outer coast estuaries, Willapa Bay and Grays Harbor, but there are also significant commercial aquaculture activities in Puget Sound. There is currently no authorized geoduck aquaculture occurring on SOALs.

Habitat Conservation Plan

WDNR's Aquatic Endangered Species Act (ESA) Team is creating a Habitat Conservation Plan (HCP) to ensure that WDNR's management of SOALs leads to recovery of nearly two dozen threatened and endangered species. The HCP covers all 2.6 million acres of fresh and marine SOALs across the state. The two main goals of the HCP are to protect sensitive, threatened, and endangered species that may be vulnerable to WDNR's authorized activities, and to gain assurance under the federal ESA that WDNR can continue to authorize activities on SOALs. The HCP includes conservation measures and strategies that can be applied to all new and existing leases for overwater structures, log booming and aquaculture.

Involvement in Local Shoreline Master Planning

WDNR's land managers are familiar with all Shoreline Master Programs (SMP) in their assigned areas. When amendments are proposed or SMPs are being updated, the Program's land managers work closely with local planning agencies and the Washington Department of Ecology to determine whether the proposed changes will effect SOALs. Particular attention is given to proposed changes which may impose greater restrictions on water-dependent uses (e.g., the prohibition of aquaculture) or proposed changes that which may place fewer restrictions on nonwater-dependent uses (e.g., smaller residential setbacks). These types of changes may hinder the Program's ability to effectively manage SOALs for the "Four Plus" public benefits. Managers also evaluate proposed uses of SOALs to ensure they are consistent with the local SMP.

Aquatic Reserves Program

The Aquatic Reserves Program was created to increase the conservation of selected aquatic lands. This program aims to enhance the health of native marine and freshwater aquatic habitats. It ensures environmental protection through habitat preservation, restoration and enhancement, and encourages public use and access. There are four currently designated Aquatic Reserves: Maury Island, Fidalgo Bay, Cypress Island, and Cherry Point. Three other sites have been nominated for Aquatic Reserve designation and are under evaluation. These sites are Nisqually Reach, Protection Island and Smith/Minor Island.

Stewardship Science

WDNR's Stewardship Science program provides expert scientific advice to support the proper management of state-owned aquatic lands and embedded natural resources. The guiding principles of the Stewardship Science Program include the application of an ecosystem approach, the implementation of adaptive management, building partnerships with other agencies, tribes and organizations, and ensuring no net loss in habitat and a net gain in ecological function on SOALs.

Dredge Materials Management Program

WDNR is a member of the Dredge Materials Management Program (DMMP), a multi-agency program which determines the suitability of dredged materials and how it should be properly dredged, handled, transferred and disposed. The agencies which make up the program include the U.S. Army Corps of Engineers, the Environmental Protection Agency, the Washington Department of Ecology and WDNR. All projects which dredge sediments from Washington's waters must go through the DMMP for a suitability determination. The primary program users are ports and water-dependent businesses. WDNR's role consists of managing and monitoring the disposal sites located on state-owned aquatic lands.

Invasive Species Program

WDNR is statutorily mandated to control and eradicate a number of invasive noxious weeds from state-owned aquatic lands (RCW 79A-25-310). Much of the Program's current focus is on the eradication of *Spartina*, (commonly known as cordgrass), which is an aggressive, non-native noxious weed that severely alters marsh and mudflat ecosystems on the west coast. Significant progress has been made towards the eradication of *Spartina* in Willapa Bay, with over 8,000 acres of the invasive species eradicated to date.

Derelict Vessel Removal Program

In response to a growing number of derelict and abandoned vessels in our waters, the Washington State Legislature created the Derelict Vessel statute (RCW 79-100), which authorizes and provides funding for public entities to remove and dispose of derelict and abandoned vessels in State waters. The Derelict Vessel Removal Program (DVRP) manages funding and provides expertise and assistance for derelict and abandoned vessel removal and disposal. To date, 188 vessels have been removed by 35 public entities since January 2003. There are currently 191 vessels on the DVRP removal list, 36 of which are actively being worked.

Table 4: Public Benefits Provided by WDNR's Management Activities

	Public Benefits				
Management Activities	**Encourage direct public use and access**	**Foster water-dependent uses**	**Ensure environmental protection**	**Utilize renewable resources**	**Generate revenue in manner consistent with other four benefits**
Operation of commercial wild stock geoduck fishery		X	X	X	X
Shoreline Master Planning Coordination	X	X	X	X	
Habitat Conservation Plan	X	X	X	X	
Aquatic Reserves Program	X	X	X	X	
Transfer of management authority to local, state, and national parks services	X	X	X	X	
Near-shore Habitat Program			X	X	
Restoration Partnerships	X	X	X	X	

Management Activities	Encourage direct public use and access	Foster water-dependent uses	Ensure environmental protection	Utilize renewable resources	Generate revenue in manner consistent with other four benefits
Stewardship Science	X	X	X	X	
Dredge Materials Management Program	X	X	X		X
Invasive Species Program			X	X	
Ports Program		X	X		X
Derelict Vessel Removal Program			X		

1.0 An Overview of Climate Change Impacts to Washington's Coastal Areas

Question 1: Why should the Aquatic Resources Program start preparing for climate change today?

This section of the Strategy provides an overview of observed and projected changes in climate in Washington State, with a focus on impacts to Washington's coastal areas. This information on climate change and coastal impacts provides the foundation for the scoping of the potential effects of climate change to state-owned aquatic lands and the Aquatic Resources Program and for the pilot vulnerability assessment presented later in the Strategy.

This Strategy relies on two principal sources for information on climate change science and the impacts of climate change to Washington's Coasts: 1) the United Nations Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC 2007), and the University of Washington's Climate Impacts Group's (CIG) Washington Climate Change Impacts Assessment (Climate Impacts Group 2009). Information from other reports and subject matter experts is incorporated where noted.

1.1 Observations and Projections from the Intergovernmental Panel on Climate Change Fourth Assessment Report

The IPCC Fourth Assessment Report (AR4) from 2007 is the most thorough, detailed, and extensively peer-reviewed assessment of climate change undertaken to date. This assessment provides several important findings, including a consensus that: 1) "warming of the climate system is unequivocal" (IPCC 2007a, p.5) and, 2) "most of the observed increase in global average temperatures since the mid-20th century is very likely [90 – 99% probability] due to the observed increase in anthropogenic greenhouse gas concentrations" (IPCC 2007a, p.10). The AR4 finds the amount of greenhouse gases (e.g., carbon dioxide, methane, nitrous oxide) in the earth's atmosphere has increased considerably since 1750 as a result of human activity; the amount of carbon dioxide in the atmosphere in 2005 was 379 parts per million (ppm), an amount which greatly exceeds the range of the last 650,000 years (180 to 300 ppm).[1]

Numerous observed changes in the global climate are summarized in the AR4. Observed changes related to temperature include fewer cold days, cold nights, and frost events, and more hot days, hot nights, and heat waves. The assessment finds that global temperatures increased over the last 100 years by 0.74 °C, with eleven of the twelve warmest years between 1995 and 2006 ranking among the 12th warmest years on record (since 1850), (IPCC 2007a). Observed ocean conditions show that the oceans have absorbed 80% of the heat added to the climate system since 1961, with ocean temperatures increasing to depths of at least 3000 m (9800 ft), (IPCC 2007a). Increases in wind intensity, decline of permafrost coverage, and increases of both drought and heavy precipitation events have also been observed (IPCC 2007a).

[1] The amount of carbon dioxide in the atmosphere has steadily increased since 2005. The globally averaged marine surface annual mean data for 2008 show carbon dioxide levels at 384.85 ppm (Dr. Pieter Rans, NOAA/ ESRL, accessed at www.esrl.noaa.gov/gmd/ccgg/trends/).

Mountain glaciers and snow cover have declined on average in both hemispheres (IPCC 2007a).

Regarding observed sea level rise, the AR4 finds that sea levels rose at an average rate of about 1.8 (range of 1.3 to 2.3) mm/year between 1961 and 2003; this rate increased to an average rate of 3.1 (range of 2.4 to 3.8) mm/year from 1993 to 2003 (IPCC 2007a). There is high confidence (8 out of 10 chance of being correct) that the rate of sea level rise increased from the 19th to 20th century (IPCC 2007a). The assessment finds that losses from the land-based ice sheets of Greenland and Antarctica have very likely (90 - 99% probability) contributed to sea level rise between 1993 and 2003, and that "widespread decreases in glaciers and ice caps have contributed to sea level rise,"(IPCC 2007a, p.5).[2]

The AR4 identifies future climate trends for the 21st century using global climate models based on different emissions scenarios. These modeled projections find that fewer cold days and nights over most land areas this century are virtually certain (>99% probability), and an increase in warm spells and heat waves is very likely (90 – 99% probability) (IPCC 2007a). An increased frequency of heavy precipitation events over most land areas is very likely (90 - 99%), and increase of extreme high sea levels are likely (66 to

[2] It is noted in the AR4 that "ice caps do not include contributions from the Greenland and Antarctic Ice Sheets." IPCC, 2007a: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p.5

90%), (IPCC 2007a). AR4 projects global average sea level rise at the end of the 21st century (2090-2099 relative to 1980-1999) in the range of 0.18m to 0.38 m in a low emissions scenario[3] and in the range of 0.26m to 0.59 m in a high emissions scenario.[4] Recent observations and research reveal that these estimates for sea level rise may be overly conservative, as the AR4 estimates do not include the possible contribution to sea level rise from the melting of ice sheets in Greenland and Antarctica (Mote et al. 2008). A recent paper by Bamber et al. (2009), "Reassessment of the Potential Sea-Level Rise from a Collapse of the West Antarctic Ice Sheet," estimates that the contribution to global eustatic sea level rise from a rapid collapse of the West Antarctic Ice Sheet would be about 3.3 meters (Bamber et al. 2009).

1.1.1 Impacts to Coasts

Projected changes in temperature, precipitation, and sea level identified in the assessment can have impacts on coastal areas. The AR4 examines the impacts of climate change on natural, managed, and human systems (IPCC 2007b). The report finds that the combination of sea level rise and human development in coastal areas is contributing to losses of coastal wetlands and leading to increased damage from coastal flooding in many areas (IPCC 2007b). Wetlands can be negatively impacted by sea level rise; systems that

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[3] SRES Emissions Scenario B1: for more information on the emissions scenarios used in AR4, see the IPCC Special Report on Emissions Scenarios at: http://www.grida.no/publications/other/ipcc_sr/

[4] SRES Emissions Scenario A1F1: for more information on the emissions scenarios used in AR4, see the IPCC Special Report on Emissions Scenarios at: http://www.grida.no/publications/other/ipcc_sr/

are starved of sediment or physical constrained (i.e., unable to migrate landward) are at risk of drowning as seas rise. "Many millions more people are projected to be flooded every year due to sea-level rise by the 2080s," (IPCC 2007b, 12), and densely populated, low-lying areas are identified as particularly at risk (IPCC 2007b).

1.1.2 Impacts to Marine Ecosystems

The AR4 finds that the resilience of many global ecosystems is likely to be exceeded this century by "an unprecedented combination of climate change, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g., land-use change, pollution, over-exploitation of resources)," (IPCC 2007b, p. 11.) The report links observed shifts in ranges and other changes in algal, plankton and fish abundance in high-latitude oceans to observed changes in climate with a high degree of confidence (about an 8 in 10 chance to be correct), (IPCC 2007b). Ocean acidification, resulting from an increase in atmospheric carbon dioxide, is projected to negatively impact oceanic calcifying organisms and their dependent species (IPCC 2007b).

1.2 The Washington Climate Change Impacts Assessment

In 2007, the University of Washington's Climate Impacts Group (CIG) was directed by the Washington State Legislature through House Bill 1303 to collaborate with research scientists from Washington State University and the Pacific Northwest National Laboratory to produce an assessment of likely climate change impacts to eight sectors: agriculture, coasts, energy, forests, human health, salmon, urban stormwater infrastructure, and hydrology & water resources. On February 12, 2009, CIG presented the "Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate," at the Washington Climate Change Impacts Assessment Conference. This assessment provides climate change projections that are specific to Washington State. The Washington Climate Change Impacts Assessment (WACCIA) uses a combination of downscaled global climate models and regional climate models to provide climate change projections that account for the unique climate of Washington State.

1.2.1 Changes in Washington's Temperature and Precipitation Patterns

WACCIA climate models project increases in annual average temperature of 2.2° F (range of projections from all models: +1.1° F to +3.3° F) by the 2020s; 3.5° F (range: +1.5° F to 5.2° F) by the 2040s; and 5.9° F (range: +2.8° F to 9.7° F) by the 2080s, with a warming of around +0.5° F per decade in the 21st century (Mote and Salathé 2009). This projected warming is expected during all seasons, but most models project the largest temperature increases in the summer. Projected changes in annual precipitation varied by model but are small (+1 to +2%), (Mote and Salathé 2009). Some models project an amplification of the current climate cycle, with wetter autumns and winters and drier summers. Little is presently known about changes in precipitation patterns (i.e., if precipitation will occur as a steady drizzle or a series of extreme events and periodic downpours) (Mote and Salathé 2009).

WACCIA models reveal a difference of 1.2°C in sea surface temperature (SST) during the time period of 1970-99 and the period of 2030-2059 for the three emissions scenarios that were considered (Mote and Salathé 2009).[5] While this change in near-shore sea surface temperature is smaller than projected temperature changes for the terrestrial environment, it represents a significant change when compared with the present day inter-annual variability of SST (Mote and Salathé 2009).

1.3 Impacts to Washington's Coastal Areas

The WACCIA considers the impacts to Washington's coasts in chapter 8 by Huppert et al. (2009), "Impacts of climate change on the coasts of Washington State." Huppert et al. (2009) find that sea level rise may lead to the gradual inundation of low-lying areas, more extensive flooding of coastal areas during major storm events, accelerated erosion of coastal bluffs, and saltwater intrusion into coastal freshwater aquifers (Huppert et al. 2009). Flooding and erosion events could also be affected by increases in wave height and shifting storm patterns, and by changes in precipitation and hydrology (Huppert et al. 2009). Initial research by Huppert et al. (2009) determined that saltwater intrusion should not be considered a high-risk priority and as such

[5] IPCC SRES A2, A1B and B1 were used in the WACCIA paper: Philip W. Mote and Eric P. Salathé Jr., "Future climate in the Pacific Northwest."

will not be considered in this Strategy. The other impacts will be considered below.

1.3.1 Local Sea Level Rise in Washington

The WACCIA uses findings from a recent report by Mote et al. (2008), "Sea Level Rise in the Coastal Waters of Washington State," for its discussion of sea level rise (SLR) estimates. Mote et al. (2008) provide low, medium, and high estimates for local sea level rise for Washington's coasts for 2050 and 2100. The four main drivers of local sea level rise (also referred to as relative sea level rise), are: 1) global sea level rise driven by thermal expansion of the oceans, 2) global sea level rise driven by the melting of the cryosphere, 3) local dynamical SLR driven by changes in atmospheric circulation (i.e., wind), and 4) local tectonic movement (Mote et al. 2008). Mote et al. (2008) take these four drivers into consideration to produce estimates for the Northwest Olympic Peninsula, the central and southern outer coast of Washington, and the Puget Sound coastline.

The estimates of sea level rise for Washington's coasts are presented in Table 5. Mote et al. (2008) provide a medium estimate for 2050 of 0 cm (0") for the NW Olympic Peninsula, 12.5 cm (5") for the Central and Southern Coast, and 15 cm (6") for Puget Sound. They provide a medium estimate for 2100 of 4 cm (2") for the NW Olympic Peninsula, 29 cm (11") for the Central and Southern Coast, and 34 cm (13") for Puget Sound (Mote et al. 2008). The low SLR estimates provided for the NW Olympic Peninsula are largely due to an offsetting rise in vertical land movement resulting from tectonic plate activity. As the Juan de Fuca plate subducts beneath the northwestern portion of the North American Continental plate, the northwest portion of Washington State (namely, the northern portion of the Olympic peninsula) is experiencing a gradual uplift of about 2 mm/yr (Mote et al. 2008). In a very low SLR scenario the rate of uplift in the NW Olympia peninsula produces a negative rise in sea level for that region (Mote et al. 2008).

While Mote et al. (2008) provides a useful starting point for local and state planners to begin thinking about SLR scenarios, the report does not provide a probabilistic analysis of the estimates provided. Mote et al. (2008) stress that the estimates provided in the report should used for advisory purposes and not viewed as actual predictions of sea level rise for any specific location. The authors stipulate that the very low and very high SLR estimates provided should be viewed as low probability scenarios, and acknowledge that a more rigorous quantification of probabilities and uncertainties is needed (Mote et al. 2008).

1.3.2 Shoreline Responses to Climate Change

The response of Washington's coastal environments to climate change will vary, as different types of shorelines will react in diverse ways to similar physical forces, depending on the substrate, slope, and exposure of a given shoreline (Huppert et al. 2009). A coastal geologist at the Washington Department of Ecology has explored how the shorelines of Puget Sound will respond to climate change impacts (Shipman 2009). Table 3 is adapted from his ongoing work in this area; it summarizes the likely responses of different coastal environments to climate change. In a recent presentation to local planners on shoreline response to climate change, Shipman emphasized three key points: 1) shorelines will respond *dynamically* to climate change; 2) different geomorphic settings will respond differently, and 3) sea level rise will be experienced initially as a series of natural disasters (Shipman 2009). While shorelines have always responded dynamically to various physical forcing mechanisms, in the context of climate change and accelerated rate of SLR, it is important to remember that coasts will continue to respond in a dynamic manner. In other words, it will be important for coastal managers and planners to think beyond inundation maps when considering sea level rise, because sea level rise will not only cause gradual inundation but also cause shoreline changes like erosion, landslides, and breaching of barriers islands and spits (Shipman 2009). Human response to these changes in the physical environment will likely be in the form of disaster response (Shipman 2009).

The geomorphic response of a given shoreline to climate change will be dependent on the following factors:

1. The rate of sea level rise
2. The frequency and character of the individual storm event
3. The type of landform
4. Sediment availability (Shipman 2009)

Table 6 (adapted from Shipman 2009) shows the likely responses of Puget Sound shorelines to climate change and the associated impacts. Rocky shorelines, headlands and artificial shorelines may exhibit relatively little response, while bluffs, barrier beaches and spits, estuaries and lagoons, and river deltas may respond in numerous ways. Bluffs are eroding beach systems, and sea level rise is projected to accelerate the naturally occurring process of bluff toe erosion and bluff retreat, and lead to increases in mass-wasting events (Shipman 2009). Barrier beaches and spits may be able to respond to sea level rise by migrating landward if: 1) the rate of sea level rise is sufficiently low, and 2) landward migration is not inhibited by a built structure or a steep slope. Estuaries, lagoons, and deltas face significant loss of wetland habitat if the rate of sea level rise is too fast and/or sediment supply to the system is too low. Like barriers, if marshes are unable to migrate landward, they risk drowning as the seas rise (Shipman 2009). A possible positive outcome of the accelerated erosion of bluff systems is these erosion events may increase the sediment supply to the system, possibly helping nearby beaches and marshes to maintain elevation as seas rise (Shipman 2009).

1.3.3 Major Storm Events

Major storm events and associated extreme high water, increased wave energy, increased wave height, and increased wind speed drive major erosion events on Washington’s coast today. Sea level rise will exacerbate the effects of such events on shorelines. Mass wasting of bluffs, over-washing of spits, and flooding coastal lowlands will all be experienced with increased frequency (Huppert et al. 2009). Sea level rise models indicate that a 12” rise in sea level would shift the 100-year storm surge induced flood event to once every 10 years (Shipman 2009). As Mote et al. (2008) provide a medium SLR estimate of 13” for Puget Sound by 2100 it is reasonable to conclude that the Puget Sound region will experience a 100 year storm at least once a decade by the end of the Century. Washington currently experiences considerable seasonal and inter-annual variability in sea levels as a result of local atmospheric circulation patterns. The presence of a steady northward wind offshore in the winter months pushes coastal waters landward, resulting in mean winter sea levels around 50 cm (20”) higher than mean summer sea levels (Mote et al. 2008). During El Niño events, sea level can be elevated by as much as 30 cm (12”), (Mote et al. 2008). Shipman suggests that the shoreline changes that occur during these periods of elevated sea level (e.g., mass wasting of bluffs and accelerated erosion of beaches) may be indicative of the sorts of shoreline changes that may be experienced with greater frequency in the future as sea levels rise. As planners and decision-makers begin to conceptualize how sea level rise may influence their coastal communities, a review of the impacts of past El Niño events may be a good place to begin.

