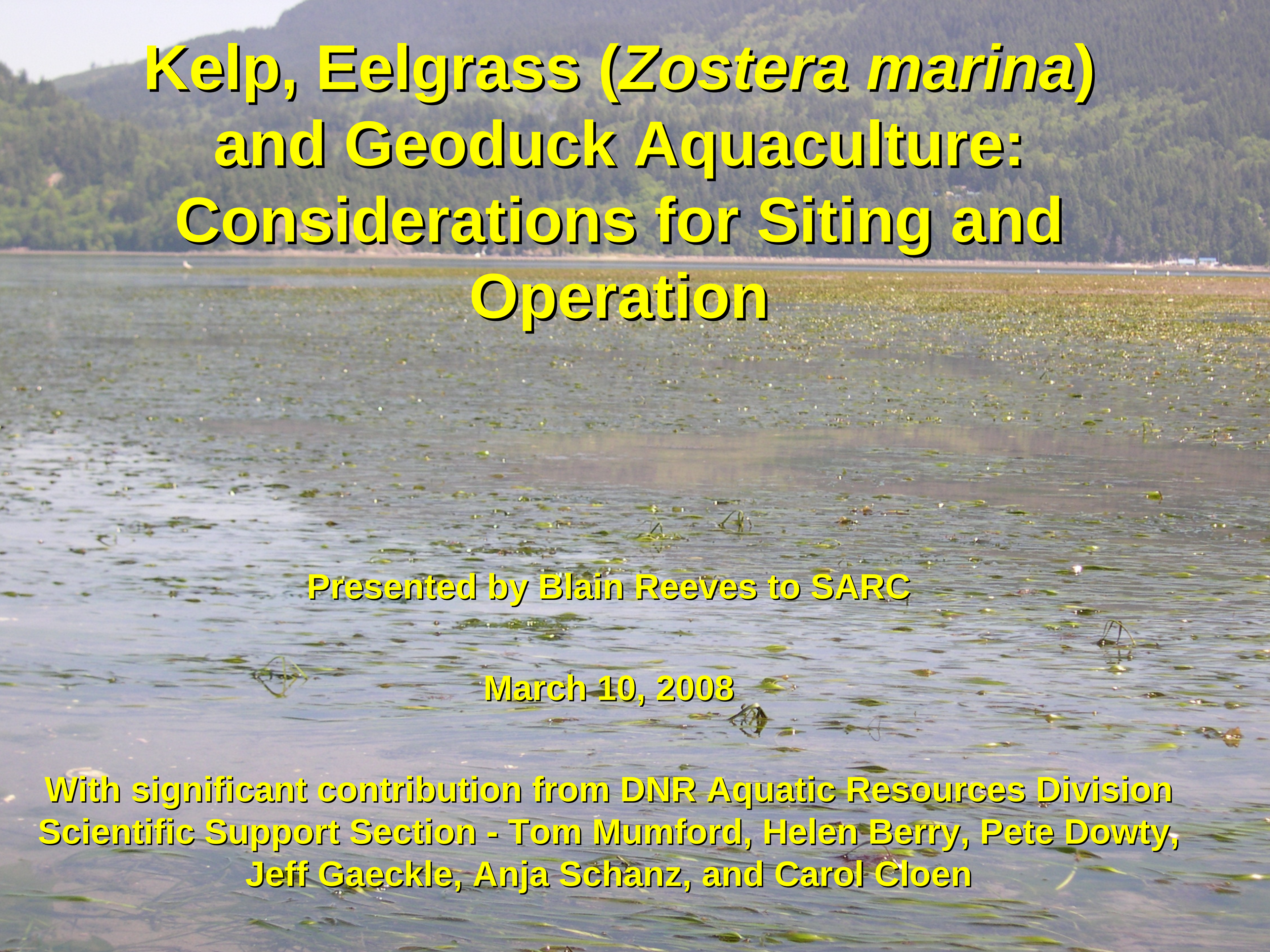
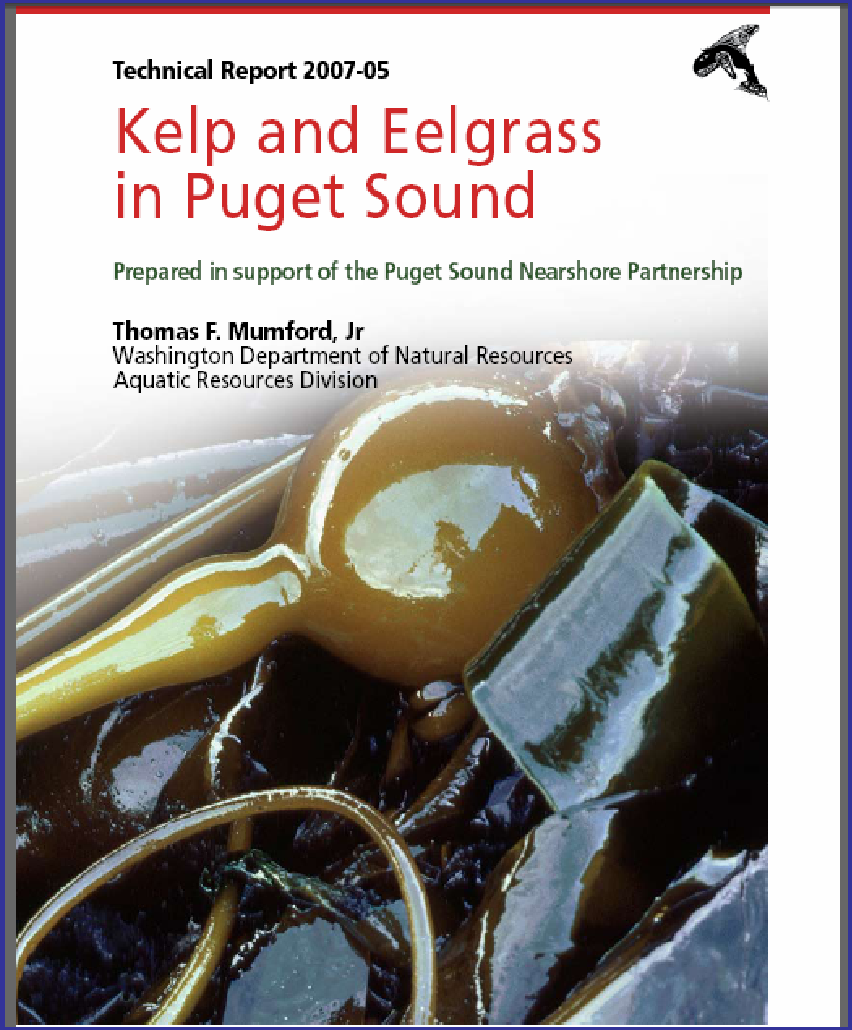

Kelp, Eelgrass (*Zostera marina*) and Geoduck Aquaculture: Considerations for Siting and Operation
Presented by Blain Reeves to SARC
March 10, 2008
With significant contribution from DNR Aquatic Resources Division Scientific Support Section - Tom Mumford, Helen Berry, Pete Dowty, Jeff Gaeckle, Anja Schanz, and Carol Cloen

Biology of Kelp and Eelgrass



http://www.pugetsoundnearshore.org/technical_papers/kelp.pdf

Kelp and Eelgrass Function

- Slow erosion and wave energy (Fonseca and Cahalan 1992)
- Increase recruitment of larval invertebrates (Reusch and Chapman 1995)
- Eelgrass remove nutrients directly (Thursby and Harlin 1982) and increase nitrogen processes (Luening et al. 1980, Flindt et al. 1999)
- Eelgrass adds oxygen to sediment (Kraemer and Alberte 1995, Goodman et al. 1995)
- Kelp remove nitrate and ammonia (Ahn et al. 1998)
- Eelgrass is a direct food source for black brant (Wilson and Atkinson 1995) and supplement the diet of other waterfowl (Baldwin and Loworn 1994)
- Kelp is direct food source for abalone and sea urchins (Shaffer 2000)
- Eelgrass provides habitat and refuge for juvenile fish (Dean et al. 2000, Pasten et al. 2003, Guido et al. 2004) and invertebrates (Armstrong et al. 1988, McMillan et al. 1995), with pinto abalone inhabiting kelp beds (Shaffer 2000, Sloan 2004).
- Eelgrass is particularly important to juvenile salmonids (Webb 1991, Shaffer 2004).
- Pacific Herring spawn predominantly within eelgrass meadows (Barnhart and Moran 1988, Rooper and Haldorsen 2000).

Kelp and Eelgrass Regulation

- Kelp and eelgrass protected under federal, state and local laws
- Kelp and eelgrass designated as critical habitat under the Critical Areas Ordinance (currently GMA but shifting to SMA)
- Commercial harvest of kelp and eelgrass prohibited everywhere in WA with one exception, herring spawn-on-kelp fishery with approval of WDFW and DNR, and personal use harvest is limited to 10 pounds per person per day with valid WDFW license (RCW 79.135.410)

DNR Kelp and Eelgrass Inventory and Monitoring Projects

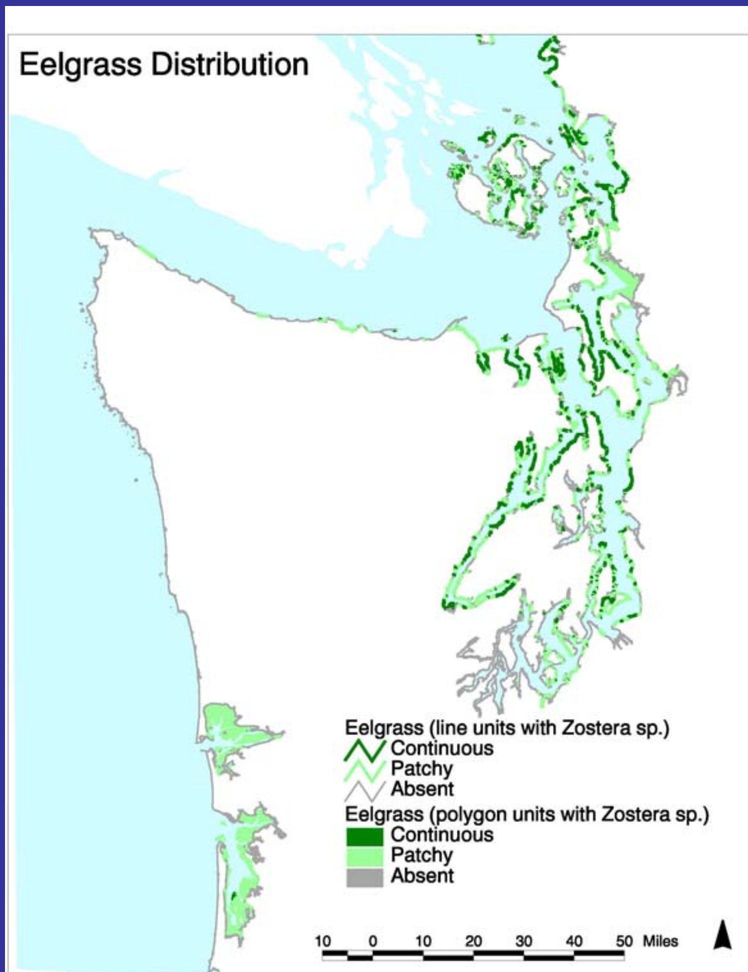
WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