1.4 Ocean Acidification

Since the beginning of the industrial area, oceans have absorbed 30% of the anthropogenic carbon released into the atmosphere (Doney et al. 2009).

This process of CO_2 uptake has lead to changes in the chemical balances of the oceans; since pre-industrial times, the average ocean surface water pH has fallen by about 0.1 units, from around 8.21 to 8.10 (Royal Society 2005). This decline in ocean pH is expected to continue, with pH decreasing by 0.3-0.4 units if CO_2 atmospheric concentrations reach 800 ppm (which is the projected end-of-the-Century amount under the IPCC's IS92a "business as usual" emissions scenario) (Orr et al. 2005). Declining pH, (ocean acidification), has implications for many marine organisms. In experimental studies, CO_2 rich waters have been found to decrease the calcification rates of coccolithophores, planktonic foraminifera, molluscs, echinoderms, tropical corals, and coralline red algae (Doney et al. 2009). These organisms require calcium carbonate ($CaCO_3$) to form their shells and skeletons; when CO2 reacts with seawater, the availability of carbonate ions, (which are needed to form $CaCO_3$), declines, thus inhibiting the calcification process. The reproduction rates of mollusks and echinoderms also decreased when exposed to an increase of CO_2 (Doney et al. 2009).

At present, the impacts of ocean acidification on ecosystems are largely unknown. While the reduced calcification of many planktonic organisms in CO_2 rich waters has been demonstrated, the response is not uniform, and possible food web interactions are not well understood (Feely 2009). A recent study on ocean acidification determines that changes in ocean pH could very likely have serious implications for marine ecosystems. The study states that:

> Although the changes in seawater chemistry that result from the oceanic uptake of anthropogenic CO_2 are well characterized over most of the ocean, the biological impacts of ocean acidification on marine fauna are only beginning to be understood. Nevertheless, sufficient information exists to state with certainty that deleterious impacts on some marine species are unavoidable, and that substantial alteration of marine ecosystems in likely over the next century… We conclude that ocean acidification and the synergistic impacts of other anthropogenic stressors provide great potential for widespread changes to marine ecosystems. (Fabry et al. 2008)

The pH levels in upwelled waters off the Pacific Coast are presently decreasing more quickly than anticipated (Feely et al. 2008, Wootton et al. 2008). In Washington, the threat of ocean acidification coupled with increases in sea surface temperature will likely negatively impact the State's shellfish industry (Huppert et al. 2009). Potential threats to the shellfish industry will be discussed in greater detail later in this Strategy.

Table 5. Relative Sea Level Rise Projections for Washington State (adapted from Mote et al. 2008)

SLR Estimate	By the year 2050			By the year 2100		
	NW Olympic Peninsula	Central & Southern Coast	Puget Sound	NW Olympic Peninsula	Central & Southern Coast	Puget Sound
Very Low	-5” (-12cm)	1” (3cm)	3” (8cm)	-9” (-24 cm)	2” (6cm)	6” (16cm)
Medium	0” (0cm)	5” (12.5cm)	6” (15cm)	2” (4cm)	11” (29 cm)	13” (34 cm)
Very High	14” (35cm)	18” (45 cm)	22” (55cm)	35” (88cm)	43” (108cm)	50” (128 cm)

Table 6: Shoreline Response to Climate Change (adapted from Shipman 2009)

Geomorphic Setting in Puget Sound			
Type	Description	Response	Impact
Rocky (21%)	Bedrock, resistant to erosion Residential, undeveloped	Minimal erosion or change	Limited erosion and inundation
Bluff (38%)	Erodible, often elevated Residential, undeveloped	Accelerated toe erosion, mass-wasting, accelerated bluff retreat	Landslides and erosion, modified bluff habitats
Beach (11%)	Low lying spits and barriers. Dunes. Often back-barrier wetlands Residential, parks, undeveloped	Erosion, overwash, migration Breaching, shifting tidal inlets	Erosion, flooding, storm damage, altered backshore habitat
Estuaries and Lagoons (13%)	Small, sheltered estuaries and lagoons. Stream mouths. Residential, Undeveloped	Tidal prism change, altered inlet dynamics, marsh erosion/ accretion	Marsh/ habitat loss, shoreline erosion
Delta (8%)	Broad, low elevation alluvial features at river mouths Agricultural and urban/ industrial	Sedimentation patterns change, altered riverine influences, marsh erosion/ accretion, inundation	Increased flood vulnerability, damage to dikes and levees, vegetation shifts, difficult drainage
Artificial (10%)	Engineered, fill, hardened Usually low elevation Urban/ industrial/ residential	Limited change	Storm damage, flooding

2.0 Developing a Climate Change Adaptation Strategy for the Aquatics Resources Program

Question 1: Why should the Aquatic Resources Program start preparing for climate change today?

The observed and projected changes in Washington's climate and the anticipated impacts to Washington's coastal areas presented in Section 1.0 provide the scientific rationale to begin planning for climate change today. Current climate change science shows that Washington's climate will almost certainly change in very significant ways during this century, and that the climate of the 20th century will not be an accurate indicator of future climate conditions (Climate Impacts Group 2009). It is also clear that changing climate conditions will have significant impacts on Washington's coastal areas and aquatic environments. The magnitude of impacts to the natural, human, and built systems of Washington's coasts will vary according to how well society prepares for and manages these changes (Littell et al. 2009). While some uncertainty surrounds future climate scenarios, there is sufficient information about likely changes in climate to begin preparing for these shifts today (Petersen 2007).

While climate change must be addressed at all levels of governance, a strong rationale exists for initiating climate change adaptation activities at a local scale. The Washington Climate Change Impacts Assessment has identified the following primary reasons for planning for climate change at the state and local level:

1) Significant regional-scale climate change impacts are projected;
2) State and local governments will be on the "front line" when it comes to dealing with climate impacts;
3) Decisions with long-term impacts are being made at the local level every day, and today's choices will shape tomorrow's vulnerabilities;
4) Significant time is required to motivate and develop adaptive capacity, and to implement changes;
5) Preparing for climate change may reduce the future costs of climate impacts and responses;
6) Planning for climate change can benefit the present at well as the future (Whitely Binder et al. 2009).

2.1 Mitigation and Adaptation: A Two-pronged Approach to Addressing Climate Change

Responses to climate change fall into two general categories: mitigation and adaptation. In the context of climate change, *mitigation* reduces the sources or enhances the sinks of greenhouse gases (IPCC 2007a Annex I), while *adaptation* responds to changes in the climate. This Strategy focuses on climate change adaptation. A focus on adaptation is appropriate for a state agency tasked with natural resource management for two reasons. The first is the rationale for focusing on adaptation at the state level that has been provided above. The second is that as a natural resource manager, WDNR has a statutory mandate to manage the resource in question, (i.e., state-owned aquatic lands), for the benefit of all Washingtonians in perpetuity (RCW 79-105-030). As such, the agency must consider how to best prepare for and adapt to climate change in a manner that protects Washington's aquatic lands and associated public benefits.

While this Strategy focuses on adaptation rather than mitigation, it must be strongly emphasized that any government entity wishing to comprehensively address climate change must consider both mitigation and adaptation, as both approaches are essential and the two approaches are highly interconnected. Mitigation is essential as greenhouse gas emissions must be drastically reduced if the extreme climate changes projected for the end of this century, (under high emissions scenarios), are to be avoided. Adaptation is equally essential as mitigation alone will insufficiently address the unavoidable climate change impacts that past greenhouse gas emissions have already ensured (IPCC 2007b). Ultimately, the best adaptation strategy is to reduce greenhouse gases, as "impacts are expected to increase with increases in global average temperature…[and] unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt" (IPCC 2007b, p.2). While this Strategy constitutes an excellent step forward in WDNR's planning for climate change, it is essential that the agency work to address climate change mitigation in a simultaneous and ongoing manner.

2.3 Climate Change Adaptation

In the broadest sense, climate change *adaptation* is the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007b Appendix I). Several different types of adaptation are identified in the climate change literature. *Planned adaptation* is "the result of a deliberate policy decision based on an awareness that conditions have changes or area about to change and that action is required to return to, maintain, or achieve a desired state" (IPCC 2007b Appendix I). *Anticipatory adaptation,* (also referred to as *proactive adaptation*), is adaptation that takes place before the impacts of climate change are observed (IPCC 2007b Appendix I). The objective of anticipatory adaptation is to decrease the sensitivity of a system to climate change stressors (Petersen 2007). *Reactive adaptation* is adaptation in response to climate events (Whitely Binder et al. 2009). The objective of anticipatory adaptation is to limit the negative outcomes of climate change stressors. (Peterson 2007). One type of reactive adaptation is *autonomous* (or *spontaneous*) *adaptation*. Autonomous adaptation is not a conscious response to climate change but rather is "triggered by ecological changes in natural systems and by market or welfare changes in human systems" (IPCC 2007b Appendix I). Autonomous adaptation will occur independently of and simultaneously to planned or proactive adaptation measures.

This Climate Change Adaptation Strategy is both a planned and proactive adaptation effort. The primary goal of this Strategy is to make the human and natural systems associated with the WDNR Aquatic Resources Program more resilient to the impacts of climate change. Adaptive responses aimed at increasing the resiliency and decreasing the vulnerability of the systems associated with state-owned aquatic lands and the Aquatic Resources Program are proposed.

2.4 A Framework for Preparing for Climate Change

In 2007, King County, Washington worked with the University of Washington's Climate Impacts Group at the Center for Science in the Earth System (The Climate Impacts Group) Joint Institute for the Study of the Atmosphere and Ocean, University of Washington and King County, Washington, in association with Local Governments for Sustainability (ICLEI), to produce a climate change adaptation guide authored by Snover et al (2007) entitled, "Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments." This Guidebook was created to help local entities prepare for climate change by increasing their resilience to climate change and associated climate change impacts. In the context of climate change, *resilience* is "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change" (IPCC 2007b, Appendix I). A *climate resilient community* is a community "that takes proactive steps to prepare for climate change impacts" by reducing the associated vulnerabilities and risks (Snover et al. 2007).

Snover et al. (2007) provide a step-by-step process for preparing for climate change for governments. The authors identify several critical steps for initiating a climate resiliency effort. These critical steps align with the five Milestones of ICLEI's Climate Resilient Communities Program and they are:

1. Initiate climate resiliency effort;
2. Conduct a climate resiliency study;
3. Set preparedness goals and develop a preparedness plan;
4. Implement preparedness plan;
5. Measure progress and update plan (Snover et al. 2007).

This Climate Change Adaptation Strategy uses these 5 Milestones and the step-by-step process provided by Snover et al. (2007) as its framework for preparing for climate change. This Section ties the Strategy to the framework provided by Snover et al (2007), linking the achievements of the Strategy to ICLEI's 5 Milestones for Climate Resilient Communities.

<u>Milestone 1: Initiating a climate resiliency effort for the Aquatics Resources Program</u>

Snover et al (2007) identify several steps for initiating a climate resiliency effort including: 1) scoping the climate change impacts to major sectors; 2) passing a resolution or administrative order directing the government to prepare for climate change; 3) building and maintaining support to prepare for climate change; 4) building a climate change preparedness team; and 5) identifying planning areas relevant to climate change impacts. Snover et al. (2007) define *planning areas* as areas in which a government or community manages, plans, or makes policy affecting the services and activities associated with built, natural and human systems.

Milestone 1, Step 1: Scope climate change impacts

This Strategy scopes the climate change impacts to WDNR's major sectors by considering how projected climate change impacts to Washington's coastal areas are likely to effect both state-owned aquatic lands (SOALs) and the Aquatic Resources Program's management activities. The initial scoping provided in this Strategy was greatly aided by a recent state-wide effort, the Washington Climate Change Impacts Assessment, (Climate Impacts Group 2009). This assessment provides comprehensive, cutting-edge information on climate change impacts to the following sectors in Washington State: hydrology and water resources, energy, agriculture, salmon, forests, coasts, urban stormwater infrastructure, and human health.

Milestone 1, Step 2: Pass a Resolution to Prepare for Climate Change

Washington State passed an administrative order directing the government to prepare for climate change in 2007, when Governor Gregoire signed Executive Order 07-02. This Executive Order, entitled the "Washington Climate Change Challenge," formalized Washington's commitment to preparing for the impacts of climate change via the formation of Preparation and Adaptation Working Groups (PAWGs), which developed adaptation recommendations for five sectors: 1) agriculture, 2) forestry resources, 3) human health, 4) water resources & quality, and 5) coastal & infrastructure. WDNR helped develop the PAWG recommendations for the Coastal & Infrastructure and the Forestry Resources sectors.

Most recently, Engrossed Second Substitute Senate Bill 5560, "an Act relating to state agency climate leadership" was signed into law. The law directs the Departments of Ecology, Agriculture, Community, Trade & Economic Development, Fish & Wildlife, Natural Resources, and Transportation to collaboratively prepare an integrated climate change response strategy, which will identify actions to prepare for and adapt to climate change by December 1, 2011. Specifically, the law requires that this strategy include:

> (i) Efforts to identify priority planning areas for action, based on vulnerability and risk assessments;
> (ii) Barriers challenging state and local governments to take action, such as laws, policies, regulations, rules, and procedures that require revision to adequately address adaptation to climate change;
> (iii) Opportunities to integrate climate science and projected impacts into planning and decision making;
> (iv) Methods to increase public awareness of climate change its projected impacts on the community, and to build support for meaningful adaptation policies and strategies (E2SSB 5560 Sec. 11).

The law establishes the Department of Ecology as the central clearinghouse for relevant scientific and technical information about climate change impacts. It further identifies the Department of Ecology as the "central convener for the development of vital programs and necessary policies to help the state adapt to a rapidly changing climate" (E2SSB 5560 Sec. 10).

This passage of this bill is an important step forward in Washington's climate change preparedness efforts, as it fosters interagency collaboration and coordination, which are essential for preparedness efforts to be effective and efficient. The law ensures that state agencies like WDNR will be provided clear guidance on how to prepare for projected climate change impacts by clearly designating DOE as the agency in charge of providing scientific and technical information. This measure also ensures that all agencies will be utilizing the same sources of information when preparing for climate change. It is hoped that this Climate Change Adaptation Strategy will help to inform WDNR's initial contribution to the development of this integrated climate change response strategy.

Milestone 1, Steps 3 and 4: Build and Maintain Support to Prepare for Climate Change, Form a Climate Change Preparedness Team

The Aquatic Resources Program has initiated the process of building and maintaining support for preparing for climate change by allowing a Marc Hershman Marine Policy Fellowship to work on climate change adaptation and preparation and to develop this Strategy for the Program. The choice to devote resources to researching climate change adaptation, rather than another topic, indicates that there is considerable support for addressing climate change within the Program. Furthermore, the Program has formed a type of climate change preparedness team, (step 4), by assigning a point person (the Marc Hershman Marine Policy Fellow) to the topic of climate change.[6] This

[6] Snover et al. (2007) articulate "assigning a point person" as one option for entities with limited resources in its "develop a climate change preparedness team" section. See: Snover et al., Preparing for Climate Change, a Guidebook for Local, Regional, and State Governments," (p. 61).

Strategy recommends the creation of a climate change preparedness team in Section 7.

Milestone 2: Conduct a climate resiliency study

The process of conducting a climate resiliency study is broken down into three steps:

1) Conduct a climate change vulnerability assessment;
2) Conduct a climate change risk assessment;
3) Prioritize planning areas for action.

A system is considered vulnerable when it is susceptible to harm from climate change (Snover et al. 2007). More specifically, a system's *vulnerability i*s the degree to which it is "susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC 2007b Appendix I). A system's vulnerability is seen a function of its sensitivity, exposure, and adaptive capacity to changes in climate and climate change impacts (Whitely Binder et al. 2009). *Sensitivity* is the degree to which a system is affected, (negatively or positively), by climate change or climate variability (Whitely Binder et al. 2009). *Exposure* is the nature and degree to which a system is exposed to significant climatic variations (IPCC 2001), and may vary depending on factors such as geography, elevation, and length of time (Whitely Binder et al. 2009). A system's *adaptive capacity* is its ability to accommodate to climate change with minimal potential damage or cost, (Snover et al. 2007), by moderating potential damages, taking advantage of opportunities, or coping with the consequences

(IPCC 2007b). A climate change *vulnerability assessment* evaluates a given planning area's sensitivity to and capacity to adapt to projected climate change impacts (Snover et al. 2007). This Strategy conducts a pilot qualitative vulnerability assessment of the Program's key management activities – its co-management of Washington's commercial wild stock geoduck fishery. The information from the initial scoping of climate change impacts and from the pilot qualitative vulnerability assessment are used to identify two priority planning areas for the Program in Section 5 of the Strategy.

Milestone 3: Set Preparedness Goals and Develop a Preparedness Plan

Once priority planning areas have been identified, Snover et al (2007) suggest that preparedness goals be set and that a climate change preparedness plan be developed. Steps for achieving Milestone 3 include: 1) establishing a vision and guiding principles for achieving climate resilience, 2) setting preparedness goals, and 3) developing, selecting and prioritizing preparedness actions (Snover et al. 2007). This Strategy achieves Step 1 by establishing a climate resilient vision for the Aquatic Resources Program. This vision is established by answering the question: "*What does the WDNR Aquatic Resources Program want state-owned aquatic lands to look like in 2050?*"[7] The climate resilient vision is aligned with the Program Goals articulated in WDNR's recently completed Aquatic Lands Strategic Plan.[8] Section 7 of this

[7] This approach of "planning backward from 2050" was used by King County, WA, to create the King County 2007 Climate Plan

[8] Washington State Department of Natural Resources, "Aquatic Lands Strategic Plan: For Washington's State-owned Aquatic Lands," completed December 2008.

Strategy recommends actions for achieving the articulated vision of climate resiliency. These actions fall into two categories: 1) actions to build adaptive capacity, and 2) pro-active adaptive actions.

3.0 Scoping Climate Change Impacts to Aquatics Resources Program

Question 2: Which WDNR management activities may be most vulnerable to projected climate change impacts?

This Section provides an initial scoping of how the Aquatic Resources Program may be effected by projected climate change impacts to Washington's coasts. It examines possible effects to both WDNR-managed state-owned aquatic lands and to WDNR's management activities. This initial scoping exercise is one of the suggested steps for initiating a climate resiliency effort provided by Snover et al. (2007). Because this Strategy constitutes the Aquatic Resources Program's first attempt to assess the impacts of climate change to its management of state-owned aquatic lands, this initial scoping of impacts to management activities is highly appropriate.

The literature reviewed earlier in this Strategy has been used to identify potential climate change impacts. Given a lack of studies specific to Washington for most of the impacts to WDNR resources and programs identified here, this scoping process was accomplished via conversations with the directors of the relevant management activities. The determinations made are qualitative in nature. When information is lacking or highly uncertain, real risks have been overstated. This initial scoping should help WDNR determine where further research might be directed.

3.1 Climate Change Impacts to Marine State-Owned Aquatic Lands

To comprehensively consider how climate change may impact the Program, it is necessary to consider both how the Program's management activities and the resource itself may be effected by climate change. The Strategy focuses specifically on impacts to coasts, i.e., the nearshore environment. The term "nearshore" is used here as it is used by the Puget Sound Nearshore Partnership (PSNERP). PSNERP describes the nearshore as:

> Extending from the top of shoreline bluffs to the depth offshore where light penetrating the Sound's water falls below a level supporting plant growth, and upstream in estuaries to the head of tidal influence. It includes bluffs, beaches, mudflats, kelp and eelgrass beds, salt marshes, gravel spits, and estuaries" (PSNERP, 2009).