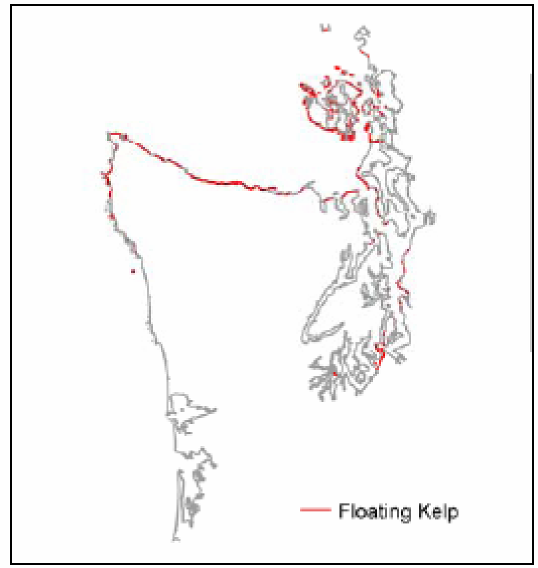
PSAMP
Puget Sound Assessment and Monitoring Program

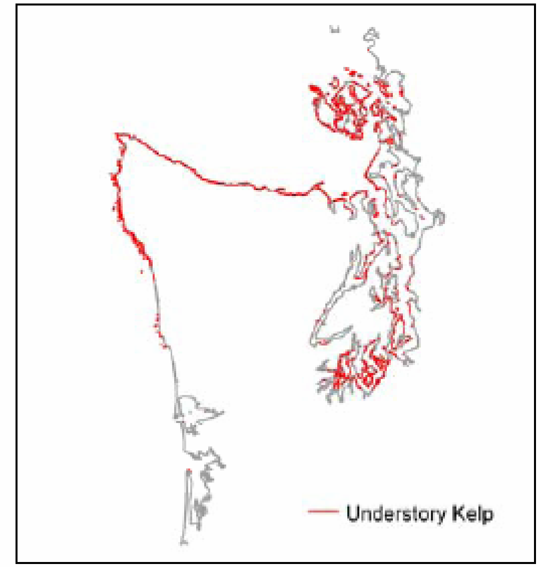
Washington State ShoreZone Inventory

http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_inventory_projects.aspx (GIS Data available for download)

Kelp and Eelgrass Distribution

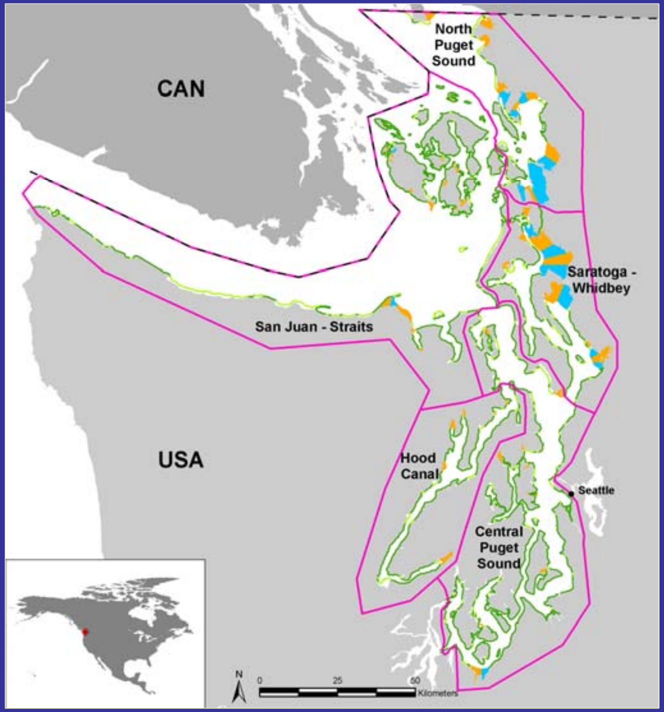






Area	Total Miles	Eelgrass	Floating Kelp	Non-floating Kelp
State	3067	37%	11%	31%

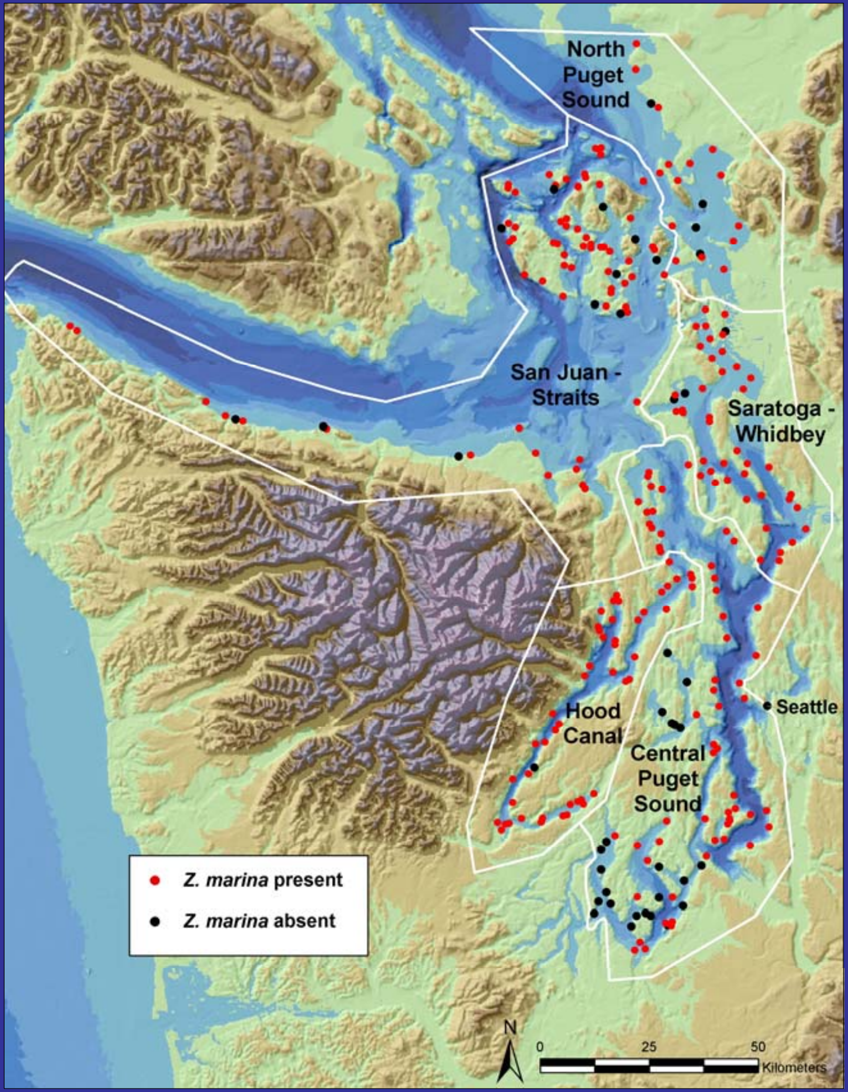
Submerged Aquatic Vegetation Monitoring



http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_eelgrass_monitoring.aspx (GIS Data available upon request)

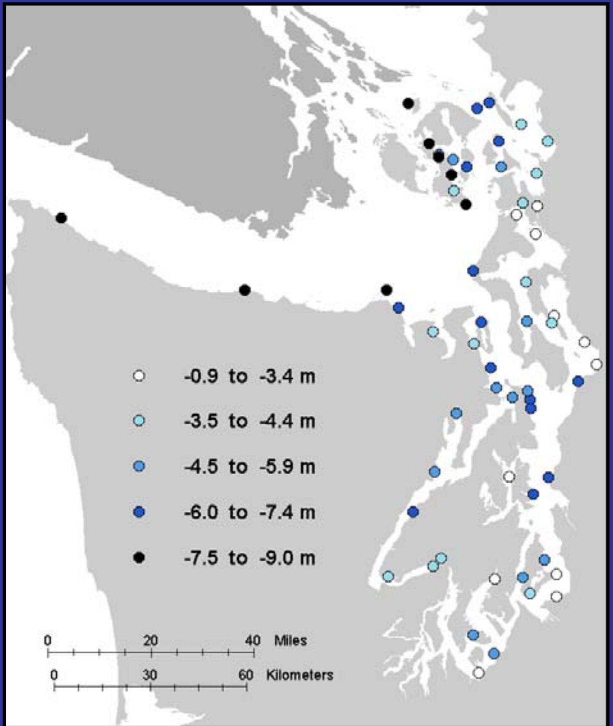
Eelgrass Area Sound-wide

- Sampled 270 sites since 2000, 230 (85%) have eelgrass
- Total *Z. marina* area in Greater Puget Sound is approximately 21,000 hectares (52,000 acres) – Thayer and Phillips (1977) estimated 50,586 hectares (125,000 acres)
- The *Z. marina* in Greater Puget Sound is evenly distributed between Flats and Fringe sites
- Greatest amount in Padilla & Samish Bays (approx. 25%)



Eelgrass Depth Sound-wide

Region	Minimum Depth (m)		Maximum Depth (m)	
	Absolute	Range in Site Means	Absolute	Range in Site Mea
Central Puget Sound	+1.6	+1.1 to -3.0	-11.9	-0.5 to -6.9
Hood Canal	+1.8	+1.1 to -1.7	-7.3	-1.4 to -4.4
North Puget Sound	+1.4	+0.6 to -3.3	-8.4	-0.7 to -6.6
San Juan-Straits	+1.5	+0.4 to -5.4	-12.4	-0.4 to -11.0
Saratoga-Whidbey Basin	+1.3	+0.5 to -1.7	-8.0	-0.3 to -4.5



Eelgrass Monitoring Project Key Findings

Puget Sound – No evidence of decline at a level that is measurable by our year-to-year analysis

Regions – Data suggest Hood Canal and San Juan / Strait of Juan de Fuca are regions of greatest concern

Sites – Strong evidence of decline identified at 18 sites throughout Puget Sound

Causal factors -

- Eelgrass Stressor Response Project
  - Investigate stressors at different spatial scales

What is Eelgrass?

Eelgrass (*Zostera marina*) is a marine plant that provides key ecosystem functions in nearshore areas. Eelgrass is used as spawning grounds by forage fish, migration corridors by juvenile salmon, and foraging areas by birds. It protects shoreline features through sediment stabilization, it produces plant material for the marine food web, and it is an important component in marine nutrient and oxygen budgets.

Eelgrass is a good indicator of environmental health because it responds to natural and human-caused environmental conditions. Losses have been documented in many estuaries in the US and around the world. Common causes of eelgrass decline include:

- Changes in water quality and water clarity
- Physical disturbance (e.g. mooring or propeller scars, dredging, development, aquaculture and fishing practices)
- High levels of sulfides in sediments
- Episodes of extremely low oxygen conditions
- Outbreaks of wasting disease

Photos of eelgrass in a healthy condition (left) and sparse eelgrass overgrown by green algae (right).

Summary

This information sheet provides an overview of the Eelgrass Stressor Response Project. We are investigating causes of eelgrass losses in greater Puget Sound. This work will guide management actions to protect and restore one of Puget Sound's critical habitats by identifying the most important stressors.