While WDNR does manage some SOALs on Washington's outer coast,[9] the majority of marine SOALs under WDNR management are within the area defined by WDNR's Natural Heritage Program as the Puget Trough Eco-Region. The Natural Heritage Program considers the Puget Trough Eco-Region to be the Strait of Juan de Fuca, the San Juan archipelago, and the Puget Sound (WDNR 2009). This Strategy considers climate change impacts to the marine nearshore environment of the Puget Trough Eco-Region.

To scope how state-owned aquatic lands under WDNR management may be effected by climate change, this Strategy uses the projected climate change impacts to coastal areas provided by the Washington Climate Change Impacts Assessment (WACCIA). The WACCIA constitutes the most comprehensive, regionally specific information on climate change impacts in Washington to date. To briefly reiterate the information provided in Section 1.0 of this Strategy, the coasts of Washington will likely be directly impacted

[9] Most state-owned aquatic lands under WDNR management are within the two large outer coast embayments, Willapa Bay and Grays Harbor.

by increases in air and water temperature (Climate Impacts Group 2009). Coasts will also likely be impacted by small changes in current precipitation patterns (Climate Impacts Group 2009). Projected precipitation changes varied between climate models, but overall an amplification of the current cycle (drier summer and wetter autumns and winters) is likely (Climate Impacts Group 2009). In addition, regional climate models generally predict an increase in extreme heavy precipitation events, especially in the Puget Sound area (Climate Impacts Group 2009).

Marine ecosystems may also be directly impacted by small changes in the pH of seawater, or ocean acidification, which occurs as a result of the uptake of atmospheric carbon by the world's oceans (Doney et al. 2009, Feely et al. 2009, Huppert et al. 2009, Miller et al. 2009, Fabry et al. 2008). A recent study on ocean acidification concluded that "ocean acidification and the synergistic impacts of other anthropogenic stressors provide great potential for widespread changes to marine ecosystems" (Fabry et al. 2008).

Washington's nearshore will also be directly impacted by sea level rise. Projected rises in sea level vary in different parts of the State due to local factors like wind patterns and vertical land movement (Mote et al. 2008). Much uncertainty still exists about the rate and magnitude of projected sea level rise (Mote et al. 2008). It is likely, however, that rising sea levels will be experienced initially in coastal areas through the amplification of major storm events, e.g., storm surges (Shipman 2009). Flooding of low-lying areas along coasts (especially at river deltas) will likely occur with greater frequency and magnitude, via the combined effect of higher sea levels and an increase in extreme heavy precipitation (Huppert et al. 2009, Shipman 2009). The combination of gradually rising seas and major storm events during winter high tides (sea levels are elevated in Washington during winter months due to shifts in local atmospheric circulation) may result in major, sudden changes to the shorelines, via mass wasting of bluffs and over-washing or breaching of barrier islands and spits (Shipman 2009).

The impact of climate change on existing weather patterns and patterns of regional climate variability is an area of active research. Very little is presently known about how climate change may influence local wind patterns (and consequently wave height and action) in Washington's coastal areas (Spencer Reeder, May 3 2009, conversation with author). There is some evidence that higher storm waves are breaking on the southwest Washington coast due to a northward shift in the storm track as a consequence of broader global climate changes (Huppert et al. 2009), but it is unclear if this shift will have any impact on wind and wave action in Puget Sound (Spencer Reeder, May 3, 2009, conversation with author). Even without a clear understanding of how winds and waves may change, it is reasonable to conclude that shorelines composed of unconsolidated sediments (e.g., beaches and bluffs) in Puget Sound and the Strait of Juan de Fuca will experience an amplification of the natural shoreline responses of erosion, avulsion, and accretion in systems as a result of the projected impacts discussed above.

In the long-term, low-lying shorelines will be increasingly susceptible to inundation as seas rise (Petersen 2008, Huppert et al. 2009). Wetlands and beaches that are unable to migrate landward and that lack sufficient sediment supply may be at high risk of drowning (Huppert et al. 2009, Glick et al. 2009, Shipman 2009). Mud flats will be particularly susceptible to inundation (Glick et al. 2009). Estuaries and bays may be effected by changes in the quantity and timing of freshwater inputs (Engoltz 2002).

The geomorphic response of rocky shorelines to climate change will be relatively minimal, but over time these shorelines and their associated habitats will likely be inundated by sea level rise (Shipman 2009). In the short-term, barrier beaches and spits may be exposed to more frequent over-washing and breaching (Shipman 2009). Bluff systems will likely experience accelerated toe erosion, which will increase bluff instability and set the stage for an increase in landslides (Huppert et al. 2009, Shipman 2009). As bluff erosion increases over time, Puget Sound may see a shift from highly vegetated bluffs to more bare slopes (Shipman 2009). A similar shift may occur with vegetated barrier beaches and spits.

If bluff and dune systems are able to respond to climate change impacts in the natural, highly dynamic manner typical of these systems, then the near-shore habitats associated with these systems may survive. If the ecosystem processes that support the habitat attributes of these coastal environments remain robust, then Washington's near-shore environment may become an increasingly dynamic, but relatively healthy, environment – one that continues to provide a suite of changing but viable habitats for species. In instances where shorelines have been significantly altered through the erection of protective structures, infrastructure and buildings, natural processes may be inhibited, thus significantly reducing the coast's ability to respond to climate change.

3.2 Scoping Climate Change Impacts to the Aquatic Resources Program Management Activities

This Strategy uses the methodology presented in Snover et al. (2007) to scope the effects of projected climate change impacts to WDNR's management of SOALs. This initial scoping was accomplished via conversations with WDNR division staff and regional land managers, and review of relevant literature, including agency white papers. The results of this scoping process are discussed below, grouped by management activity. Table 7 summarizes the outcome of this process, listing the possible effects of the relevant climate change impacts on each activity.

3.2.1. Impacts to Shellfish Aquaculture

WDNR authorizes the use of SOALs for aquaculture because aquaculture is a historically important use which provides the two public benefits of fostering water-dependent uses and utilizing renewable resources. Aquaculture also generates revenue from SOALs in a manner consistent with the other public benefits provided. An initial scoping of climate change impacts reveals that shellfish aquaculture may be negatively effected by all projected climate change impacts. Gradual inundation may alter the viability of certain state-owned aquatic lands currently appropriate for aquaculture leases. The boundaries of SOALs leased for shellfish aquaculture in the outer coast bays (Gray's Harbor and Willapa Bay), for example, are stationary boundaries (i.e., the boundaries are not defined by tidal datums). This means that as these lands are inundated, water depths may become too great for certain types of shellfish aquaculture to be viable on existing tracts. Inundation of uplands adjacent to SOALs may increase pollution if contaminated upland sites become submerged; this could lead to negatively impact shellfish and fin-fish aquaculture.

Inundation will almost certainly increase the demand to armor Washington's shorelines, as property owners will seek to protect coastal property from the rising sea. An increase in hard armoring would perpetuate the following negative feedback loop: Shorelines will be armored to protect against shoreline changes such as erosion and avulsion; the reflective wave energy produced by the presence of hardened armored structures will lead to erosion and ultimately scouring of substrate on adjacent shorelines. More extreme heavy precipitation events in the Puget Sound area may intensify scouring of substrate, especially in areas where shorelines have been hardened. This will negatively impact the suitability of substrate for shellfish aquaculture.

Erosion, accretion, and avulsion may increase turbidity in the water column, negatively impacting shellfish aquaculture. Flooding and heavy precipitation may damage aquaculture infrastructure (e.g., lines or stakes may break for line aquaculture) and equipment, uproot in-ground stocks, and make harvesting of in-ground stocks more challenging.

Shellfish aquaculture may be negatively indirectly impacted by an increase in water temperatures, as studies reveal a positive correlation between warmer sea surface temperatures and an increase in the outbreak of harmful algal blooms (Moore et al. 2008). Wetter winters may make planting and harvesting more challenging. And finally, ocean acidification may effect shellfish in numerous ways. Scientific understanding of how various species may be impacted by ocean acidification is still evolving, but it is possible that shellfish may be directly negatively impacted by increasingly acidic seawater as larvae, juveniles, and adults. They may also be indirectly negatively impacted via reduced phytoplankton abundance.

3.2.2 Impacts to Overwater Structures

The Aquatic Resources Program authorizes the use of many different kinds of overwater structures on SOALs. The use category "overwater structures" encompasses many different types of structures and uses, from non-water dependent uses like restaurants and condominiums to water-oriented uses like floating homes to water-dependent uses like boat ramps, docks, terminals, and marinas. The ability of these diverse structures to accommodate to projected climate change impacts will vary greatly. Overwater structures are built to accommodate the maximum expected flux in tidal range for that region. As sea level rises, some overwater structures may be able to accommodate gradual inundation and the impacts of coastal flooding as long as water levels remain within the range of these expected extremes. As sea level continues to rise throughout the 21st century, however, a time will come when high tides and storm surges routinely exceed the capacity of overwater structures to accommodate these higher water levels. In coming decades, in-water structures such as docks and piers will likely need to be reconfigured or rebuilt to accommodate higher water levels as sea levels rise. In the short-term, increased exposure of overwater structures to extreme weather conditions (resulting from wetter winters and increases in heavy precipitation events) may damage the structures and increase the frequency of repairs and/or replacements. Extreme shoreline changes (erosion, avulsion, accretion) could also damage overwater structures. As shoreline changes bring shifts in sediment supply and water depths, the utility of some overwater structures may change as well. Long-term, warmer air temperatures and drier summers could increase the usage of and demand for overwater structures associated with recreational activities (e.g., private recreational docks, marinas, boat ramps, etc.).

3.2.3 Impacts to Log Booming and Storage

The Aquatic Resources Program recognizes the use of log booming and storage on SOALs, as it provides the public benefits of fostering water-dependent uses and utilizing renewable resources. It also generates revenue in a manner consistent with these other public benefits. As areas used for log storage are generally quite sheltered areas with relatively little wave action, the activity may not be negatively effected by an increase in episodic flooding or storm surges. Shoreline responses to sea level rise in these areas may be gradual enough to avoid any negative effect on the activity. It is conceivable that certain shoreline responses, like mass wasting in bluff systems, could render an existing site unsuitable. It is conceivable that intense storm surges coupled with sea level rise could break up boomed logs, or wash logs up onto adjacent uplands, but this is unlikely given the sheltered locations in question.

While the activity of log booming and storage may not be greatly negatively impacted by climate change, projected climate change impacts could present future challenges to the activity by exacerbating the existing negative environmental effects of the activity. Storm surges may increase the areas impacted by the activity (e.g., wood waste may wash onto adjacent uplands through flood events). Other climate change impacts, such as ocean acidification and increasing water temperature, may place additional stress on nearshore species and habitats that are already under stress due to the negative effects of log booming and storage. This may effect the Program's ability to ensure environmental protection on SOALs where log booming and storage takes place. As the effects of climate change stressors on coastal ecosystems become more apparent in subsequent decades, the question of whether an activity with such well-documented negative impacts on near-shore habitat and species is an appropriate use of state-owned aquatic lands may arise. Even more likely is the continued decline of this activity due to changes in logging and log transport practices as well as the location of lumber mills.

3.2.4 Impacts to Dredge Materials Management Program

An initial scoping of impacts to the Dredge Materials Management Program (DMMP) indicates that the DMMP may be effected by several projected climate change impacts. Sea level rise may decrease some of the need for dredging; if ports and other water-dependent industries are able to rebuild or retrofit their terminals and piers to accommodate rising sea levels, these entities could potentially benefit from deeper berths at their facilities and the need for dredging could diminish. Overall, however, the need for dredging to allow for safe navigation will almost certainly continue, even as sea levels rise. This is because climatic changes may lead to increased sediment input into the nearshore environments from rivers and from the mass wasting of bluffs. This could result in a continuous and ongoing need for dredging in the State's bays and harbor areas. Looking forward, the demand for dredged materials for restoration and mitigation projects may increase as climate change impacts take hold. As beach erosion and wetland inundation increases, dredged materials may be used for the beneficial purpose of beach and/or wetland nourishment.

3.2.5 Impacts to Ports Program

Projected climate change impacts could effect WDNR's Ports Program in a number of ways. Marine ports may be considerably effected by projected climate change impacts, especially sea level rise. The very nature of marine ports requires that they be located at sea level. In Washington State, they are also often located at or near the mouth of a river, making them highly susceptible to both gradual inundation from sea level rise and increased coastal and riparian flooding. As seas rise and ports face an ever-greater risk of periodic flooding from sea level rise, existing terminals, piers, wharves may need to be raised to accommodate rising water levels. A Port's ability to accommodate its terminals to sea level rise may not necessarily sufficiently protect it against the threat of inundation. While retrofitting existing terminals will be important, terminals (vessel berths, staging areas, on-terminal storage) are just one part of a larger transportation network that can include intermodal transfer yards, cargo storage, cargo-handling equipment, road and rail infrastructure, and neighboring port-related industries. The viability of marine ports depends on their ability to move goods to inland locations quickly and efficiently along the transportation chain. If the transportation networks that serves Washington's are unable to adapt to climate change impacts, the adaptive capacity of port terminals may be irrelevant.

Sea level rise may not be entirely negative for ports. If the necessary industries and infrastructure can be successfully protected from the rising seas, ports may benefit from sea level rise via a reduced need for dredging. Most marine ports in Washington require frequent dredging services, as sediment continually flows into the State's bays and harbor areas from nearby rivers. As vessel size has steadily increased in recent decades, the demand for deep draft berths (especially at large ports like the Ports of Seattle and Tacoma) has grown, increasing the demand for dredging. Sea level rise may provide Washington ports with deeper draft berths as water levels rise. On the other hand, a more dynamic shoreline (i.e., more frequent erosion, accretion, and avulsion) and increased inputs from riparian systems (resulting from upland land-use activities, increased tree die-off from warmer, drier summers and increased fires) could increase ports' needs for dredging.

When ports expand their facilities, mitigation for the negative environmental impact of their expansion is often required. Looking forward, projected climate change impacts could seriously impact ports' ability to acquire the necessary permitting and approval for their mitigation and enhancement projects. The success of mitigation as a strategy to ensure environmental protection is already a highly contested issue, and as the nearshore environment becomes threatened by climate change, the success rate of mitigation and restoration projects could decline.

3.2.6 Impacts to Invasive Species Program

Changes in climate may effect both aquatic invasive species and WDNR's ability to eradicate them. Present day understanding of how noxious weeds may be effected by projected climate change impacts is limited. Inundation could negatively impact noxious weeds, as plants may drown if they are unable to successfully migrate landward. Increased coastal flooding could drown invasive species, but it could also facilitate the spread of noxious weeds; flood events in freshwater systems have facilitated the spread of invasive species like knot weed in the past (Wendy Brown, March 23, 2009, conversation with the author). Shoreline changes (erosion, accretion, and avulsion) and changes in freshwater inputs to system (resulting from changes in precipitation patterns and regional hydrology) may negatively impact plant growth, as existing habitats may become less suitable. Ocean acidification may have negative impacts on non-native noxious weeds, but scientific understanding of what this relationship may be is still evolving. Similarly, changes in precipitation patterns and intensity may impact the growth of noxious weeds, but the nature of these impacts is still unknown.

Changes in precipitation patterns may positively effect the Program's effective treatment of invasive species like *Spartina*. In order for treatment of Spartina to be effective, spraying must occur during the summer months, when the plant is actively growing and when low summer tides allow for the longest "dry period" (when the plant is not submerged in water). The projected amplification of Washington's precipitation cycle and subsequent hotter, drier summers may facilitate effective *Spartina* treatment, as the summer dry season may become longer. If temperatures reach high enough levels, plants may also be directly negatively impacted by these extreme temperatures.

The Invasive Species Program may also be effected by the threat of new invasive species as air and water temperatures rise. Warmer temperatures could mean that some of the invasive species populations found in California (e.g., invasive species from the Mediterranean like *Caulerpa*) could migrate northward into Washington waters.

3.2.7 Impacts to Derelict Vessel Removal Program

Projected climate change impacts to Washington's coasts may negatively effect WDNR's Derelict Vessel Removal Program (DVRP). Sea level rise could increase the risks to human health and safety that derelict vessels pose. Episodic flood events and storm surges could ram derelict vessels against docks, causing further damage to both the vessel and its berth or mooring, potentially creating hazardous conditions. Such events could also push over grounded vessels, increasing damage to benthic habitat and possibly prompting the release of oil and other contaminants into the surrounding environment. During extreme floods, floating vessels could come loose from their moorings and grounded vessels could become completely submerged.

Over time, gradual inundation resulting from sea level rise could exacerbate these issues.

Unlike most other WDNR activities in the Aquatic Resources Program, the DVRP is sometimes involved with removing vessels not on state-owned aquatic lands, including vessels on Washington's outer coast. Shifts in storm tracks may result in increased wave height and wave action on the outer coasts. This increase in wave action could cause derelict vessels to break up. During major storms, higher waves could toss derelict vessels onto the shore, causing greater environmental damage, and potentially increasing the vessel's threat to human health and safety. Higher waves on the outer coast and an increase in heavy precipitation events could also slow down the process of dismantling or removing vessels, as these activities cannot be carried out in hazardous weather conditions. Shoreline changes (erosion, accretion, and avulsion) could bury and unbury derelict vessels. While these changes could provide a sort of benefit to the Program by uncovering old vessels, overall these shoreline changes would likely be more detrimental than beneficial, as they could cause further damage to vessels, could cause vessels to further damage the surrounding environment, or could inhibit the Program's ability to safely remove or dismantle the vessel.

3.2.8 Impacts to Contaminated Site Clean Up

WDNR's clean up of contaminated sites may be effected by climate change in that the agency may inherit contaminated sites through sea level rise and associated shoreline responses. Contaminated upland sites adjacent to WDNR-managed state tidelands may be transferred into state ownership as aquatic lands if water levels rise to the point where these contaminated sites are under regular tidal influence or submerged completely. Temperature is not likely to effect existing contaminated sites under WDNR management, aside from a possible subtle shift in the suites of organisms that are using the contaminants at natural recovery sites as a source of energy (Lionel Klikoff, April 16, 2009, conversation with the author). Strong changes in currents may effect the integrity of capped sites, and may change the dispersion process at dispersive sites, but not enough is presently known about how currents within the Puget Trough Eco-Region may change as a result of climate change to state how contaminated sites may be effected.

<u>3.2.9 Impacts to Habitat Conservation Plan</u>

WDNR's Aquatic Resources Program is developing the Aquatic Lands Habitat Conservation (HCP) in response to the listing of several species as threatened or endangered under the federal Endangered Species Act (ESA). The HCP is being developed "to ensure that the legally authorized, planned and mandated actions that can continue to occur on state-owned aquatic lands without risk of violating the ESA or resulting in an unlawful take of threatened or endangered species" (WDNR 2009). Further, the HCP also formalizes the Aquatic Resources Program's efforts to conserve and enhance submerged habitats, thereby guaranteeing that WDNR continues to meet its mandated obligation to provide a balance of public benefits, including ensuring environmental protection. The goals of the HCP are to: (1) avoid and minimize effects to covered species and habitats, (2) improve and restore habitat conditions on state-owned aquatic lands, and (3) identify and protect important habitats on state-owned aquatic lands (WDNR 2009).

The species considered in the near-shore saltwater ecosystem section of the HCP include the bald eagle, the brown pelican, the common loon, the harlequin duck, the marbled murrelet, the western snowy plover, the bull trout/ Dolly Varden, the coastal cutthroat trout, the coho salmon, the chinook salmon, the chum salmon, the pink salmon, the sockeye salmon, the steelhead, the green sturgeon, the white sturgeon, and the southern resident orca. The HCP addresses the direct and indirect effects of three groups of activities on these species: shellfish aquaculture, log booming and storage, and overwater structures.

This section considers how projected climate change impacts may exacerbate the direct effects of these covered activities (shellfish aquaculture, log booming and storage, and overwater structures) on the identified endangered species and species habitats. Identification of the likely effects of climate change on these existing stressors to endangered species and species habitat will provide the Aquatic Resources Program with information about how climate change may effect its ongoing HCP efforts. It will also allow WDNR to incorporate climate change considerations into the HCP process.

Because the HCP is one key way that the Program will be able to ensure environmental protection of SOALs in the long-term, it is vital that the effects of climate change impacts on the HCP be considered.