The project was established in 2005 by the Washington State Department of Natural Resources. Our research is currently focused on two areas of concern: Hood Canal and the San Juan Archipelago. Patterns of loss and suspected stressors in these areas are very different:

- In the San Juan Archipelago, losses have been restricted to small bays. Suspected stressors include low water clarity (and associated processes), and disease outbreak.
- Losses have occurred at sites throughout Hood Canal. Suspected stressors include anthropogenic nutrients and green algae blooms.

How is Eelgrass Doing in Puget Sound?

Eelgrass beds occur along approximately 43% of greater Puget Sound's shorelines. Long term monitoring by DNR's Submerged Vegetation Monitoring Project has identified two regions of concern for recent eelgrass losses: Hood Canal and San Juan Archipelago. Eelgrass declines in these regions indicate decreased nearshore habitat functions. Equally important, the stressors that have triggered eelgrass declines could impact other ecosystem components.

What is the Eelgrass Stressor Response Project?

The Eelgrass Stressor Response Project was established in 2005 to identify causes of eelgrass decline in greater Puget Sound. It is closely connected to DNR's long term eelgrass monitoring program. Both projects are part of the Puget Sound Assessment and Monitoring Program (PSAMP), a multi-agency monitoring effort that is coordinated by the Puget Sound Partnership.

Our stressor research is ongoing. The back side of this page summarizes our research findings to date. The overall finding is that there is no single, easily identified stressor causing losses; eelgrass losses are one manifestation of change in complex, interconnected ecosystems. Continuing work will aim to understand this system-level change and how it affects eelgrass.

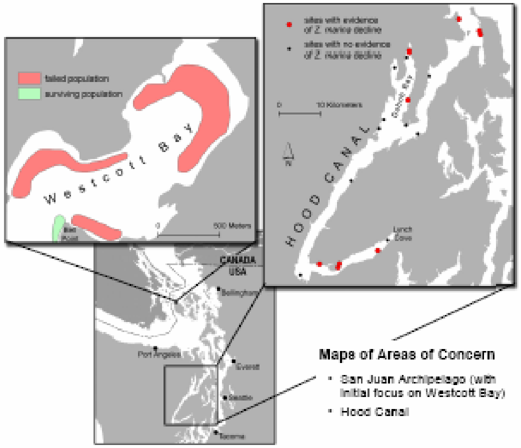
Washington State Department of Natural Resources

For more information:
Read the full report: *http://www.dnr.wa.gov/htdocs/aqr/nshr/eelgrass_stress.html*
Contact the DNR Nearshore Habitat Program: *360.902.1100, nearshore@dnr.wa.gov*
January 2008

Stressor Research

A series of collaborative projects with the University of Washington and the U.S. Geological Survey have been completed to investigate initial hypotheses concerning the causes of eelgrass decline.

Research has focused on two areas of concern that were identified by DNR's Submerged Vegetation Monitoring Program: Hood Canal and the San Juan Archipelago. Environmental conditions and eelgrass loss patterns differ greatly in these two regions, which has led to specialized research hypotheses and experiments.



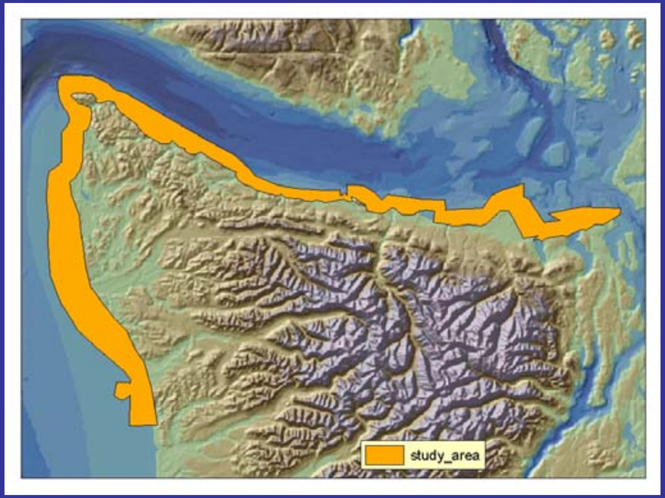
Maps of Areas of Concern

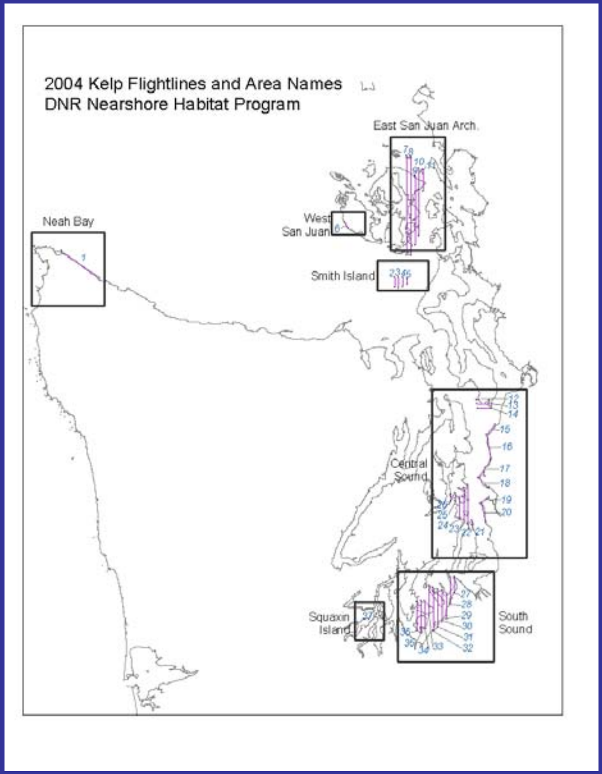
- San Juan Archipelago (with initial focus on Westcott Bay)
- Hood Canal