3.2.9.1. Effect of Projected Climate Change Impacts on Identified Effects of Shellfish Aquaculture on Endangered Species and Endangered Species Habitat

The direct effects of aquaculture on species and species habitat identified in the HCP include:

- Disturbance and harm due to the presence of humans and operation of vessels or machinery. (Examples of such harm or disturbance include entanglement in netting or collisions with boats or other machinery, trampling by foot traffic, and increased wave energy).
- Artificial lighting during night operations.
- Predator deterrence measures such as lighting, protective devices or loud noises.
- Destruction of habitat due to changes in substrate size/ quality, loss of vegetative communities, installation of structures such as anchors and stakes (WDNR 2009).

Projected climate change impacts could exacerbate these direct effects of aquaculture on species and species habitat in numerous ways. Shoreline changes like erosion and avulsion could exacerbate existing substrate disturbance from harvesting. Habitat destruction from the presence of physical structures may become an even more serious problem as nearshore habitat is lost as a result of sea level rise. Disturbance and harm due to the presence of humans and the operation of vessels and machinery may increase if extreme heavy precipitation events or weather events associated with shifting storm tracks damage tracts and infrastructure and more frequent repairs are required. Injury to species via entanglements or collisions could increase if flooding, heavy precipitation events, and increased wave energy and height due to shifting storm tracks create a more turbulent nearshore environment.

Other climate change impacts may not directly exacerbate the identified direct effects associated with aquaculture, but they may directly negatively impact the endangered species or species habitat. These projected climate change impacts include warmer air and water temperatures, ocean acidification, and changes in precipitation patterns and consequent timing and flows of freshwater inputs.

3.2.9.2 Effect of Projected Climate Change Impacts on Identified Effects of Overwater Structures on Endangered Species and Endangered Species Habitat

The direct effects of overwater structures on species and species habitat identified in the HCP include:

- Disturbance and harm due to human presence and operation of vessels and machinery (e.g., cranes).
- Increased wave energy from vessel wakes.
- Increased nearshore/littoral and surface water temperatures due to stormwater flows from adjacent impervious structures.
- Decreased nearshore/littoral and surface water temperatures due to structural shading.
- Decreased flushing at sites with breakwaters.
- Artificial night lighting during operations (WDNR 2009).

Changes in precipitation patterns and freshwater inputs could exacerbate the effects of decreased flushing at sites with breakwaters. Habitat and species may also be effected by erosion control structures such as breakwaters or bulkheads as these structures may remove or reduce riparian vegetation, which translates to a loss of natural shading and subsequent increased temperatures in nearshore and littoral systems. Warmer temperatures associated with climate change may exacerbate the effects of these localized increases in water temperature. The pressure to implement erosion control measures (such as bulkheads and seawalls) where overwater structures are present may increase as sea levels rise and erosion and flooding becomes more common. An increase in erosion control measures may lead to increased scouring of substrate.

3.2.9.3 Effect of Projected Climate Change Impacts on Identified Effects of Log Booming and Storage on Endangered Species and Endangered Species Habitat

The direct effects of log booming and storage on species and species habitat identified in the HCP include:

- Noise from boats and other machinery.
- Artificial lighting during night operations.
- Localized changes in wave energy due to log dumping, storing, and managing of log inventory.
- Alteration of sediment structure, including scouring and compacting.
- Smothering of submerged vegetation by woody debris.
- Shading from log rafts (WDNR 2009).

The direct effects of increased wave energy and alteration of sediment structure could be exacerbated by several projected climate change impacts, including shoreline responses to sea level rise, increases in heavy precipitation events, gradual inundation, and increased flooding. Other climate change impacts may not directly exacerbate the identified direct effects associated with log booming and storage, but they may negatively impact the endangered species or species habitat. For example, warmer air and water temperatures, ocean acidification, and changes in precipitation patterns may directly negatively effect the endangered species covered under the HCP.

3.2.10 Impacts to the Stewardship Science Program, Aquatic Reserves Program, and Shoreline Master Planning

An initial scoping of WDNR's Stewardship Science Program, Aquatic Reserves Program, and the Program's participation in Washington's Shoreline Master Planning process indicates that these programs may be effected by all of the projected climate change impacts to Washington's coasts identified in this Strategy. The special foci of these programs makes them valuable tools for the Program to increase its resiliency, and the resiliency of state-owned aquatic lands, to projected climate change impacts. As such, they are discussed in Section 7 of this Strategy, which discusses recommended actions for preparing for and adapting to climate change.

3.3 Summary of Impacts to Management Activities

A summary how WDNR's management activities may be effected by projected climate change impacts is provided in Table 8. This Table plots the Program's management activities against projected climate change impacts to the marine nearshore environment of the Puget Trough Eco-Region. The red areas of the Table indicate situations where a management activity may be negatively effected by a given climate change impact. The yellow areas of the Table indicate situations where a management activity may be negatively or positively effected by a given climate change impact. The green area of the Table indicates the one situation where a projected climate change impact may positively effect a given management activity. The tan areas of the Table indicate situations where management activities are not likely to be significantly effected by a given climate change impact.

Table 8 reveals that all of the scoped management areas may be negatively effected by shoreline changes (erosions, accretion avulsion) resulting from sea level rise and other climatic changes. All but one may be threatened by inundation. Nine of eleven may be negatively effected by increased flooding. Eight out of eleven scoped management activities may be negatively effected by an increase in extreme heavy precipitation events. One management activity, the Invasive Species Program, could be either positively or negatively effected by an increase in extreme precipitation events, and two management activities, log booming and storage and contaminated site clean up, are not likely to be effected.

Four out of eleven scoped management activities may be negatively effected by increases in air and water temperatures, an amplification of the current precipitation cycle, and ocean acidification. Warmer temperatures may negatively or positively effect two management activities, the Invasive Species

Program and overwater structures, and three management activities (log booming and storage, the Derelict Vessel Removal Program, and contaminated site clean up), are not likely to be effected. Overwater structures may be positively or negatively effected by wetter winters and drier summers, while the Invasive Species Program may be positively effected by this change, since drier summers would allow for more effective treatment of *Spartina*.

3.4 Effect of Climate Change Impacts on Balancing of Public Benefits

Table 9 identifies the Program's management activities and indicates which public benefits these activities provide. Table 10 plots the information on projected climate change impacts provided in Table 8 against the public benefits provided by each scoped activity so as to provide a sense of which public benefits may be most effected by each projected climate change impacts. Table 9 shows that based on the eleven management activities considered, the public benefit of "ensuring environmental protection" is the public benefit that may be most negatively effected by projected climate change impacts.

This initial scoping of climate change impacts is by no means a comprehensive assessment of the Aquatic Resources Program's vulnerability to climate change,[10] but it does provide sufficient information for the Program to begin prioritizing its climate change preparedness efforts. The information

[10] An example of a qualitative climate change vulnerability assessment using the method described in Snover et al. is provided in Section 2.2 of this Strategy

provided by this initial scoping of climate change impacts will be used later in this Strategy to develop priority planning areas for the Program.

3.5 Necessity for Further Analysis

It should be emphasized that while the information provided here is sufficient to initiate the Program's climate change preparedness efforts, a more thorough and rigorous analysis of the Program's vulnerability to climate change should be conducted in the future. Snover et al. (2007) presents a process for conducting a Climate Resiliency Study. This process includes a climate change vulnerability assessment and risk assessment. To demonstrate how such a study could be applied to the Aquatic Resources Program, a pilot vulnerability assessment of one of the Program's key management activities – WDNR's co-management of Washington's commercial wild stock geoduck fishery - is presented in the next section.

Table 7. Scoping of Climate Change Impacts to WDNR Management Activities

Authorized Use: Shellfish Aquaculture	Gradual inundation may alter the viability of certain tracts: For tracts with stationary boundaries, (e.g., Willapa Bay, Gray's Harbor), water depths may become too great. For tracts where boundaries move with shifting tidal datums (e.g., some Puget Sound tidelands), substrate on new tidelands may be unsuitable for aquaculture. Gradual Inundation may increase pollution from contaminated upland sites. Increased pollution could negatively effect shellfish. Episodic Flooding and increased increases in extreme heavy precipitation events may: Damage infrastructure (e.g., lines or stakes may break for line aquaculture) and equipment.

	Uproot in-ground stocks. Make harvesting of in-ground stocks more challenging. Gradual inundation, episodic flooding, and shoreline changes (erosion and avulsion) may increase pressure to armor shorelines. Increased shoreline armoring could negatively effect shellfish via increased scouring of substrate. Increases in extreme precipitation events may lead to scouring of substrate. Shoreline changes (increased erosion, accretion, avulsion) may increase turbidity in the water column and/ or change substrate conditions. Hard armoring of shoreline may exacerbate increased turbidity (reflected wave energy). Warmer water temperatures and drier summers may lead to increased incidence of HAB outbreaks. Wetter winters may make planting and harvesting more challenging. Ocean acidification may directly negatively impact shellfish in larval, juvenile, and adult life stages, and may indirectly negatively impact shellfish via reduced food abundance. All of projected changes above may negatively or positively effect shellfish predators and food abundance.
Authorized Use: Overwater Structures	Gradual Inundation: Docks may need to be reconfigured to accommodate future tidal fluctuations resulting from sea level rise. Increases in flooding frequency and intensity could damage overwater structures. Shoreline changes (increased erosion, avulsion, accretion), could damage overwater structures and surrounding area. Shoreline changes could increase or decrease need for dredging at marinas and terminals. Increases in extreme heavy precipitation events could damage overwater structures. In the long-term, warmer temperatures could increase demand and/or usage of overwater structures associated with recreational activities (e.g., private recreational docks, marinas, boat ramps, etc.)
Authorized Use: Log Booming and Storage	Inundation: As sea levels rise, new areas that are appropriate for log booming and storage may become available.

	Inundation and flooding could break up boomed logs and cause logs to wash ashore or drift away. Shoreline changes (increased erosion, avulsion, accretion) could make existing sites unsuitable.
Dredge Materials Management Program	Gradual Inundation may decrease some need for dredging at Ports, as rising water levels will create deeper berths. Climate change impacts to terrestrial and riparian systems and changes in the regional hydrological system could increase sediment loading in bays from riparian environment. Shoreline changes (increased erosion, avulsion, accretion) may increase sediment supply to nearshore environment, potentially increasing the demand for dredging in some areas. Demand for dredged materials may increase, as demand for "beneficial uses" of dredged materials, especially for nourishment of eroded beaching and drowning wetlands, may increase as sea levels rise and erosion and inundation increases.
Ports Program	Impacts to Ports' Dredging Needs: • Shoreline changes (increased erosion, accretion, avulsion) and increased inputs from riparian systems could result in an increase in Ports' need for dredging. • Sea level rise could reduce dredging needs. Impacts to Terminals and Port Infrastructure: • Existing terminals, piers, wharves may need to be raised to accommodate sea level rise. Impacts on Port-related Transportation Network/ Industries: • For Ports situated in low-lying river deltas, thetransportation network and industries serving the port and situated in riparian or coastal flood plain are also vulnerable to effects of SLR (e.g., gradual inundation and more frequent flooding). Impacts to Mitigation/ Enhancement Activities: • Success of near-shore mitigation/ enhancement projects could be negatively effected by projected climate change impacts.

	Impacts on WDNR's Ports Program • As WDNR's Ports Program reviews all permits submitted by Ports, the Program's capacity could become overwhelmed if projected climate change impacts prompt Ports to engage in climate change adaptation activities that require permits.
Invasive Species Program	Flood events can facilitate the spread of invasive species. Depending on rate of sea level rise, sediment supply, and ability of plant to migrate landward, certain noxious weeds could drown as seas rise. Flooding, inundation, shoreline changes (erosion, accretion, avulsion) and changes in freshwater inputs to system can impact plant growth. Hotter drier summers would be ideal for treatment of *Spartina.* If an amplification of the current precipitation cycle leads to wetter springs this may delay treatment of *Spartina* until later in the summer. Cannot treat *Spartina* in high wind conditions - If shifting storm tracks lead to an increase in high winds in outer bays, treatment of Spartina may occur less frequently. Threat of new invasive species – warmer temperatures could mean that Mediterranean invasive species (e.g., *Caulerpa*) found in California could migrate northward in Washington waters.
Derelict Vessel Removal Program	Sea level rise and associated inundation and flooding could further damage vessels, moorings, and berths. Threats to human health and safety could increase. Degradation and pollution of nearshore environment could increase. Severe weather conditions (high winds, increased wave height and wave action) resulting from shifting storm tracks on Washington's outer coast could cause derelict vessels to break up. Increased wave height and action could toss derelict vessels onto adjacent upland, causing greater environmental damage, and potentially increasing the vessel's threat to human health and safety Severe weather conditions (high winds, increased wave height & wave action) resulting from shifting storm tracks on Washington's outer coast could slow down the process of dismantling or towing derelict vessels, as these activities cannot always be carried out in severe weather conditions.

	Shoreline changes (increased erosion, accretion, avulsion) could increase damage to vessels, infrastructure and habitat. Extreme changes could also bury and unbury derelict vessels.
Contaminated Site Clean Up	Warmer temperature are not likely to dramatically effect contaminated sites – a subtle shift in the suite of organisms that are using these contaminants as a source of energy at natural recovery sites may be observed. Program could inherit contaminated sties through sea level rise and associated shoreline changes (increased erosion, accretion, avulsion).
Habitat Conservation Plan: Covered Activity, Shellfish Aquaculture **How Climate Change May Exacerbate Identified Effects of Activity on Threatened or Endangered Species and Associated Habitat Covered under Habitat Conservation Plan**	Inundation, Flooding, and Shoreline Changes (increased erosion, accretion, avulsion) could exacerbate substrate disturbance from harvesting. Inundation, Flooding, and Shoreline Changes (increased erosion, accretion, avulsion) may lead to significant loss of nearshore habitat. This could exacerbate the effect of habitat destruction from the presence of physical structures as an increasingly large amount of nearshore habitat will be threatened. Flooding, heavy precipitation events, and increased wave height and energy due to shifting storm tracks on the outer coast could exacerbate effect of injury or mortality to species through entanglement in predator netting or collision with boats or machinery as conditions could become more hazardous during these events. These events could also exacerbate the effect of the recurrent episodic presence of humans and machinery and noise from seeding and site maintenance if increases in these events causes damage and repairs become more frequently required. The cumulative effects of projected climate change impacts such as warmer air and water temperatures, ocean acidification, and changes in precipitation patterns combined with the identified negative effects of shellfish aquaculture and other non-climatic stressors could be detrimental to covered species and habitat.
Habitat Conservation Plan: Covered Activity, Overwater Structures **How Climate Change May Exacerbate Identified Effects of Activity on Threatened or Endangered Species and Associated Habitat Covered under Habitat Conservation**	Inundation, flooding, shoreline changes, and increases in extreme heavy precipitation events could exacerbate effects of increased wave energy, erosion, scour and alteration of depth/ slope from boat traffic. Shoreline changes could exacerbate scouring of substrate caused by presence of erosion control devices like breakwaters and bulkheads. Shoreline changes could also increase pressure to erect erosion control measures, thus creating a negative feedback loop and leading to further

Plan	scouring and erosion seaward of protective structure. Warmer water temperatures may exacerbate the localized effect of increased nearshore and surface water temperatures caused by stormwater flows from adjacent impervious structures. Warmer water temperatures may exacerbate the effect of increasing nearshore and surface water temperatures caused by removal or reduction of riparian vegetation due to presence of erosion control structures such as breakwaters or bulkheads. The cumulative effects of projected climate change impacts such as warmer air and water temperatures, ocean acidification, and changes in precipitation patterns combined with the identified negative effects of overwater structures and other non-climatic stressors could be detrimental to covered species and habitat.
Habitat Conservation Plan: Covered Activity, Log Booming and Storage **How Climate Change May Exacerbate Identified Effects of Activity on Threatened or Endangered Species and Associated Habitat Covered under Habitat Conservation Plan** **Conservation Plan**	Inundation, flooding, shoreline changes and increases in extreme heavy precipitation events could exacerbate effects of increased wave energy and alteration of sediment structure from boat traffic. The cumulative effects of projected climate change impacts such as warmer air and water temperatures, ocean acidification, and changes in precipitation patterns combined with the identified negative effects of log booming and storage and other non-climatic stressors could be detrimental to covered species and habitat.

Table 8. How Climate Change Impacts May Effect WDNR Management Activities

	Impacts Associated with sea level rise			**Warmer Air and Water Tempera-tures**	**Ocean Acidifica-tion**	**Wetter Winters, Drier Summers**	**Increased Heavy Precipi-tation Events**
	Gradual Inundation of low-lying areas	**Increased Flooding** (magnitude & frequency)	**Shoreline Changes** (Erosion, Avulsion, Accretion)				
Shellfish Aqua-culture							
Over-water Structures							
Log Booming and Storage							
Dredged Materials Mngmt. Program							
Ports Program							
Invasive Species Program							
Derelict Vessel Removal Program							
Contam. Site Clean- Up							
HCP: Shellfish Aqua-culture							
HCP: Overwater Structures							
HCP: Log Booming and Storage							

Table 9. Public Benefits Provided by WDNR's Management Activities

	Public Benefits				
Management Activities	**Encourage direct public use and access**	**Foster water-dependent uses**	**Ensure environmental protection**	**Utilize renewable resources**	**Generate revenue in manner consistent with other four benefits**
Operation of commercial wild stock geoduck fishery		X	X	X	X
Authorized Use: Shellfish Aquaculture		X	X	X	X
Authorized Use: Overwater Structures	X	X	X	X	X
Authorized Use: Log Booming and Storage		X	X	X	X
Habitat Conservation Plan	X	X	X	X	
Aquatic Reserves Program	X	X	X	X	

Dredge Materials Management Program	X	X	X	X	X
Ports Program		X	X		
Invasive Species Program			X		
Derelict Vessel Removal Program			X		
Contaminated Site Clean Up			X		
Stewardship Science	X	X	X	X	
Near-shore Habitat Program			X	X	
Shoreline Master Planning	X	X	X	X	

Table 10. How Climate Change Impacts May Effect WDNR's Balancing the "Four Plus" Public Benefits

	Public Access	Water-Dependent Uses	Environmental Protection	Renewable Resources	Generate Revenue
Inundation	5	7	10	6	3
Flooding	5	8	10	7	3
Shoreline Response	5	8	11	7	3
Warmer Air and Water Temperatures	3	4	4	4	1
Ocean Acidification	3	4	4	4	1
Wetter Winters, Drier Summers	3	4	4	4	1
More Heavy Precipitation Events	5	6	7	5	2
Total	**29**	**41**	**50**	**37**	**13**

4.0 Pilot Vulnerability Assessment of WDNR's Co-management of Washington's Commercial Wild Stock Geoduck Fishery

Question 2: Which WDNR management activities may be most vulnerable to projected climate change impacts?

Section 3 of this Strategy scoped the potential effects of projected climate change impacts to SOALs and to many of the Aquatic Resources Programs' management activities. This scoping process provides the Program with some sense of which climate change impacts may most seriously effect the Program, and which management activities may be most sensitive to these impacts. Because this Strategy is the Program's first comprehensive look at climate change, it is useful and appropriate to initiate the Program's climate change preparedness efforts with this broad, high-level scoping exercise to identify key climate change issues for WDNR. The initial scoping provides the agency with sufficient information to begin prioritizing its initial climate change preparedness efforts.

Looking forward, however, it is likely that the Aquatic Resources Program will wish to gain a more detailed understanding of how vulnerable it is to climate change, and what its opportunities for increasing resiliency may be. WDNR could gain such a level of understanding by conducting a climate change resiliency study. Snover et al. (2007) divide the process of conducting a climate resiliency study into two steps: 1) a climate change vulnerability assessment, and 2) a climate change risk assessment (Snover et al. 2007).

This Section of the Strategy presents a pilot climate change vulnerability assessment of one of the Aquatic Resources Program's key management activities, the co-management of Washington's Commercial Wild Stock Geoduck Fishery. This assessment follows the three step process articulated in Snover et al. (2007): 1) a sensitivity analysis of the relevant systems, 2) an evaluation of the adaptive capacity of the relevant systems, and 3) an assessment of how vulnerable the systems are to the effects of climate change. This vulnerability assessment is presented in this Strategy as a *pilot* climate change vulnerability assessment, and it is qualitative in nature. The objective of its inclusion is to demonstrate the utility of such a process for determining how vulnerable the Aquatic Resources Program may be to projected climate change impacts. This assessment provides valuable information about the vulnerability of WDNR's co-management of Washington State's Commercial Wild Stock Geoduck Fishery to climate change.