	Hypothesized Stressors	Highlights of Research Findings
San Juan Archipelago	Eelgrass losses have been confined to shallow embayments. The most extensive losses have been observed in Westcott Bay, where eelgrass completely disappeared from the inner bay. Our conceptual model of stressors focuses on low water clarity. This could be caused by phytoplankton blooms, turbidity plumes (tidal or wind-driven resuspension, periodic Fraser River plumes), or oyster farm detritus. Genetic isolation of populations at the heads of bays could reduce population viability. An outbreak of eelgrass wasting disease is another potential stressor.	The remnant eelgrass population in inner Westcott Bay at Bell Point has the lowest genetic diversity of all populations analyzed. Surface water sampling suggests that the Fraser River plume does not have a strong influence in the Westcott Bay area. Respiration and photosynthesis rates suggest that physiological performance of eelgrass is reduced at the site with remnant eelgrass in Westcott Bay. High resolution mapping was completed to characterize habitat conditions in Westcott Bay. These data will be used in future efforts to model sediment transport and habitat conditions.
Hood Canal	Losses occurred in multiple habitat types, throughout Hood Canal. Our conceptual model of stressors focuses on anthropogenic nutrient inputs and green algae blooms. Hood Canal is widely recognized to experience periodic low dissolved oxygen levels. This condition is commonly associated with high nutrient loads. Multiple research efforts are examining dissolved oxygen levels, causal factors, and effects on biota.	Stable isotope analysis of eelgrass leaves showed a relatively large contribution of anthropogenic nitrogen in Southern Hood Canal and Dabob Bay. This finding confirms that anthropogenic nitrogen gradients affect eelgrass bed condition and, likely, other nearshore ecosystem components. Hood Canal eelgrass populations have higher genotypic richness than in the San Juan Archipelago. The lowest genetic diversity was measured at a stable eelgrass site (Lynch Cove). This finding suggests that genetic diversity does not play a role in eelgrass decline in Hood Canal.

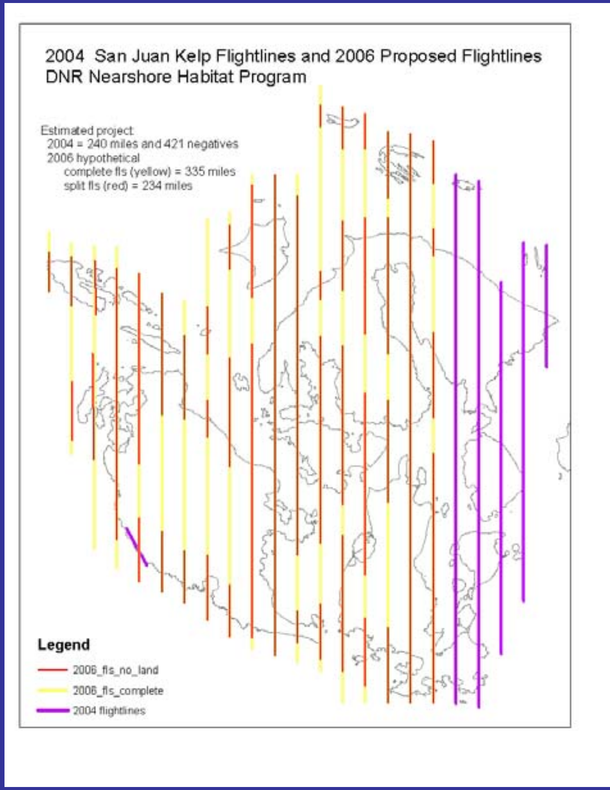
http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_eelgrass_stressor_response.aspx

Floating Kelp Monitoring





Friends of the San Juans (2007)