4.1 Conducting a Vulnerability Assessment

Vulnerability is "a function of a system's sensitivity to climate and the capacity of that system to adapt to climate changes," (Snover et al. 2007, p.6). This means that systems that are more sensitive to climate change and less able to adapt are generally considered to be more vulnerable to climate change impacts (Snover et al. 2007). The IPCC identifies seven key components that influence vulnerability to climate change. These key components are: 1) the magnitude of impacts (e.g., scale and intensity); 2) the rate and timing of impacts (e.g., fast vs. slow; near-term vs. long-term); 3) the persistence and reversibility of impacts; 4) the likelihood of impacts; 5) the potential for adaptation; 6) distributional aspects of impacts and vulnerabilities (e.g., across regions and population groups), and 7) the importance of the system(s) at risk (IPCC 2007).

A system's vulnerability to climate change can be exacerbated by the presence of non-climatic stressors (IPCC 2007). Common non-climatic stressors acting on coastal and marine environments include population growth, increasing demand for resources, competition from invasive species, and development in or near sensitive habitats (Whitely Binder et al. 2009). To effectively address a planning area's vulnerability, it is important to consider both climatic and non-climatic stressors as they are inherently interconnected. Lara Whitely Binder of the University of Washington's Climate Impacts Group encourages planners and managers to discard any notion that planning for climate change may be a process that is distinct from planning for other environmental stressors (NOAA 2009). Whitely Binder stresses that preparing for climate change is less about initiating an entirely new and separate planning process and more about approaching existing coastal and natural resource management issues through a slightly different lens (NOAA 2009).

4.2 Analyzing Sensitivity

The objective of a sensitivity analysis is to determine if the *systems* associated with a given *planning area* are likely to be effected by climate change. *Systems* are defined as "the built, natural, and human networks that provide important services or activities within a community or region" (Snover et al. 2007, p. 65). *Planning areas* are "the areas in which a government or community manages, plans, or makes policy effecting the services and activities associated with built, natural and human systems" (Snover et al. 2007, p.65). If a system is likely to be effected by projected climate change impacts, it should be considered sensitive to climate change (Snover et al. 2007). A system may be effected by climate change directly, (e.g., a change in species distribution in response to a change in temperature), or indirectly (e.g., damages caused by flooding due to sea level rise) (Whitely Binder et al. 2009). Both direct and indirect effects should be considered when assessing a planning area's sensitivity.

Snover et al (2007) provides questions for governments to consider when analyzing a given system's degree of sensitivity. These questions include:

1) How exposed a system is to the impacts of climate change.

2) Whether a system is already subject to existing stresses.

3) Whether climate change will cause the demand for a resource to exceed its supply.

4) Whether a system has limiting factors that may be effected by climate change.

5) If the system has an associated "impact threshold" that should be considered (Snover et al. 2007).

4.3 Determining Adaptive Capacity

Adaptive capacity is "the ability of built, natural and human systems associated with a given planning area to accommodate changes in climate with minimum disruption or minimum additional cost" (Snover et al. 2007, 78). Snover et al. (2007) suggest that governments reflect on several factors when determining how adaptive systems are to projected climate change impacts. These factors are:

1) A system's present-day ability to accommodate to changes in climate.

2) Barriers that inhibit a system's ability to adapt, including legal or regulatory restrictions, the number of competing uses for a system.

3) The number of organizations involved with managing a system.

4) A system's biological, geographic, or physical barriers.

5) Existing stresses within a system that will limit the system's ability to adapt/

6) If the rate of projected climate changes may be faster than the adaptability of a system.

7) If there are already efforts underway to address the impacts of climate changes to a system (Snover et al. 2007).

4.4 Assessing Vulnerability

Once the sensitivity and the adaptive capacity of the systems in a planning area have been assessed, the vulnerability of that planning area to climate change can be determined. If the sensitivity of systems in a planning area is high, and the adaptive capacity of those highly sensitive systems is low, then that planning area is highly vulnerable to projected changes in climate. Conversely, if the systems associated with a given planning area are not very sensitive to climate change, and can easily adapt to the relevant projected climate change impacts, then that planning area is not very vulnerable to climate change.

4.5 Rationale for Conducting a Vulnerability Assessment of Washington's Commercial Wild Stock Geoduck Fishery

When the Legislature opened the Commercial Wild Stock Geoduck Fishery in 1969, it mandated that revenue from the sales of geoducks fund both the protection of aquatic resources and the management of the geoduck resources. To fulfill this mandate, revenue from the State's Geoduck Fishery funds two accounts: the Aquatic Lands Enhancement Account (ALEA) and the Resource Management Cost Account – Aquatics (RMCA-A). The demand for geoducks in Asian markets has grown significantly since the establishment of the fishery. Today Washington's Commercial Wild Stock Geoduck Fishery is the largest and most valuable clam fishery on the west coast of North America

(WDNR and WDFW 2008, Dethier 2006). The State's Commercial Wild Stock Geoduck Fishery harvested between 1.7 and 2.2 million pounds of geoduck per year between 2000 and 2006, generating between roughly $6 million and $10 million in revenue a year (Joint Legislative Audit and Review Committee 2008).

Geoduck revenue is particularly important for the Aquatic Resources Program, as the Program is highly dependent on both the ALEA, and the RCMA-A for its operating budget. Moreover, WDNR's co-management of the Commercial Wild Stock Geoduck Fishery is one of the primary ways the agency complies with its statutory mandate to generate revenue from state-owned aquatic lands (RCW 79-105-030). The fishery is also the main source of revenue from the Program's management of state-owned aquatic lands; during the 2005-07 biennium geoduck sales accounted for 52% of revenues generated by the Aquatic Resources Program (Joint Legislative Audit and Review Committee 2008). Given the significance of the fishery to the Aquatic Resources Program, it is an obvious choice for a pilot vulnerability assessment.

4.6. Overview of Commercial Wild Stock Geoduck Fishery

Geoducks (*Panopea generosa)* are very large clams, found abundantly in both the Puget Sound and the Strait of Juan de Fuca, but not on Washington's outer coast. Geoducks are primarily a sub-tidal species, but do extend into the low intertidal zone in some areas (Dethier 2006). Geoducks are a long-lived species, with life spans of up to 160 years. The clams usually attain their maximum size (shell length of ~ 150 mm) and weight (up to ~ 7 pounds) within 15 to 25 years, reaching an average harvestable size of 1.5 pounds in 4 to 5 years time (WDNR and WDFW, 2008). Geoducks live in substrates ranging from soft mud to small gravel, but are found most frequently in stable mud or sand bottoms. The clams grow fastest in substrate composed of sand or mud mixed with sand (Dethier 2006, Goodwin and Pease 1987), at shallower depths, and in areas with higher current speeds (Dethier 2006).

Geoduck spawning occurs from April to September. Geoducks remain in their free-floating larval stage for 4 to 6 weeks before settling into their benthic habitat. Juvenile geoducks attach to the other substrates or use a sand anchor to attach themselves to the sea floor (Dethier 2006). Once juveniles have reached 1.5 – 2.0 mm in length, they begin burrowing into the sediment, at a rate of about 1 foot per year (Dethier 2006, WDNR and WDFW 2008). Once geoducks have burrowed 2 to 3 feet down into the substrate, they will remain there for the duration of their long lives.

Geoducks are filter feeders. Predators of larval and juvenile geoducks include fish (sole and flounder), starfish, crabs, scooters and snails. Adult clams can usually bury deeply enough to avoid predators, (except for humans), but their stationary nature makes them vulnerable to environmental stressors like anoxic water conditions and excessive sedimentation (Dethier 2006). Larvae and juveniles are likewise highly sensitive to changes in water conditions, and require water that is relatively free of contaminants for survival. Larvae require an abundant, non-toxic supply of plankton, and minimal amounts of suspended sediments (Dethier 2006). Geoducks are tolerant of salinities ranging from 5-35 ppt; and optimum salinity is 25 ppt (Dethier 2006). The clams can tolerate a range of temperatures, but require cold water (<16°C) during spawning.

Commercial harvest of Washington's Wild Stock Geoduck Fishery began in 1969, when WDNR and Washington Department of Fish and Wildlife (WDFW), (formerly Washington Department of Fisheries), successfully petitioned the Legislature to open Washington's waters to commercial harvest of the species. The 1994 Rafeedie decision affirmed the rights of the Puget Sound Treaty tribes to fish up to 50 % of the harvestable quantity of geoduck within their usual and accustomed fishing grounds [*U.S. v. Washington,* 898 F. Supp 1453 (1995)]. Today, Washington's Commercial Wild Stock Geoduck Fishery is co-managed by WDNR, WDFW and the Tribes.[11]

In Washington State, Geoduck harvest occurs on designated beds, or tracts, in water ranging from -18 feet (shallow-water boundary) to - 70 feet (deep-water boundary) in depth from the mean lower low water mark (RCW 77-60-070, WAC 220-52-19). The shallow-water boundary (-18 feet) exists to protect sensitive nearshore habitats (e.g., eelgrass beds) (WDNR and WDFW

[11] The following tribes presently have treaty rights to harvest geoducks: Squaxin Island, Nisqually, Puyallip, Tulalip, Muckelshoot, Skokomish, Port Gamble, S'Klallam, Suquamish, Jamestown S'klallam, Lower Elwha S'klallam, Swinomish, Nooksack, Lummi, Marak, and Upper Skagit.

2008). The deep-water boundary (-70 feet) is the limit for effective diving operations (i.e., the limit at which divers can harvest without requiring extensive decompression) (WDNR and WDFW 2008). Commercial geoduck tracts are present in southern and central Puget Sound, Hood Canal, Admiralty Inlet, the Strait of Juan de Fuca, northern Puget Sound, and the San Juan archipelago. A greater number of tracts exist in central and southern Puget Sound, as geoducks are generally larger and more densely populated in these areas (WNDR and WDFW 2008, Goodwin and Pease 1989).

Geoducks are harvested by divers operating from anchored boats (generally 25 to 60 feet long) (WDNR/ WDFW 2008). Divers harvest the clams by hand, using a water jet to loosen the substrate immediately around the clam. Pumps and compressors on the boat provide air for the divers and pressured water for the water jets. Water jet hoses can be up to 400 feet in length (WDNR/ WDFW 2008). During harvest, geoduck fishery vessels must remain at least 200 yards from shore at all times, to minimize noise effects on shoreline residents (RCW 7760-070). As WDNR is in charge of enforcement and compliance for the commercial wild stock geoduck fishery, a WDNR enforcement vessel is always present on the water when the fishery is open. WDNR ensures that harvesting occurs only on designated tracts, during designated hours.

4.7 Vulnerability Assessment of Washington's Commercial Wild Stock Geoduck Fishery

The sensitivity analysis of the Wild Stock Geoduck Fishery considers the current and expected stresses to the *natural, built*, and *human* systems associated with the fishery. The analysis considers *current and expected stresses* to the following planning areas associated with the fishery: geoduck habitat, food web interactions, recruitment, fishery closures due to harmful algal bloom (HAB) events, bacterial outbreaks, WDNR geoduck boat operations, boat maintenance, geoduck harvest tracts, funding for fishery management, and miscellaneous ongoing fishery management challenges. Stresses that may impact the given planning areas are identified, *the possible impacts of climate change to each identified stress are considered*, and a qualitative sensitivity rating (low, moderate, high) is determined.

It should be noted that the likely outcome of interactions between projected changes in climate and existing stresses could not be always be determined. When current scientific understanding limited the ability to predict how the impacts of climate changes might alter existing stresses, the sensitivity is designated as uncertain or unknown. The same process and parameters are used in the adaptive capacity analysis. *The vulnerability assessment weighs the sensitivity of the planning area against the adaptive capacity of the planning area*. When a planning area's sensitivity or capacity to adapt is unknown or uncertain, it is reflected in the qualitative vulnerability rating.

4.8 Findings

The sensitivity analysis, adaptive capacity analysis, and vulnerability assessment of the geoduck fishery are presented in Appendix I of this Strategy. The analyses and assessment provide detailed information about how sensitive, adaptive, and vulnerable the natural, built, and human systems associated with each planning area may be to projected climate change impacts. The reader should refer to Appendix I to obtain a complete understanding of the findings of this vulnerability assessment. Two things are clear from this vulnerability assessment: 1) the geoduck fishery may be highly vulnerable to climate change; 2) the geoduck fishery is likely most vulnerable to stresses to the natural environment. Since the fishery is so important to the Program, and since the fishery is highly vulnerable to stresses in the natural environment, the Aquatic Resources Program should prioritize actions which increase the resiliency of the natural systems associated with the fishery when developing its climate change preparedness plan. Recommended actions aimed at increasing the resiliency of the geoduck fishery are presented in Section 7 of this Strategy.

5.0 Priority Planning Areas

Question 2: Which WDNR management activities may be most vulnerable to projected climate change impacts?

This Section identifies priority planning areas for the Aquatic Resources Program's climate change preparedness efforts. Snover et al. (2007) define priority planning areas as "the planning areas which your community or government determine to be the most important given your community's vulnerability to climate change" (Snover et al. 2007, p. 90). An initial scoping of climate change impacts to WDNR's management activities and state-owned aquatic lands, and a qualitative vulnerability assessment of WDNR's co-management of Washington's commercial wild stock geoduck fishery, have provided some idea of how vulnerable state-owned aquatic lands and the Aquatic Resources Program may be to projected climate change impacts. This Section uses the information provided by the scoping and assessment processes in Sections 3 and 4 of the Strategy to identify the priority planning areas for the Aquatic Resources Program. Section 7 of this Strategy provides recommended actions for addressing these priority planning areas.

5.1 Priority Planning Area 1: Preparing for Sea Level Rise

It is clear from the scoping and assessment process that the projected climate change impacts associated with sea level rise (SLR) will effect all of the Program's management activities. The impacts associated with sea level rise bring up several key management issues for the Aquatics Resources Program.

5.1.1 Management Issue Associated with Sea Level Rise: Shifting Location of State-owned Aquatic Lands and Determination of Ownership

Coasts are naturally dynamic environments that have been responding to near-shore processes for millennia. Washington Administrative Code (WAC) 332-30-060 recognizes the dynamic nature of marine coasts in that it defines the boundaries of 1st class tidelands (within two miles of corporate city limits on either side) and 2nd class tidelands (more than two miles outside of corporate city limits) by the line of ordinary high tide and the line of extreme low tide. As seas rise and coastlines respond dynamically to rising water levels, boundaries of state-owned aquatic lands may shift landward as tidal datums move. WAC 332-30-060 supports the notion that the location of SOALs may change as coastlines gradually change. The statute describes the process of *accretion* as “the natural buildup of shoreline through the gradual deposit of alluvium” (WAC 332-30-060-1) and the process of *erosion* as “the gradual cutting away of a shore by natural processes” (WAC 332-30-060-17). It further states title to land is generally lost by erosion, and title to land is generally gained by accretion (WAC 332-30-060-17).[12]

Unlike the laws of erosion and accretion, the law of avulsion provides a case where title is not transferred in the event of a shoreline change. *Avulsion*

[12] There is also a statutory definition for reliction, which states that (60) "Reliction" means the gradual withdrawal of water from a shoreline leaving the land uncovered. Boundaries usually change with reliction (WAC 332-30-60-60). But as the law of reliction is unlikely to apply in the context of sea level rise, it is not considered in this Strategy.

is described in statute as "a sudden and perceptible change in the shoreline of a body of water" (WAC 332-30-060-8). Statute states that "generally no change in boundary lines occurs" during avulsive events (WAC 332-30-060-8). This means that when shorelines change suddenly, ownership boundaries do not change. The primary distinction between erosion/ accretion scenarios and avulsion scenarios is the *rate* of change. Erosion and accretion are both described as gradual processes, while avulsion is described as a sudden change. As sea level rise will likely prompt an increase both scenarios, both scenarios will be discussed below.

In the context of sea level rise, the laws of erosion, accretion and avulsion have multiple management implications for the Aquatic Resources Program. Erosion is expected to increase widely as sea levels rise, and will likely impact beach, bluff, and wetland systems. Avulsive events are projected to occur via bluff landslides and breaching of barriers and spits. As incidences of avulsion, erosion, and accretion increase, WDNR will need to begin planning for how it will respond to these changes in ownership.

Avulsive events are likely to occur during major storm events, and will likely be categorized as natural disasters (Shipman 2009). Reactions from coastal property owners to avulsive events will likely vary greatly, and each case may be different. While reactions to shoreline changes may vary, it is reasonable to conclude that WDNR can expect that the need to determine the precise location of SOALs, and to clearly delineate the boundary between

SOALs and adjacent privately-owned property, will increase as sea levels rise and shorelines respond to these higher water levels. An increased need to determine the location of SOALs can also be expected with as incidences of erosion and accretion increase. The processes of erosion and accretion are by definition more gradual than avulsive events, but this does not mean that the resulting transfer of ownership will not be contested.

At present, the precise location of state ownership of aquatic lands is often determined on a responsive basis, meaning that state-ownership is often determined on a case-by-case, “need to know” basis. This means that while the agency has a good descriptive knowledge of the *approximate* location of SOALs, it often lacks knowledge about the *precise* location of these lands. As state coastlines become increasingly dynamic, it is reasonable to conclude that WDNR may find that it is increasingly important to obtain a more precise understanding of the exact location and boundaries of SOALs.

<u>5.1.1.1. Determination of Ownership in the Event of Inundation</u>

The legal framework for transfer of ownership in the event of accretion, avulsion, and erosion is well-defined. The legal framework for transfer of ownership in the event of inundation, however, is significantly less well-defined. There is no discussion in statute about transfer of ownership in the event of gradual, permanent inundation. This is not surprising since sea level rise on the magnitude that is projected as a result of climate change has not been a factor in the past. It is reasonable to conclude that boundaries will move and title will be transferred for any shoreline change that is gradual, including the gradual inundation that is expected as sea levels rise, since boundaries move and title is transferred in the case of other gradual changes (e.g., erosion and accretion).

5.1.2.1 Management Issue Associated with Sea Level Rise: Shoreline Armoring

The issue of shoreline armoring pervades all sea level rise discussions relating to WDNR's management of state-owned aquatic lands. Armored shorelines inhibit the landward migration of coastal environments and lead to squeezing of nearshore habitat between the armored shoreline and the rising sea. Protective structures like bulkheads protect private property in the short-term, but actually increase beach erosion on the seaward side of the structure. Johannessen and MacLennan (2007) describe the issues associated with sea level rise and shoreline armoring in Washington well:

> Washington's beaches, bluffs, and spits are vulnerable to increased flooding and increased shoreline erosion due to sea level rise. Building on these properties will be increasingly risky. Bulkheads and rock walls can temporarily reduce upland erosion caused by wave action, but they can do little prevent continued erosion and sliding of the seaward bank, since waves rebound off the breakwaters and increase the rate of beach erosion. Beach armoring can cause two negative effects that act to reduce the beach area: stopping the sediment from bluff erosion from adding to the beaches and moving the sand offshore. (Johannessen and MacLennan 2007)

The impoundment of sediment on the landward side of the structure is a serious negative impact of shoreline armoring in the Puget Sound area (McDonald et al. 1994). In the context of SLR, shoreline armoring presents additional challenges. If coastal environments and their associated habitats are to survive the onslaught of sea level rise, they must be permitted to migrate landward to the greatest extent possible. Hard structures along the coastline inhibit this landward migration of beaches, bluffs, and wetlands (Titus 1998). When seas rise and hard armoring of the shoreline is present, the nearshore environment will disappear. Loss of nearshore habitat will severely inhibit the Aquatic Resources Program's ability to provide a balance of the "four plus" public benefits. In fact, all four public benefits guiding WDNR's management of SOALs are highly threatened by shoreline armoring.

5.1.2.2 Management Issue Associated with Sea Level Rise: Lack of Jurisdiction Over Projected *Future* State-Owned Aquatic Lands

Perhaps the largest management challenge that sea level rise presents to Aquatics is that in the context of sea level rise, WDNR has an imperfect sense of where state-owned aquatic lands may be in the future. It will be very challenging for WDNR to manage SOALs in a strategic manner if the agency does not know where SOALs will be in the future. Even if WDNR were to gain a better sense of where future SOALs may be, the Aquatic Resources Program has no management authority over lands that are currently privately or publicly owned uplands, but may become state-owned aquatic lands in a few decades as sea levels rise and title is transferred. This lack of jurisdiction over future SOALs is a serious impediment to WDNR's ability to plan ahead for the impacts of sea level rise and other climatic changes. Moreover, WDNR presently has no authority to stop waterfront property owners from erecting protective structures like bulkheads and seawalls on uplands adjacent to

SOALs. These protective structures inhibit the natural landward migration of tidelands and facilitate the destruction of nearshore habitat as sea levels rise.

The Washington State legislature could expand WDNR's management authority to include projected *future* state-owned aquatic lands. Until such a legislative change occurs, WDNR will need to work closely with regulatory agencies and local governments to ensure that future SOALs are managed in a way that minimizes future management problems for WDNR. In order to ensure the survival of vulnerable nearshore environments like wetlands, WDNR must begin working collaboratively with the entities that own adjacent uplands and/or regulate upland activities to develop approaches that will increase the resiliency of these vulnerable areas.

5.2 Priority Planning Area: Ensuring Continued Environmental Protection and Sustainable Utilization of Renewable Resources

The scoping and assessment provided in Sections 3 and 4 of this Strategy reveal that nearshore habitats and the species that rely on these habitats will be placed under increased stress as climate change impacts take hold. The Aquatic Resources Program's ability to ensure environmental protection of state-owned aquatic lands and to utilize renewable resources may be severely negatively effected by projected climate change impacts. In order to continue managing SOALs in a manner which balances the "Four Plus" public benefits, WDNR must seek to increase the resiliency of the saltwater nearshore ecosystem within the Puget Trough Eco-Region by reducing the sensitivity and increasing the adaptive capacity of these nearshore habitats and associated species. At the same time, WDNR must also begin seeking out new ways to continue providing a balance of public benefits from SOALs, in the event that the increased resiliency provided by the Program's climate change adaptation efforts proves insufficient.

6.0 The Necessity of a Climate Resilient Vision for WDNR Aquatic Resources Program and State-owned Aquatic Lands – Providing a Balance of Public Benefits in the Context of Climate Change

Question 3: *What does the Aquatic Resources Program* want *state-owned aquatic lands to look like in 2050?*

This Section answers the question: "What does the Aquatic Resources Program *want* state-owned aquatic lands to look like in 2050?" by reviewing the Program's recently completed Strategic Plan (WDNR 2008). When the Program's strategic plan is reviewed through the lens of climate change, the adverse effect that climate change may have on the ability of the Program to meet its strategic management goals is revealed. If WDNR is to meet its strategic goals, a climate resilient vision must be articulated. Section 7 of the Strategy provides a climate resilient vision for the Aquatic Resources Program by applying the Guiding Principles for developing a climate resilient community articulated in Snover et al. (2007) to the Program.

6.1 Why a Climate Resilient Vision is Needed for the Aquatic Resources Program

The information presented earlier in this Strategy demonstrates that the projected climate change impacts to Washington's coasts present considerable challenges to WDNR's ability to continue managing the state's aquatic lands in a manner that provides a balance of the "Four Plus" public benefits for all the citizens of Washington. Looking forward, the Program will likely have to make increasingly difficult decisions that involve considerable trade-offs in order to continue meeting the complex and often conflicting needs of the many users of Washington's aquatic lands. As climate change will likely exacerbate existing management challenges within the Aquatic Resources Program, strategic planning will become increasingly vital to the successful operation of the Program. Because strategic, long-term planning will be required if WDNR is to adequately prepare for the impacts of climate change, the Program should develop a climate resilient vision to help guide the planning process. It is prudent to initiate the development of the Program's climate resilient vision by asking the question "What does the Aquatic Resources Program *want* state-owned aquatic lands to look like in 2050?"

6.2 Aquatic Resources Program Strategic Plan

The recently completed *Aquatic Lands Strategic Plan for Washington's State-owned Aquatic Lands* (WDNR 2008) articulates the Program's ten-year management goals, the intended outcomes of the stated goals, strategies for achieving these goals, and activities and performance measures for each strategy. This Strategic Plan provides the best sense of how the Aquatic Resources Program would like state-owned aquatic lands to look like in 2050. The Plan identifies several goals for the Aquatic Resources Program, including:

> Goal 1: Protect, restore and enhance aquatic ecosystems through innovative stewardship.
> Goal 2: Encourage direct public access, foster water-dependent uses, navigation and commerce.
> Goal 3: Renewable resources are sustainably managed. (WDNR 2008)

6.3 Balancing the "Four Plus" Public Benefits in the Context of Climate Change

It is clear from the goals identified in above that the Aquatic Resources Program expects to be able to continue to provide a balance of all "four plus" public benefits through its management goals. The intended outcomes identified in the Strategic Plan indicate that the Program intends not only to continue providing this balance, but also to expand the ways in which it fosters these public benefits. For example, the Strategic Plan states that by 2018 the WDNR intends to have improved the health and abundance of aquatic vegetation and associated biodiversity, and protected ecologically sensitive habitats (WDNR 2008). The Plan also calls for an expansion of public access points so as to provide a variety of recreational opportunities, and envisions thriving harbor areas, with continued viable locations for water-dependent uses and waterfront businesses (WDNR 2008). Ongoing recreational and commercial harvest of healthy shellfish and aquatic vegetation is also envisioned, as are improvements in water quality, and a reduction in shellfish closures (WDNR 2008).

If this Strategic Plan is reviewed through the lens of climate change, it is clear that the vision of WDNR's management of SOALs articulated in the Program's Strategic Plan will be increasingly difficult to achieve as climate change impacts take hold. Fortunately, if the Program initiates a climate resiliency effort today, the vulnerability of state-owned aquatic lands and the Aquatic Resources Program may be much reduced.

6.4 Guiding Principles for a Climate Resilient Community

It is clear that both state-owned aquatic lands and WDNR's management of these lands will be effected by climate change. In order for WDNR to continue providing a balance of the "Four Plus" public benefits in the decades to come, its management of SOALs must be expanded to include preparing for projected climate change impacts. Local Governments for Sustainability (ICLEI)'s concept of a "climate resilient community" can be applied to help the Aquatic Resources Program develop a climate resilient vision that will increase its resiliency to climate change (Snover et al. 2007). A *resilient system* is one that has the capacity to "absorb and rebound from weather extremes, climate variability, or change and continue functioning" (Luers and Moser 2006 in Whitely Binder et al. 2009 p.5. See also Turner et al. 2003, IPCC 2007). A *climate resilient community* is a community that "takes proactive steps to prepare for climate change" by reducing the vulnerabilities and risks associated with projected climate change impacts (Snover et al. 2007 p.5). By undertaking anticipatory adaptation measures and building its adaptive capacity, the Aquatic Resources Program will increase its resilience to climate change.

Snover et al. (2007) defines five guiding principles for increasing resilience. These guiding principles are:

1. Increase public awareness of climate change and its projected impacts.
2. Increase technical capacity to prepare for climate change impacts.

3. “Mainstream” information about climate change vulnerabilities, risks, and preparedness into planning, policy, and investment decisions.
4. Increase the adaptive capacity of built, natural and human systems.
5. Strengthen community partnerships that reduce vulnerability and risk to climate change impacts. (Snover et al. 2007)

These guiding principles for increasing resiliency are used to frame the discussion of policy responses to projected climate change impacts presented in Section 7.

One of the intended outcomes identified articulated in the Program’s Strategic Plan is that WDNR’s management practices relating to the protection, restoration, and enhancement of aquatic ecosystems be “widely recognized as exemplary” (WDNR 2008). Projected climate change impacts will place the saltwater nearshore ecosystem of the Puget Trough Eco-Region under increased stress. In order to ensure environmental protection while providing a balance of other mandated public benefits, the Aquatic Resources Program will have to be a truly innovative steward. The program has an opportunity to show exemplary, forward-thinking management by proactively preparing for climate change.

7.0 Next Steps for Improving the Climate Resiliency of the Aquatic Resources Program and State-owned Aquatic Lands

Question 4: *What are the next steps the Aquatic Resources Program can take to prepare for and adapt to climate change?*

This Section answers the question, "What are the next steps the Aquatic Resources Program can take to prepare for and adapt to climate change?" by providing recommendations for increasing the resiliency of the Program and SOALs to projected climate change impacts in coastal areas. Several reports have identified policy responses that are relevant to WDNR's climate resiliency effort. Existing recommendations that are relevant to this Strategy include those made by Washington's Preparation and Adaptation Working Groups (PAWGs) in "Leading the Way: Preparing for the Impacts of Climate Change in Washington, Recommendations of the Preparation and Adaptation Working Groups" (WDOE and WCTED 2008), particularly those made by the Coastal and Infrastructure PAWG. The policy options identified in Chapters 8 and 11 of the Washington Climate Change Impacts Assessment (Huppert et al. 2009, Whitely-Binder et al. 2009) are also highly relevant, as are those provided by Snover et al. (2007) and Glick et al. (2009). This Strategy incorporates the recommendations made in the literature above and applies them to the specific needs of the WDNR Aquatic Resources Program.

7.1 Building the Adaptive Capacity of the Aquatic Resources Program

One way the Program can increase its resiliency to climate change is through increasing its adaptive capacity. Actions aimed at building adaptive capacity work to overcome the institutional, legal, technical, cultural, fiscal, and other barriers to planning for climate change (Whitely Binder et al. 2009). Adaptive capacity can be built regardless of the uncertainty associated with existing climate change projections and as such can be considered a "no regrets" strategy for preparing for climate change (Whitely Binder et al. 2009). The following recommended actions will develop the adaptive capacity of the Aquatic Resources Program, increasing the Program's resiliency to climate change.

7.1.1 Articulate a Formal Climate Change Preparedness Message

As the Aquatic Resources Program prepares for climate change, a formal Preparedness Message, i.e., a program-wide "position" or stance, on preparing for climate change should be articulated (Snover et al. 2007). All Program staff should be aware of the Program's Preparedness Message and should apply it in their daily work. Many climate change adaptation activities will require collaboration with other agencies, local governments, non-governmental organizations and other stakeholders. It is vital that all Program staff present a uniform message (the Program's Preparedness Message) on climate change adaptation when engaging in collaborative efforts. An ideal Preparedness Message for the Aquatic Resources Program would mirror and be linked to WDNR's agency-wide climate change Preparedness Message. A formal declaration from the Commissioner of Public Lands articulating the agency's position on preparing for climate change would provide the strongest foundation for initiating any climate change adaptation effort within the Aquatic Resources Program.

7.1.2. Dedicate Staff Time to Climate Change Adaptation Activities and Form an Internal Climate Change Adaptation Work Group

Staff time should be officially allocated for climate change adaptation activities via the establishment of an internal climate change adaptation work group (Snover et al. 2007). Members of the work group should coordinate the Program's climate change preparedness efforts, and should develop and implement policies for preparing for climate change within the Aquatic Resources Program. Several near-term and long-term adaptive actions are recommended in this Strategy. The group's work could begin with taking steps to implement these recommendations. Initial work could also include completing more vulnerability assessments like the pilot assessment of the Wild Stock Geoduck Fishery presented in this Strategy. This work group could be limited to Division staff and Land Managers within the Aquatic Resources Program, or it could be expanded to an intra-agency work group, which would coordinate climate change adaptation activities throughout the Department of Natural Resources.

WDNR staff should also conduct internal outreach and education within the Aquatic Resources Program and WDNR, and work to "mainstream" climate change information and preparedness actions into the Program's planning and policy documents (Snover et al. 2007). It is vital that all agency staff understand the threats and opportunities posed by climate change, and that all agency planning and policy reflect this awareness of climate change. Senior management at WDNR should formally convey to staff that there is an expectation that all agency work take climate change issues into account. Management could also make the incorporation of climate change information and preparedness actions one of the criteria for reviewing staff performance (Edward Miles, May 22, 2009, conversation with author).

7.1.3 Engage in Adaptation and Preparation Activities at State and Regional Levels

In addition to working within the agency and the Aquatic Resources Program, staff should continue to participate in state and regional adaptation efforts. At the State level, Senate Bill 5560, "An Act relating to state agency climate leadership," mandates the coordination of the Departments of Ecology, Agriculture, Community, Trade & Economic Development, Fish & Wildlife, Natural Resources, and Transportation to develop an integrated climate change response strategy, by December 2011. The Aquatic Resources Program should advocate within WDNR to have a representative from the Program participate in this collaborative effort to ensure the needs and concerns of aquatic lands are represented in the development of this integrated response strategy. In particular, the Aquatic Resources Program should advocate for the inclusion of the recommendations made by Washington's Coastal and Infrastructure Preparation and Adaptation Working Group in 2008 into the integrated climate change response strategy (DOE and CTED 2008).

Regionally, initiatives such as the West Coast Governors' Agreement on Ocean Health Climate Change Action Coordination Team (WCGA CCACT) provide WDNR the opportunity to share its expertise and to benefit from the resources and expertise of other agencies and governments. Given the current constraints of the agency's budget, it is important to take advantage of opportunities to leverage resources and share expertise across agencies and states. Ongoing involvement at the state and regional level will also ensure the State's proprietary interests and rights are addressed.

The work of the WCGA CCACT to date provides one example of how participation in regional efforts can yield very useful results. One recommendation made by the Coastal & Infrastructure PAWG is to "improve mapping and characterization of sea level rise vulnerability for all Washington Coasts" (DOE and CTED, 2008). This recommendation is of particular importance to the Aquatic Resources Program, as SLR will effect all of its management activities. Through the regional work of the WCGA ACT, progress towards achieving improved mapping and characterization of sea level rise vulnerability will very likely soon be underway via an anticipated National Academy of Sciences (NAS) study which will develop a consensus of estimates and uncertainties of SLR and changes in storminess (including overall atmospheric and oceanic processes) along the west coast of the United States for the years 2030, 2050, and 2100.[13]

7.1.4 Advocate for the Creation of a Formal Interagency Climate Change Adaptation Work Group

The State's capacity to adapt to climate change would also be greatly enhanced by the formal creation of an interagency climate change adaptation work group such as the one proposed in Senator Phil Rockefeller in the 2009 Washington legislative session (SB 5138). A formally established forum for interagency communication would encourage the development of complimentary policies across agencies and would create opportunities for the State to implement adaptation activities that require interagency, cross-jurisdictional collaboration. In the absence of such a forum, Washington State runs the risk of having disjointed and inconsistent approaches to climate change adaptation.

7.1.5 Develop Technical Capacity to Create Inundation Maps

A scoping of climate change impacts reveals that nearly all of the Program's management activities may be negatively affected by gradual inundation. The Aquatic Resources Program must acquire an improved understanding of which state-owned aquatic lands are most vulnerable to inundation (i.e., those tidelands that are at the highest risk of becoming permanently inundated). Inundation maps will also assist the Program in

[13] More information on this proposed National Academy of Sciences study will be available in the West Coast Governors' Agreement on Ocean Health Climate Change Action Coordination Team's Draft Work Plan, which will be available soon at: http://westcoastoceans.gov/teams/#climate

determining possible locations of future SOALs (i.e., those adjacent uplands in low-lying areas that are likely to become permanently inundated). Such maps will also allow the Program to identify areas where it may be feasible to implement a policy of managed retreat (which will be discussed in Section 7.3). The Program could develop its technical capacity for inundation mapping by partnering with an organization that already possesses the technical capability to produce inundation maps, like the University of Washington's Climate Impacts Group, or by developing the capacity to create inundation maps in-house. Inundation maps that identify high-risk areas will be valuable tools for educating WDNR staff and the public about the risks associated with sea level rise and flooding in coastal areas. These maps can also be used to inform several of the future management actions described below. The creation of an inundation layer for the Program's ArcGIS system will allow land managers to begin determining the risks associated with SLR when authorizing a proposed use.

7.1.6 Determine when Boundaries Between Land Classifications Will Shift as Sea Levels Rise

The management issues associated with determining ownership of state-owned aquatic lands as sea levels rise are discussed in Section 5 of this Strategy. There are several sub-questions associated with the principal questions of determining the location and boundaries of SOALs, such as:

- Will boundaries shift only in cases when erosion or accretion can be determined, or will they shift in the event of inundation as well?

- How will this shift in boundaries be determined?
- If boundaries shift and the State inherits structures or infrastructure, who will be responsible for removing these structures?
- If boundaries shift, how might WDNR's jurisdiction be expanded to include management of *projected future* public trust lands?

As a propriety agency, WDNR will need to continue developing its legal position on issues relating to shifting boundaries and changing coastal environments to prepare itself for potential future litigation involving shoreline change.

Assistant Attorney General of Washington's Natural Resources Division Joseph V. Panesko has prepared a memorandum on sea level rise, accretion, avulsion, submersion, and boundary issues in response to a Legal Services Request from the author of this Strategy. This is an initial step towards answering the question, "Will boundaries shift only in cases when erosion or accretion can be determined, or will they shift in the event of inundation as well?" Panesko determines that "in general, absent future legislation touching the subject, courts would probably apply the common law principles regarding moving boundaries to most sea level rise situations" (Attorney General of Washington, 2009). This means that in situations where shoreline changes are slow and imperceptible (as may be the case with inundation), a change in property boundaries would probably occur.

If an increased demand for the determination of the specific location of state-owned aquatic lands arises, the Program may consider augmenting its technical capacity to determine SOAL locations (e.g., the Program may need to increase its surveying capacity).

7.1.7 Research Potential Effects of Projected Climate Change Impacts on Geoducks

The pilot vulnerability assessment of WDNR's co-management of Washington's Commercial Wild Stock Geoduck Fishery provided in Section 2.2 of this Strategy reveals that: (a) geoducks may be highly vulnerable to climate change, and (b) the effects of projected climate change impacts to geoducks are largely unknown. Given the large percentage of revenue generated annually through WDNR's co-management of the fishery, it would be prudent for WDNR and the other co-managers of the fishery to invest in research that determines how sensitive geoducks may be to climate change impacts such as increased sea surface temperature and increased ocean acidification. There is currently a lack of research on the response of geoducks to changing ocean chemistry. A recent study on the influence of acidification on oyster larvae calcification and growth in estuaries suggests that biological responses to changes in pH will be species-specific and therefore quite variable and complex (Miller et al. 2009). Research that focuses specifically on how geoduck respond in the larval and juvenile phases would be very useful for the Aquatic Resources Program. If research reveals that geoducks may be highly vulnerable to ocean acidification and other climate change impacts, the Program may need to seek out ways to assure (through resiliency management) and diversify its revenue sources.

7.1.8 Research Potential Effects of Projected Climate Change Impacts to Shellfish

Only about 2% of the revenue generated from SOALs annually comes from lands leased for shellfish aquaculture, but because shellfish aquaculture is such an important historic use and continues to be a significant part of the State's economy, the Aquatic Resources Program has a strong interest in how it may be effected by climate change. As a renewable resource, the Program fulfills its statutory responsibility to provide the public benefit of "utilizing renewable resources" by fostering shellfish aquaculture on SOALs (RCW 79-105-030). The scoping and assessment provided in Section 3 of this Strategy and the research of Huppert et al. (2009) find that shellfish are likely highly sensitive to climate change. As such, WDNR should collaborate with other entities to fund research focused on: (1) improving understanding of the effects of climate change stressors on shellfish growth and mortality, and (2) improving the adaptive capacity of shellfish species (Huppert et al. 2009). Possible research areas include the effects of increased sea surface temperature and ocean acidification on various strains of shellfish and the potential for developing more climate-tolerant strains (Huppert et al. 2009).

7.1.9 Increase Involvement in Coastal Land-Use Planning Processes

It has been well established in this Strategy that climate change is projected to alter coastal environments in fundamental ways. One outcome of these projected changes for WDNR is the increased potential for activities permitted on coastal uplands adjacent to state-owned aquatic lands to negatively effect WDNR's management of SOALs. As such, the Aquatic Resources Program would benefit greatly from increasing its involvement in coastal land use planning discussions whenever possible. WDNR should push for cities and counties to consider how their permitting and planning processes may exacerbate the negative effects that projected climate change impacts may have on state-owned aquatic lands.