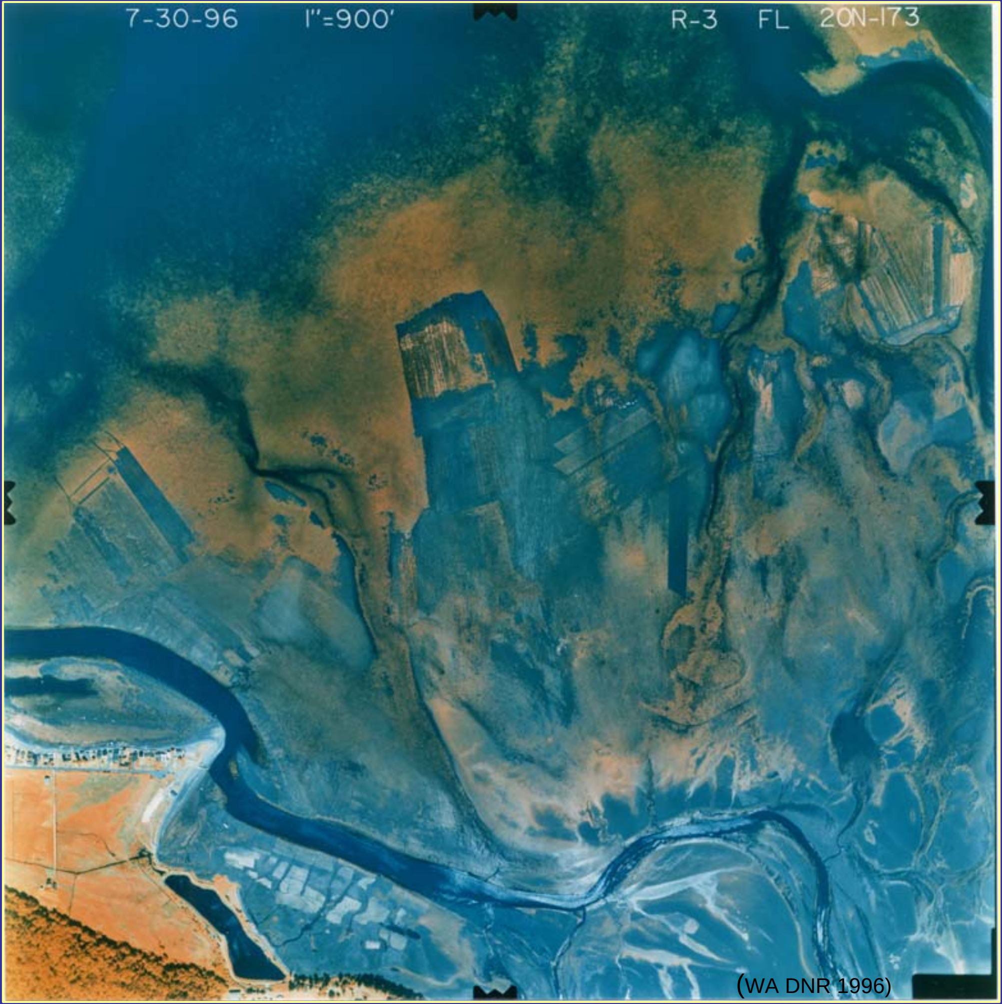


http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_kelp_monitoring.aspx (GIS Data available for download)

So, what about geoduck aquaculture siting considerations?

Human Impacts

- physical disturbance -



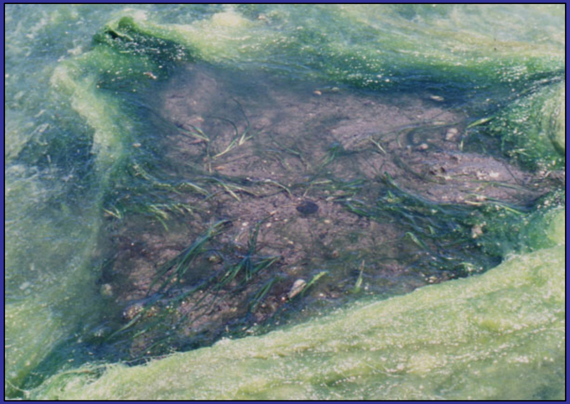
(WA DNR 1996)


(Short 1997)

– shoreline development (Short & Burdick 1996, Nielsen et al. 2000)
– sediment accumulation (Ibarra-Obando & Escofet 1987)
– boats & docks (Burdick & Short 1999)

– Aquaculture (Rumrill & Poulton 2004, Ruesink 2007)

Other Stressors



- loss of water clarity (Short et al. 1991, Zimmerman 2006)
- low oxygen (Holmer & Bondgaard 2001, Koch 2001, Greve et al. 2003, Kemp et al. 2004)
- grazing & bioturbation
  - waterfowl (Buchsbaum & Valiela 1987)
  - sand dollars (Backman 1984)
  - limpets (Zimmerman et al. 1996)
- disease
  - Labyrinthula (Short et al. 1986)
- competition with algae
  - *Ulva* (Kentula & McIntire 1986)

[formerly *Entermorpha* (Gabrielson et al. 2006)]

Recommended Guidelines for Geoduck Aquaculture Siting and Operation*

- **Site Selection**
  - Conduct vegetation survey and avoid areas with significant vegetation
- **Bed Preparation / Planting**
  - Plant an area no closer than 10 feet from an eelgrass bed (4 shoots or more per square meter)
  - Adhere to BMP’s (equipment staging, accessing site, etc.)
- **Bed Maintenance**
  - Maintain activity log and maintenance plan
  - Adhere to BMP’s (equipment staging, accessing site, etc.)
- **Harvesting**
  - < 50 feet from eelgrass - dry harvest only
  - > 50 feet from eelgrass - dry or wet harvest (divers)
- **Adaptive Management**
  - Use best available science to inform BMP’s
  - Address research gaps

*These guidelines are based on best professional judgment by the DNR Aquatic Resources Scientific Support and Operations Sections

Research Gaps

- Kelp
  - Substrate requirements for sporophytic phase
  - Degree of loss and relationship to WQ
  - Relationship to other primary producers
  - Role of fisheries
- Eelgrass
  - Substrate requirements and sensitivity to increased sedimentation rates
  - Role of degraded WQ and sensitivity to direct or indirect changes in amount of light
  - Relationship to other primary producers

Literature Cited

Ahn, O, RJ Petrell, and PJ Harrison. 1998. Ammonium and nitrate uptake by *Laminaria saccharina* and *Nereocystis leutkeana* originating from a salmon sea cage farm. Journal of Applied Phycology 10: 333-340.

Armstrong, DA., JL Armatrong, and PA Dinnel. 1988. Distribution, abundance and habitat associations of Dungeness crab, *Cancer magister* in Guemes Channel, San Juan Islands, Washington. Journal of Shellfish Research 7: 147-148.

Backman TWH. 1984. Phenotypic expressions of *Zostera* marina L. ecotypes in Puget Sound, Washington. Ph.D. Dissertation, University of Washington, Seattle, Washington. p 178.

Baldwin, JR, and JR Loworn. 1994. Habitats and tidal accessibility of the marine foods of dabbling ducks and brant in Boundary Bay, British Columbia. Marine Biology 120: 627-638.

Barnhart, RA, and D. Moran. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific southwest). Pacific herring. Fish and Wildlife Service Biological Report 82 (11.79).

Buchsbaum R, Valiela I. 1987. Variability in the chemistry of estuarine plants and its effect on feeding by Canada geese. Oecologia 73:146-153.

Dean, TA, L Haldorson, DR Laur, SC Jewett, and A Blanchard. 2000. The distribution of Nearshore fishes in kelp and eelgrass communities in Prince William Sound, Alaska: associations with vegetation and physical habitat characteristics. Environmental Biology of Fishes 57: 271-287.