The Program is already involved in local shoreline planning processes; Program staff currently review all Shoreline Master Plans (SMPs) as they are being updated. Looking forward, WDNR's role should transition away from the passive role of reviewing existing documents to a more active participation in the development of SMPs in concert with the Department of Ecology and other agencies. When engaging in land use planning conversations, WDNR staff should clearly articulate the Program's climate change Preparedness Message, and work to increase public awareness of the potential effects of climate change impacts to state-owned aquatic lands. In particular, WDNR staff should work to educate local communities about how activities on waterfront property (e.g., hard armoring, nutrient loading) may exacerbate projected climate change impacts. Another reason WDNR should engage in land use planning conversations is that it is quite likely that conflicts between waterfront property owners and WDNR may arise in the future, as sea level rise may place these two parties at odds as property owners seek to protect their property and WDNR seeks to protect the nearshore environment.

Consistent and ongoing documentation of WDNR's proactive stance on addressing climate change impacts in public records will place the agency in a strong position in the event of future litigation (Burr Stewart, January 23, 2009, conversation with the author).

7.2 Near-term Adaptive Actions for the Aquatic Resources Program

The following adaptive activities are recommended to target specific climatic vulnerabilities of both state-owned aquatic lands and the Aquatic Resources Program. Section 2 of this Strategy revealed the priority planning areas for the Aquatic Resources Program to be: (1) preparing for sea level rise, and (2) ensuring continued environmental protection and sustainable utilization of renewable resources. The adaptive actions below address the key management issues associated with the Program's priority planning areas.

7.2.1 Implement Aquatic Lands Habitat Conservation Plan Conservation Measures

Given the multiple stressors that climate change is expected to bring to the saltwater nearshore environments of the Puget Sound Trough, it is more important than ever to implement the numerous conservation measures articulated in WDNR's Aquatic Lands Habitat Conservation Plan (HCP). A healthy ecosystem will be more resilient to climate change impacts than an ecosystem that is already under considerable non-climatic stress (Snover et al. 2007, Whitely Binder et al. 2009). Rapid implementation of the conservation measures developed for the HCP will help to reduce non-climatic stressors in the nearshore environment. These conservation measures include the banning of virtually all new bulkheads on SOALs, and the gradual replacement of existing bulkheads with softer shoreline protection systems, and banning of fixed or attached breakwaters in favor of floating breakwaters.

Conservation measures have also been developed to avoid habitat degradation and substrate damage, maximize water flow, increase light transmission, protect aquatic vegetation, and prevent pollution. The HCP calls for these conservation measures to be incorporated as use authorizations are renewed or as new uses are proposed. To increase the effectiveness of these conservation measures, policy options for incorporating the measures into existing uses should be explored, as should options for expanding the number of activities subject to these conservation measures.[14]

7.2.2 Increase Efforts to Ban Construction of New Bulkheads on or Adjacent to State-Owned Aquatic Lands

The Conservation Measures in the Aquatics HCP ban new bulkheads on state-owned aquatic lands. The Aquatic Resource Program should make this conservation measure a top priority, given the many issues associated with hard armoring and sea level rise discussed in this Strategy. As a proprietary agency, WDNR has very limited authority to ban construction of bulkheads on coastal uplands adjacent to state-owned aquatic lands or on privately owned tidelands. Nevertheless, the likely negative effects to state-owned aquatic lands caused by adjacent bulkheads should compel WDNR to work with other

[14] The activities presently covered under the WDNR Aquatics HCP are: Overwater Structures, Shellfish Aquaculture, and Log Booming & Storage

stakeholders to prevent new and remove existing hard armoring from adjacent uplands and privately-owned tidelands wherever possible. In the long-term, the highly urban, industrialized areas of Washington's coastlines will likely be highly armored to protect these areas from the rising sea. If the decision-makers of Washington State choose to protect waterfront urban areas from sea level rise, a net loss in ecological function in those areas will ensue. In anticipation of this loss, WDNR and other natural resource agencies should work together to promote ecological function in other coastal areas. Removing existing and/or preventing new hard armoring on waterfront property or privately owned tidelands in strategically selected rural or suburban areas could be one way of promoting ecological function.

7.2.3 Inform Lessees of State-owned Aquatic Lands about Sea Level Rise and Other Climate Change Risks

Given that many of WDNR's leases on SOALs are 30-year leases, it is vital that lessees of state-owned aquatic lands be informed about projected climate change impacts to SOALs and the risks associated with these impacts, as Washington's climate is projected to change appreciably during the next thirty years. The Aquatic Resources Program should develop language to be included in the Best Management Practices in the Plan of Operations used as an Exhibit for leases. WDNR will need to periodically update the climate change information provided to lessees as climate change science evolves and our understanding about likely impacts to specific environments improves.

7.2.4 Consider Sea Level Rise Estimates when Reviewing Existing Uses or Authorizing New Uses on SOALs

WDNR Land Managers should consider sea level rise when reviewing existing uses or authorizing new uses. Sea level rise could be considered either by using the inundation maps developed for the Aquatic Resources Program (see recommendation 7.1.5), or by using the range of SLR estimates provided by Mote et al. (2008).[15] Specific guidance for land managers on how to incorporate sea level rise into the review process should be developed. Over time, Division staff should work with Land Managers to determine how the current process for evaluating the baseline conditions of aquatic lands can be expanded to consider changes in the conditions of the land projected to occur during the time period specified in the lease.

7.2.5 Increase Monitoring Capacity and Implement Adaptive Management

Adaptive management is the recommended management approach for natural resources managers coping with climate change, as the structured, iterative process provided by adaptive management allows for optimal decision making in the face of uncertainty (Glick et al. 2009). WDNR's Stewardship Science Program is already in the process of developing a plan for implementing an adaptive management approach within the Aquatic Resources Program; this effort should be strongly supported. To that end, increased funding for monitoring is essential, as monitoring is a key component of any

[15] Inundation maps would provide a far more accurate estimate of possible inundation at specific sites.

adaptive management process (Noss and Cooperrider 1994). Moreover, as some degree of uncertainty will always exist regarding future climate change impacts, continued monitoring of the ecosystem will be required to understand the effects of climate change on ecosystem health (Glick et al. 2009). The Aquatic Resources Program should seek to expand the existing monitoring activities of its Nearshore Program. WDNR's collaborative work with the Puget Sound Partnership (PSP) may allow for such opportunities, particularly in regard to PSP's monitoring of key indicators of ecosystem health (Puget Sound Partnership 2009).

7.3 Long-term Adaptive Actions for the Aquatic Resources Program

In addition to implementing the near-term adaptive actions discussed above, the Aquatic Resources Program will also need to begin pursuing the following long-range actions in order to increase its resiliency to climate change. The successful implementation of the adaptive actions listed below will be a time-consuming and challenging process, as multiple stakeholders, including other state agencies, local governments, private property owners, and many coastal users, will be invested in the outcomes of these processes. In some cases, shifts in public perceptions and attitudes will be required. In all cases, ongoing communication and collaboration between agencies and across sectors will be necessary. Because they will take some time to implement, these long-term adaptive actions should be initiated today.

7.3.1 Implement Suite of Proactive Adaptation Measures to Increase Ecological Resilience

The resiliency of state-owned aquatic lands in the saltwater nearshore Puget Trough Eco-Region can be enhanced through the implementation of a suite of proactive adaptation actions aimed at increasingly ecological resiliency by: (1) reducing non-climatic stressors, and (2) increasing restoration and protection of habitat. These measures will enhance the ecosystem's natural ability to respond to changes in climate. The Program's Strategic Plan identifies multiple activities aimed at reducing non-climatic stressors and protecting and improving habitats on SOALs. Achieving the performance measures within the specified timeframe of the Strategic Plan will be a good start towards increasing the resilience of state-owned aquatic lands to climate change via the reduction of non-climatic stressors. It must be noted, however, that these performance measures were not created taking projected climate change impacts into account. Other recommended actions for increasing ecological resiliency to climate change are presented below.

7.3.1.1 Reduce Non-climatic Stressors in Puget Trough Eco-Region

Because a system's vulnerability to climate impacts is affected by non-climatic stresses like population growth, competition from invasive species, and development in or near sensitive habitats, climate change adaptation is more effective when both the climatic and non-climatic stresses effecting a system are addressed (Glick et al. 2009, Whitely Binder et al. 2009). Addressing non-climatic stressors like pollution, invasive species, and structures that inhibit natural sedimentation and littoral processes can increase the resilience of SOALs to climate change.

The Aquatic Resources Program is already engaged in many efforts to reduce non-climatic stresses and ensure environmental protection on state-owned aquatic lands. These management activities include:

- Aquatics Habitat Conservation Plan
- Derelict Vessel Removal Program
- Invasive Species Program
- Contaminated Site Clean Up
- Creosote Removal Program
- Collaboration with the Puget Sound Partnership

As noted above, the Program's existing management activities aimed at ensuring environmental protection provide a good starting point for making SOALs climate resilient. Given the potential magnitude of climate change impacts, however, existing efforts alone will likely be insufficient to ensure the environmental protection of state-owned aquatic lands. To increase the ecological health of the marine nearshore environment, WDNR may consider partnering with other governments and non-governmental organizations to address long-standing threats to marine ecosystem health, such as the presence of outfalls on state-owned aquatic lands. Non-point source pollution is another major non-climatic stressor that could be addressed.

7.3.1.2 Increase Restoration and Protection of Existing Habitat

Ecological resilience can also be improved by increasing restoration and protection of state-owned aquatic lands. Restoration efforts should focus on restoring or enhancing ecological function and processes, and protecting biological diversity, as healthy, biologically diverse ecosystems may be better able to withstand some impacts of climate change (Glick et al. 2009). WDNR has several tools that can be employed to protect SOALs from various uses. These tools include:

- Withdrawn Areas: WDNR's Lands Commissioner has the authority to withdraw an area from all authorized uses.
- Conservation Leasing: The Aquatic Resources Program has developed a program for Conservation Leasing, but no state-owned aquatic lands have been leased for the conservation purposes to date. WDNR should educate non-governmental organizations and foundations interested in protecting ecologically sensitive tidelands and bedlands about the Conservation Leasing Program.
- Aquatics Reserves Program

To enhance the protection afforded by the tools above, the Aquatic Resources Program could choose to partner with Washington Department of Fish and Wildlife (WDFW) to combine WDNR's authority to withdraw uses with WDFW's authority to establish "no take" areas.

7.3.2 Implement a Policy of Managed Retreat

Managed retreat (also called managed realignment) is one policy response to coastal erosion and inundation (NOAA 2009). Managed retreat allows coastal environments to migrate landward unimpeded as sea levels rise and beaches and bluffs erode. As coasts erode, waterfront structures and infrastructure are demolished and relocated farther inland, thus providing space for coastal environments (e.g., beaches, wetlands) to better respond to rising seas. Another approach to addressing sea level rise is *protection*, where protective structures like seawalls, bulkheads, and other structures are constructed to protect water front property. *Accommodation* is another approach to sea level rise, and involves modifying existing structures or habitats to accommodate changing water levels. Beach and wetlands nourishment are one way that rising sea levels and erosion may be accommodated; as beach erosion increases, or as wetlands are in danger of drowning as water levels rise, additional sediment is added to the system, thus potentially delaying the effects of erosion and rising waters. Neither protection nor accommodation are ideal responses to sea level rise. The detrimental effects of utilizing hard structures to hold back the sea have been discussed extensively earlier in this Strategy. Hard armoring can prevent erosion on the landward side of the structure, but does not prevent bank erosion on the seaward side of the structure. Beach nourishment uses dredged material to replace sediment lost through coastal erosion, thereby widening or rebuilding an eroding beach. There are ecological concerns associated with beach nourishment, and the costs are considerable (NOAA 2009). As long as the coastal environment is subject to the processes of erosion, beach nourishment may need to be repeated within a few years time. Managed retreat is also not without its challenges. Policies of retreat may be difficult to implement in the short-term, as they involve the relocation of coastal structures and infrastructure. Policies of managed retreat also require a change in how the public perceives coastline, and what it means to live on the coast. A gradual shift in public perception away from a view of coastlines as static towards a view that recognizes the dynamic and highly variable nature of coastal environments will need to occur.

Implementing a policy of managed retreat is likely to be an unpopular and politically challenging process. Even so, depending on the magnitude and rate of sea level rise, managed retreat may be the policy response to SLR that provides the most effective long-term solution. As the impacts of climate change take hold, however, the necessity of such an approach may become clear. As the steward of state-owned aquatic lands, policies that facilitate managed retreat should be encouraged by WDNR, as it the best policy response for ensuring the environmental protection of the nearshore environment as sea levels rise. If managed retreat is not facilitated, and only policies of protection (e.g., shoreline armoring) and accommodation (e.g., beach nourishment) are pursued, Washington State faces the prospect of squeezing the nearshore environment to the point of possibly losing it altogether. Caldwell and Segall (2007) provide the following example of what could occur to California's coasts as sea levels rise in the absence of a policy of managed retreat:

> Property owners, if allowed to do so, will attempt to forestall the inevitable with seawalls, rock revetments, and other barriers to the sea. But these walls, though temporarily freezing the coast in place, will have significant social and ecological costs. Beaches below the walls may be eroded away, or the thin

> ribbon of sand remaining will be blocked from the public by massive shoreline protection structures. Where estuarine marshes, which provide significant nursery habitat for many marine species, are threatened by sea level rise, coastal armoring will prevent marsh migration, leading to the eventual loss of ecosystem function. All along the coast, the direct effects of climate change may be amplified by the effects of shoreline armoring. (Caldwell and Segall 2007)

Other states that have faced erosion problems for many decades (e.g., Hawaii, Maine, North Carolina, South Carolina, Texas) have already implemented various managed retreat policies, ranging from designating setbacks and restricted areas, to developing building codes with size restrictions to allow for relocation of coastal structures as shorelines erode (Klarin et al. 1990).

7.3.2.1 Implementation of Rolling Easements

To facilitate managed retreat, WDNR could advocate for Washington State to implement setback requirements for coastal property owners. One challenge presented by setbacks, however, is that this type of regulation can result in a "takings" claim under the 5th Amendment of the U.S. Constitution if it is determined that the setback has removed reasonable use of the land. In the event of a "takings," the private property owner experiencing a loss of reasonable use must receive just compensation. Past precedent for such a "takings" exists in the case of *Lucas v. South Carolina Coastal Commission* (1992). In this case, the U.S. Supreme Court held that the setback line established by the South Carolina Coastal Council via the South Carolina Beach Front Management Act of 1988 to address erosion resulted in a "takings" of private property, as the new setback line rendered the coastal property “undevelopable” (*Lucas* 1992). The State had to compensate the coastal property owner, David Lucas, for the lost use of his property.

Rolling easements present one possible solution for balancing the two potentially conflicting goals of protecting the rights of private property owners and protecting coastlines for the benefit of the public (Petersen, 2007, Johnson et al. 1992). James Titus (1998) developed the concept of a rolling easement as a potential solution for the “takings” issue associated with setbacks. Simply put, rolling easements are policies that allow for coastal development but prohibit waterfront property owners from holding back the sea. Rolling easements place no restrictions on development. They allow coastal property owners to build, with the understanding that they will not be permitted to protect their property with the use of armoring or stabilization structures if erosion or inundation occurs. As the sea advances, the easement automatically moves or “rolls” landward. In this way wetlands, beaches, and other coastal environments can naturally migrate landward, allowing for the preservation of nearshore habitat. Public use and access of the coast is also preserved where rolling easements are in place.

Following the *Lucas* decision, South Carolina amended its Beach Front Management Act to allow for a rolling easement on any lot seaward of the setback line to avoid the need for future "takings" compensations (NOAA 2009). As a result, lots seaward of the setback line can be developed but no hard shoreline stabilization structures can be used to protect the property.

Texas has implemented a similar policy, through the Texas Open Beaches Act. This Act ensures the rights of all Texans to access the beach by requiring that owners of private beachfront property allow the public free and unrestricted access to and use of the beach (Texas Natural Resource Code 2E-61). In Texas, the line of vegetation marks the boundary between private and public ownership along the coast, just as the line of ordinary high tide marks this boundary in Washington (Texas Natural Resource Code 2E-61-001(5)). Through the Texas Open Beaches Act, this boundary designation becomes a rolling easement; as beaches erode and the line of vegetation moves landward, property that was once privately owned becomes a state-owned beach (Texas Natural Resource Code 2E-61-017(2)). If a similar act were passed by the Legislature in Washington, WDNR's ability to provide public use and access on state-owned aquatic lands would be ensured.

While a rolling easement may be established via statutory or judicial action, Caldwell and Segall (2007) argue that rolling easements are "most fundamentally rooted in common law principles - primarily the public trust doctrine" (Caldwell and Segall 2007). Caldwell and Segall (2007) also assert that since the public trust doctrine requires the state to protect its coastal resources and to hold them in perpetual trust for the people, "the doctrine provides the most fundamental basis for responding to the threats of coastal armoring" in the state of California (Caldwell and Segall 2007, p. 552). Crisman-Glass (2009) supports the argument made by Caldwell and Segall

(2007), and determines that the legal framework in Washington supports the implementation of rolling easements grounded in common law principle such as the public trust doctrine (Crisman-Glass 2009).

7.3.2.2 Establish Buffer Areas for Beach and Wetland Migration

Managed retreat of coastal environments may also be facilitated by the establishment of buffer areas that will allow for the landward migration of beaches and wetlands. The Aquatic Resources Program can work with governmental and non-governmental partners to identify possible areas where migration of coastal environments might successfully occur, and work to designate these areas as conversation or reserve areas. The current Nisqually Delta Habitat Restoration project provides one local example of how such a process might occur.[16] While the restoration of the Nisqually Delta was envisioned as a habitat restoration project, one outcome of restoring the Nisqually wetlands will be the establishment a buffer area that will allow for some degree of landward migration of wetlands as sea levels rise. WDNR should actively pursue restoration opportunities like the Nisqually Delta restoration for all low-lying coastal environments where SOALs are present. Low-lying areas of particular significance to the Aquatic Resources Program are the mudflat habitats of the outer coast bays. Mudflats are extremely susceptible to SLR; as such, the Program should begin exploring opportunities

[16] For more information on this project, see: www.fws.gov/Nisqually/ (accessed June 43, 2009)

to restore adjacent inter-tidal areas in anticipation for habitat losses that may occur as a result of sea level rise.

7.3.3 Foster New Uses of SOALs to Ensure an Ongoing Balance of "Four Plus" Public Benefits

The second priority planning area identified in this Strategy concerns WDNR's ability to ensure a balance of the "Four Plus" public benefits on state-owned aquatic lands in the context of climate change. The ability of the Aquatic Resources Program to continue ensuring environmental protection and the sustainable utilization of renewable resources may be jeopardized by projected climate change impacts. The Program should foster emerging uses of SOALs that both provide public benefits and may be less vulnerable to climate change impacts than traditional uses like shellfish aquaculture. For example, fostering the development of wave and tidal energy projects on leased SOALs could be encouraged, as hydrokinetic energy presents a new sustainable way for WDNR to foster the utilization of new renewable resources while generating revenue. Another opportunity for fostering new renewable resources and generating revenue may be through supporting the cultivation of more climate-resilient strains of shellfish for shellfish aquaculture (Huppert et al. 2009). Much more research in this area is needed, but WDNR could choose to support such research and take advantage of early findings. It is possible, for example, that geoducks may be more resilient to climate change than other types of shellfish. In a recent presentation ocean acidification expert Dr. Terrie Klinger concluded by emphasizing that climate change will prompt inevitable ecological and biological changes in our marine environments (Klinger 2009). She suggested that it will be critical for our society to begin to value the species that will be resilient that these changes (Klinger 2009). Along these lines, WDNR should take advantage of information about the resilience of individual species to climate change as it becomes available, and should actively promote the growth and utilization of these more resilient species.