Flindt, MR, MA Pardal, AI Lillebo, I Martins, and JC Marques. 1999. Nutrient cycling and plant dynamics in estuaries: a brief review. Acta Oecologia 20:237-248.

Fonseca, MS, and JA. Cahalan. 1992. A preliminary evaluation of wave attenuation by four species of seagrass. Estuarine, Coastal and Shelf Science 35: 565-576.

Gabrielson PW, Widdowson TB, Lindstrom, SC. 2006. Keys to the seaweeds and seagrasses of southeast Alaska, British Columbia, Washington and Oregon. PhycoID, 7, p 209.

Greve TM, Borum J, Pedersen O. 2003. Meristematic oxygen variability in eelgrass (*Zostera marina*). Limnol Oceanogr 48:210-216.

Goodman, JL, KA Moore, and WC Dennison. 1995. Photosynthetic responses of eelgrass (*Zostera marina* L.) to light and sediment sulfide in a shallow barrier island lagoon. Aquatic Botany 50: 37-47.

Guido, P, M Omori, S Katayama, and K Kimura. 2004. Classification of juvenile rockfish *Sebastes inermis,* to *Zostera* and *Sargassum* beds, using the macrostructure and chemistry of otoliths. Marine Biology 145: 1243-1255.

Holmer M, Bondgaard EJ. 2001. Photosynthetic and growth response of eelgrass to low oxygen and high sulfide concentrations during hypoxic events. Aquat Bot 70:29-38.

Kemp WM, Batiuk R, Bartleson R, Bergstrom P, Carter V, Gallegos CL, Hunley W, Karrh L, Koch EW, Landwehr JM, Moore KA, Murray L, Naylor M, Rybicki NB, Stevenson JC, Wilcox DJ. 2004. Habitat requirements for submerged aquatic vegetation in Chesapeake Bay: Water quality, light regime, and physical-chemical factors. Estuaries 27:363-377.

Kentula ME, McIntire CD. 1986. The autecology and production dynamics of eelgrass (*Zostera marina* L.) in Netarts Bay, Oregon. Estuaries 9:188-199.

Koch EW. 2001. Beyond light: physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. Estuaries 24:1-17.

Kraemer, GP and RS Alberte. 1995. Impact of daily photosynthetic period on protein synthesis and carbohydrate stores in *Zostera marina* L. (eelgrass) roots: implications for survival in light-limited environments. Journal of Experimental Marine Biology and Ecology 185: 191-202.

Luening, K. 1980. Photobiology of seaweeds: Ecophysiological aspects. International Seaweed Symposium, Goeteborg, Sweden, 11 Aug 1980.

McMillan, RO, DA Armstrong, and PA Dinnel. 1995. Comparison of intertidal habitat use and growth rates of two northern Puget Sound cohorts of 0+ age Dungeness crab, *Cancer magister.* Estuaries 18: 390-398.

Pastén, GP, S Katayama and M Omori. 2003. Timing of parturition, planktonic duration and settlement patterns of the black rockfish, *Sebastes inermis.* Environmental Biology of Fishes 68: 229-239.

Reusch, TBH, and ARO Chapman. 1995. Storm effects on eelgrass (*Zostera marina* L.) and blue mussel (*Mytilus edulis* L.) beds. Journal of Experimental Marine Biology and Ecology 192: 257-271.

Rooper, CN and LJ Haldorson. 2000. Consumption of Pacific herring (*Clupea pallasi*) eggs by greenling (Hexagrammidae) in Prince William Sound, Alaska. Fishery Bulletin 98: 655-659.

Ruesink, J. 2007. Geoduck clam (*Panopea abrupta*) aquaculture as press and pulse perturbations to eelgrass (*Zostera marina*), Presentation at NW Workshop on bivalve Aquaculture and the Environment, sponsored by Washington SeaGrant.

Rumrill, SS, and VK Poulton. 2004. Ecological role and potential impacts of molluscan shellfish culture in the estuarine environment of Humboldt Bay, CA. Western Regional Aquaculture Center Annual Report, 2004.

Shaffer, JA. 2000. Seasonal variation in understory kelp bed habitats of the Strait of Juan de Fuca. Journal of Coastal Research 16: 768-775.

Shaffer, A. 2004. Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. 2003 Georgia Basin/Puget Sound Research Conference Proceedings. Feb 2004.

Short FT, Jones GE, Burdick DM. 1991. Seagrass decline: problems and solutions. Coastal Wetlands, Coastal Zone '91 Conference – ASCE, Long Beach, CA, p439-451.

Short FT, Mathieson AC, Nelson JI. 1986. Recurrence of the eelgrass wasting disease at the boarder of New Hampshire and Maine, USA. Mar Ecol Prog Ser 29:89-92.

Sloan, NA 2004. Northern abalone: using an invertebrate to focus marine conservation ideas and values. Coastal Management 32: 129-143.

Thayer, G and RC Phillips. 1977. MFR Paper 1271. From Marine Fisheries Review. Vol. 39, No. 11.

Thursby, GB, and MM. Harlin. 1982. Leaf-root interaction in the uptake of ammonia by *Zostera marina*. Marine Biology 72: 109-112.

Webb, DG. 1991. Effect of predation by juvenile Pacific salmon on marine harpacticoid copepods. I. Comparisons of patterns of copepod mortality with patterns of salmon consumption. Marine Ecology Progress Series 72: 25-36.

Wilson, UW, and JB Atkinson. 1995. Black brant winter and spring-staging use at two Washington coastal areas in relation to eelgrass abundance. The Condor 97: 91-98.

Zimmerman RC. 2006. Light and photosynthesis in seagrass meadows. In: Larkum AWD., Orth RJ., Duarte CM., (eds) Seagrasses: Biology, Ecology and Conservation. Springer, Dordrecht, p 303-321.