7.4 Determining the Appropriate Balance of Adaptation Strategies

It has been demonstrated in this Strategy that climate change may make it challenging for WDNR to provide a balance of the "Four Plus" public benefits mandated by law in the coming decades. The Aquatic Resources Program can employ a combination of adaptive strategies to work to ensure that its management of SOALs continues to provide this balance. Adaptation literature commonly identifies three approaches to adaptation in coastal areas: (1) accommodation, (2) protection, and (3) retreat (Huppert et al. 2009). *Accommodation* approaches involve continuing with current uses in spite of changes to coastal and ocean environments, and modifying current practices or structures to adjust to these changes. Examples of accommodation include raising the height of piers and placing shoreline building on pilings (Whitely-Binder et al., Huppert et al. 2009). *Protection* approaches involve "fending off the impacts by building structures like seawalls and dikes that keep the sea from intruding on coastal structures," thus protecting the area landward of the defensive structure (Whitely Binder et al. 2009, p. 32). *Retreat* approaches involve avoiding the harmful effects of rising sea level and other projected climate change impacts by abandoning coastal sites and moving to higher ground (Whitely Binder et al. 2009). Adaptive actions that encourage approaches of accommodation and retreat have been recommended in this Strategy.[17] Actions that encourage protection have not been emphasized in this Strategy, as the focus of the Aquatic Resources Program's adaptation activities should be on protecting the state's aquatic lands, not the waterfront property that abuts them.

Determining the appropriate balance of climate change adaptation strategies will be a challenging process for the Aquatics Resources Program, as each strategy presents a number of trade-offs between public benefits that must be weighed. An adaptation policy of pure retreat would likely be the best option for providing the public benefit of ensuring environmental protection. Retreat may also allow for the sustainable management of renewable resources and the continuation of public access in the long-term. In the short-term, however, retreat could pose challenges for the utilization of resources and public access, as a policy of retreat could require the removal of any in-water or overwater structures (e.g., fishing piers, docks).

A policy of accommodation would provide for ongoing public use and access, the utilization of renewable resources, and the fostering of water-dependent uses. The trade-off associated with accommodation, however, is

[17] For actions that encourage a policy of accommodation see: 7.2.1, 7.2.3, 7.2.4, 7.3.1.1, 7.3.1.2, 7.3.3. For actions that encourage a policy of retreat see: 7.2.2, 7.3.2

that some measure of environmental protection, via loss of ecological function and resilience, will likely be lost. Pursuing a policy of accommodation also means operating in coastal environments where there will be an increasingly high risk of natural hazards. To foster water-dependent uses, and to allow for continued navigation and commerce in harbor areas, a policy of protection will have to be employed in some areas. The trade-offs of protection include a potential loss of public access, and an almost certain loss of ecological resilience. Looking forward, WDNR may want to utilize tools like marine spatial planning, or bay wide planning, to determine where these different approaches to adaptation should be implemented. Ultimately, WDNR will need to coordinate with other agencies and local governments when making these challenging decisions.

8.0 Concluding Reflections

This Climate Change Adaptation Strategy provides a climate resilient vision for the WDNR Aquatic Resources Program. This Strategy should be viewed as the Program's the first step towards developing a more detailed and comprehensive climate change adaptation effort. As a next step the Program should begin implementing some, if not all, of the recommended actions provided in Section 7 of the Strategy. This implementation process could begin with the actions aimed at building the Program's adaptive capacity. Adaptive capacity can be built regardless of the uncertainty associated with existing climate change projections and as such can be considered a "no regrets" strategy for preparing for climate change (Whitely Binder et al. 2009). The Program could also conduct vulnerability and risk assessments of more of WDNR's management activities, following the process outlined in Snover et al. (2007), and utilized in Section 4 of the Strategy. More detailed assessments of risk and vulnerability may lead to the identification of more specific priority planning areas for the Aquatic Resources Program.

In order to comply with its statutorily mandated management guidelines, WDNR must continue to proactively prepare for the projected impacts of climate change. Protecting and preserving the public benefits associated with state-owned aquatic lands in perpetuity will be increasingly challenging as climate change impacts take hold. At some point in the future, even the most innovative stewardship will likely fail to prevent the serious ecological damage that is predicted to occur if greenhouse gas emissions continue at their present rate. It is vital that WDNR pursue every avenue available to mitigate the impacts of climate change by reducing the emissions of greenhouse gases or increasing the sinks for carbon emissions. A discussion of mitigation strategies for the agency was beyond the scope of this Adaptation Strategy. Nevertheless, the agency should take every opportunity to reduce its carbon footprint as it continues to manage the state's natural resources. Engrossed Second Substitute Senate Bill 5560, "An Act relating to state agency climate leadership," requires that state agencies meet statewide greenhouse gas emission limits of 15 percent below 2005 levels by 2020. This mandate will encourage WDNR to work towards reducing its greenhouse gas emissions. The agency should also develop and promote carbon sinks whenever possible.

The Washington Climate Change Impacts Assessment provides some fundamental principles that should be considered by WDNR as it moves forward with its climate change preparedness efforts. The first principle is that there is no "one size fits all" solution for climate change adaptation (Littell et al. 2009). The second principle is that climate change adaptation is not a "one time" activity but rather is a continual process that must be constantly repeated as climate conditions (and the human responses to those conditions) change (Littell et al. 2009). The third principle is that a greater degree of regulatory flexibility and systematic integration of "governance levels, science, regulation, policy and economics" will be needed for effective adaptation (Littell et al. 2009, 19).

The formal allocation of staff time to climate change adaptation activities will allow the Aquatic Resources Program to acknowledge these first two principles as WDNR staff can work to tailor adaptation strategies to the specific needs of the Program, and can continuously revise agency actions as climatic conditions change. The issues presented in this Climate Change Adaptation Strategy highlight the importance of the third principle. Since WDNR's authority is spatially limited, (i.e., it has no authority to manage or limit activities in nearby locations, like adjacent uplands, that may negatively effect the aquatic environment), its capacity to effectively prepare for climate change impacts to state-owned lands is quite constrained. Even on state-owned aquatic lands, the authority of WDNR is limited to proprietary activities. In practice, coordination across agencies is often a cumbersome, piecemeal process. Without a formal institutional structure to facilitate interagency efforts, climate change preparation efforts will hindered by the rigidity of existing regulatory and institutional environments. A more flexible institutional and regulatory structure would greatly facilitate the ability of WDNR and other state and local entities to prepare for and respond to the impacts of climate change.

Bibliography

Bamber, J.L., Riva, R.E.M., Vermeersen, B.L.A., and A.M. LeBrocq. 2009. Reassessment of the Potential Sea-Level Rise from a Collapse of the West Antarctic Ice Sheet, Science 324, 901

Bower, J., 2007. Aquatic Lands Ownership with a Rising Sea. White paper prepared for the Washington Department of Natural Resources, Olympia, Washington

Bryant, Hon. L. P., 2008. Governor's Commission on Climate Change DRAFT Interim Report. Prepared by the Secretary of Natural Resources, Chair of Governor's Commission on Climate Change, Richmond, Virginia

Caldwell, M. and C.H. Degall. 2007. No Day at the Beach: Sea Level Rise, Ecosystem Loss, and Public Access Along the California Coast, Ecology Law Quarterly, Vol. 34: 533

Climate Impacts Group. 2009. The Washington Climate Change Impacts Assessment, edited by M. McGuire Elsner, J. Littell, and L. Whitely Binder. Report prepared by the Climate Impacts Group, Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, Washington

Coastal States Organization. 2008. The Role of Coastal Zone Management Programs in Adaptation to Climate Change. Second Annual Report of the Coastal States Organization's Climate Change Work Group

Conservation Working Group, Channel Islands National Marine Sanctuary Advisory Council. Ocean Acidfication and the Channel Islands National Marine Sanctuary: Cause, effect and response. Adopted by the CINMS Advisory Council September 19, 2008. Prepared by S. Polefka and J. Forgie, Environmental Defense Center, Santa Barbara, California

Crisman-Glass, E. 2009. The legal implications of sea level rise in Washington. White Paper prepared for the Climate Impacts Group, University of Washington, Seattle, Washington

Dethier, M.N. 2006. Native Shellfish in Nearshore Ecosystems of Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington

Doney, S.C., V.J Fabry, R.A. Feely, and J.A. Kleypas. 2009. Ocean Acidificcation: The Other CO2 Problem. Annual Review of Marine Science. 2009. 1:169-192

Engoltz, T. 2002. Potential Impacts of Climate Variability and Change on Water Quality in South Puget Sound: A Management Perspective. Masters Thesis, University of Washington, Seattle, Washington

Fabry, V.J., B.A. Seibel, R.A. Feely, and J.C. Orr. 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science*, 65: 414-431

Feely, R. A. 2009. Ocean Acidification and the Effect to Open Ocean and Coastal Ecosystems. Powerpoint presentation presentation at: Climate Change, Natural Resources and Coastal Management: A workshop on the coastal ecosystems of California, Oregon and Washington, January 30, 2009

Glick, P., Staudt, A., and B. Stein. 2009. A New Era for Conservation: Review of Climate Change Adaptation Literature. Discussion draft accessed at: http://ncseonline.org/WHPRP/NWF/Adaptation2009/Documents/ExecutiveSummaries%20.pdf (June 5, 2009)

Goodwin, C.L. and B. Pease, 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) – Pacific geoduck clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.120). U.S. Army Corps Eng., TR EL-82-4.

Goodwin, C.L. and B. Pease, 1987: The distribution of geoduck (*Panepe abrupta)* size, density and quality in relation to habitat characteristics such as geographic area, water depth, sediment type, and associated flora and fauna in Puget Sound, Washington. Dept. Fish. Tech. Rep. No. 102.

Huppert, D., A. Moore, and K. Dyson. 2009. Impacts of Climate Change on the Coasts of Washington State. In the Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington

IPCC. 2007a. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

[Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

IPCC. 2007b. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F Canziani, J.P Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK

IPCC, 2007c: Summary for Policymakers. In: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland

IPCC. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. [McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.)]. Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA

Joint Legislative Audit & Review Committee (JLARC), State of Washington. 2008: Review of the Management of State-Owned Aquatic Lands, Report 08-06. Olympia, Washington

Johannessen, J. and A. MacLennan. 2007. Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-04. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington

Johnson, R., Goeppele, C., Jansen, D., Paschal, R. 1992. The Public Trust Doctrine and Coastal Zone Management in Washington State. Washington Law Review. 67: 521-598

Johnson, Z.P. 2000. A Sea Level Rise Response Strategy for the State of Maryland. Report for the Maryland Department of Natural Resources, Coastal Zone Management Division. Annapolis, Maryland

Johnson, Z.P. 1998. Sensitivity of the Coastal Management System in Washington State to the Incorporation of Climate Forecasts and Projections. Master's thesis, University of Washington, Seattle, Washington

Kershner, J.M. 2009. Ocean Acidification in the Puget Sound – Georgia Basin Region: Causes, Impacts, and Mitigation Strategies. Masters Thesis, University of Washington, Seattle, Washington

Klarin, P., Branch, K., Hershman, M., Grant, T. 1990a. Sea level rise policy alternatives study: Volume 1, Alternative policy responses for accelerated sea level rise and their implications. Battelle Human Affairs Research Centers for Shorelands and Coastal Zone Management Program. Washington Department of Ecology. Olympia, Washington

Klarin, P., Branch, K., Hershman, M., Grant, T.1990b. Sea level rise policy alternatives study: Volume 2, An analytical review of state and federal coastal management systems and policy responses to sea level rise. Battelle Human Affairs Research Centers for Shorelands and Coastal Zone Management Program. Washington Department of Ecology, Olympia, Washington

King County. 2007. 2007 King County Climate Plan. Accessed at: your.kingcounty.gov/exec/news/2007/pdf/climateplan.pdf (June 5, 2009)

Littell, J.S., M. McGuire Elsner, L.C. Whitely Binder, and A.K. Snover (eds). 2009. The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate – Executive Summary. In The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington

Lucas vs. South Carolina Coastal Council. 1992. Supreme Count of the United States. 505 U.S. 1003

Maryland Commission on Climate Change Adaptation and Response Working Group. 2008. Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change: Phase I, Sea-level rise and coastal storms. Annapolis, Maryland

Miller, A.W., Reynolds, A.C., Sobrino, C., Riedel, G.F. 2009. Shellfish Face Uncertain Future in High CO_2 World: Influence of Acidification on Oyster Larvae and Growth in Estuaries. PLoS ONE 4(5): e55661. doi:10.1371/journal.pone.0005661

Moore, S.K., Trainer, V.L., Mantua, N.J., Parker, D., Laws, E.A., Backer, L.C., Fleming, L.E. 2008. Impacts of climate variability and future climate change on harmful algal bloom and human health. Environmental Health 7 (Suppl 2): S4

Mote, P.W., E.P. Salathé Jr. 2009. Future climate in the Pacific Northwest. In the Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, Washington

Mote, P.W., A. Petersen, S. Reeder, H. Shipman, and L.C. Whitely-Binder. 2008. Sea level rise in the coastal wasters of Washington State. A report by the University of Washington Climate Impacts Group and the Washington Department of Ecology, Seattle, Washington

Morlock, S.M. 2005. Watershed Initiatives in the Skagit River and Tillamook Bay Watersheds: An Exploratory Analysis of Planning, Implementation, and Integration. Master's thesis, University of Washington, Seattle, Washington

Mumford, T.F. 2007. Kelp and Eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington

National Marine Fisheries Service, Northwest Region, 2008: Endangered Species Act – Section 7 Consultation Biological Opinion, Conference Opinion, Unlisted Species Analysis, Section 10(a)(2)(B) Findings And Magnuson-Stevens Fisheries Conservation and Management Act Essential Fish Habitat Consultation For issuance of an Incidental Take Permit to the Washington Department of Natural Resources for Commercial Sub-Tidal Geoduck Harvest activities in Puget Sound, the Strait of Juan de Fuca and the San Juan Archipelago, Washington

National Oceanic and Atmospheric Administration (NOAA), 2009: Climate Change: How Coastal Communities Can Plan and Adapt. In *Local Strategies for Addressing Climate Change,* originally published in *Coastal Services* magazine

Noss and Cooperrider.1994. "Monitoring," in Saving Nature's Legacy: Protecting and Restoring Biodiversity, Island Press, pp. 298-324

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarimento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M. Weirig, Y. Yamanaka, and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impacts on calcifying organisms. Nature 431: 29: 681-686.-

Petersen, A.W. 2007. Anticipating Sea Level Rise Response in Puget Sound. Masters Thesis, University of Washington, Seattle, Washington

Puget Sound Nearshore Partnership. 2009. What is the Puget Sound Nearshore and What is the Problem with It? Accessed at: http://www.pugetsoundnearshore.org/what.htm#scope on June 5, 2009

RCW (Revised Code of Washington) 77-60-070

RCW (Revised Code of Washington) 79-100

RCW (Revised Code of Washington) 79-105

RCW (Revised Code of Washington) 79a-25

Royal Society. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. London: The Royal Society

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez and F. Yemin, 2007: Assessing key vulnerabilities and the risk from climate change. *Climate* Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutiko, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 779-810

Shipman, H. 2009a. The Response of the Salish Sea to Rising Sea Level: A Geomorphic Perspective. To be published in the proceedings of the Puget Sound Georgia Basin Ecosystem Conference (February 9-11, 2009), Seattle, Washington

Shipman, H. 2009b. Sea Level Rise and Coastal Impacts. Powerpoint presentation at "Planning for Climate Change," Washington Coastal Training Program, presented at the Padilla Bay National Estuarine Research Reserve, Washington on March 4, 2009

Shipman, H. 2008. A Geomorphic Classification of Puget Sound Nearshore Landforms. Puget Sound Nearshore Landforms. Puget Sound Nearshore Partnership Report No. 2008-01. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington

South Carolina Climate, Energy and Commerce Advisory Committee. 2008. South Carolina Climate, Energy, and Commerce Committee Final Report. Columbia, South Carolina. (accessed at:

http://www.scclimatechange.us/ewebeditpro/items/O60F19029.PDF on December 5, 2008)

Snover, A.K., L.C. Whitely Binder, J. Lopez, E. Willmott, J. Kay, D. Howell, and J. Simmonds. 2007. Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments. In associated with and published by ICLEI – Local Governments for Sustainability, Oakland, California

Titus, J.G. 1998. Rising seas, coastal erosion, and the takings clause: hot to save wetlands and beaches without hurting property owners. 57 Maryland Law Rev. 1279: 1316

Turner, II, B.L., Kasperson, R.E., Matson. P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A. 2003. A framework for vulnerability analysis in sustainability science. Proc. Nat'l Acad. Sci. 100(14): 8074-8079

UKCIP (United Kingdom Climate Impacts Programme). Undated. Identifying Adaptation Optons. Available at: http://www.ukcip.org.uk/images/stories/Tools_pdfs/ID_Adapt_options.pdf Accessed May 5, 2009

Union of Concerned Scientists. 2008. Climate Change in Pennsylvania: Impacts and Solutions for the Keystone State.A Climate Impacts Assessment for Pennsylvania. (accessed at: http://www.ucsusa.org/assets/documents/global_warming/Climate-Change-in-Pennsylvania_Impacts-and-Solutions.pdf on December 5, 2008)

United States Environmental Protection Agency, Maine State Planning Office. 1995. Anticipatory Planning for Sea-Level Rise Along the Coast of Maine. United States Environmental Protection Agency, Policy, Planning, and Evaluation (2122), EPA-230-R-95-900, September 1995

United States v. Washington. 898 F. Supp. 1453 (1995)

WAC (Washington Administrative Code) 220-52-19

WAC (Washington Administrative Code) 332-30

Washington's Ocean Action Plan: Enhancing Management of Washington State's Ocean and Outer Coasts: Volume 1, Final Report of the Washington State Ocean Policy Working Groups. Olympia, WA. December 31, 2006

Washington State Department of Ecology and Washington State Department of Community, Trade and Economic Development, 2008. "Leading the Way: Preparing for the Impacts of Climate Change in Washington, Recommendations of the Preparation and Adaptation Working Groups," in Leading the Way on Climate Change: The Challenge of Our Time, Olympia, Washington

Washington Department of Natural Resources (WDNR), 2009: Draft Habitat Conservation Plan, Olympia, Washington

Washington State Department of Natural Resources, 2008. Aquatic Resources Program Strategic Plan for Washington's State-owned Aquatic Lands. Olympia, Washington. Available at: http://www.dnr.wa.gov (accessed June 5, 2009)

Washington Department of Natural Resources (WDNR) and Washington Department of Fish and Wildlife (WDFW), 2008: Commercial Wild Stock Geoduck Fishery Management Plan for State-owned Aquatic Lands. Olympia, Washington

Washington Department of Natural Resources (WDNR). 2009. Natural Heritage Plan 2009 Update. Available at: http://www.dnr.wa.gov (accessed June 5, 2009)

Washington Department of Natural Resources (WDNR) Aquatic Resources Division, 2001: The State of Washington Commercial Geoduck Fishery Management Plan. Olympia, Washington

Washington State Department of Natural Resources. 1992, Reprint 1994. *Aquatic Lands Strategic Plan*. Olympia, Washington

West Coast Governors' Agreement on Ocean Health: Action Plan. 2008. The Offices of the Governors of Washington, Oregon, and California, accessed at: http://westcoastoceans.gov/ (June 5, 2009)

Whitely Binder, L.C., J.K. Barcelos, D.B. Booth, M. Darzen, M. McGuire Elner, R. Renske, T.F. Graham, A.F. Hamlet, J. Hodges-Howell, D.D. Huppert, J.E. Jackson, C. Karr, P.W. Keys, J.S. Littell, N. Mantua, J. Marlow, D. McKenzie, M. Robinson-Born, E.A. Rosenberg, C.O. Stöckle, and J.A. Vano. 2009. Preparing for Climate Change in Washington State. In The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate, Climate Impacts Group, University of Washington, Seattle, WA

Wootton, J.M., C.A. Pfister, and J.D. Forester. 2008. Dynamic patterns and ecological impacts of decling ocean pH in a high-resolution multi-year dataset. Proceedings of the National Academy of Sciences December 2, 2008 105: 48: 18848-18853

Zelo, I.J. 2000. Group Nourishment at North Beach, Samish Island: The future of Single Family Residential erosion protection in Puget Sound? Master's Thesis, University of Washington, Seattle, Washington