Research Priorities for Nearshore Algae in Coastal British Columbia Workshop and Gap Analysis - Final Report

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A Workshop to discuss research priorities and collaborative opportunities for nearshore macroalgae research in coastal British Columbia was held at the Department of Fisheries and Oceans' Pacific Science Enterprise Centre on February 27, 2018. Twenty regional experts in phycology, algal habitat mapping, kelp restoration and fish habitat managers attended. Eleven presentations were given, providing the group with an overview of aspects of phycological science in British Columbia and Puget Sound. This report presents conclusions of group discussions on key questions on the status of knowledge on macroalgae ecology, kelp bed mapping, kelp restoration and opportunities for future collaborative research at the Pacific Science Enterprise Centre. Also presented are the extended abstracts of the talks, additional information and references.

RÉSUMÉ

Levings, C.D., and Stewart, H.L. 2020. Research Priorities for Nearshore Algae in Coastal British Columbia Workshop and Gap Analysis – Final Report. Can. Manuscr. Rep. Fish. Aquat. Sci. 3191: iv + 26 p.

Le 27 février 2018, Pêches et Océans Canada a tenu à son Centre d'Entreprise des Sciences du Pacifique un atelier visant à discuter des priorités et des possibilités de collaboration pour la recherche concernant les macroalgues littorales sur les côtes de la Colombie-Britannique. Au total, 20 experts régionaux en algologie, en cartographie de l'habitat des algues, en restauration du varech et en gestion de l'habitat du poisson ont participé à cet atelier. Pour donner au groupe un aperçu des aspects de l'algologie en Colombie-Britannique et dans le détroit de Puget, 11 présentations ont été données. Ce rapport présente les conclusions des discussions de groupe sur l'état des connaissances liées à l'écologie des macroalgues, à la cartographie des gisements de varech, à la restauration du varech et aux occasions de recherche collaborative future au Centre d'Entreprise des Sciences du Pacifique. Des résumés approfondis des discussions, des renseignements supplémentaires et des références sont aussi présentés.

1.0 INTRODUCTION

A Workshop to discuss research priorities and collaborative opportunities for nearshore macroalgae research in coastal British Columbia (BC) was held at the Department of Fisheries and Oceans' Pacific Science Enterprise Centre on February 27, 2018. The purpose of the meeting was to exchange information on various aspects of phycological science in British Columbia and to explore opportunities for collaborative algal research among attendees (Tables 1 and 2). The intent of the Workshop was to forge working relationships between researchers, practitioners, and stakeholders. This report presents conclusions of group discussions on key questions developed by organizers Colin Levings and Hannah Stewart and an overview of the status of knowledge on macroalgae ecology, kelp bed mapping, and kelp restoration in the region. Based on the discussions, suggestions are given for future collaborative research at the Pacific Science Enterprise Centre in this field of study.

2.0 QUESTIONS POSED AT THE WORKSHOP AND RESPONSES BASED ON PRESENTATIONS, DISCUSSIONS, AND BREAKOUT GROUPS

Several methods were used to develop responses to a series of questions developed by the Workshop organizers. Where information relevant to them was given in a presentation and/or the speaker's abstract, it was integrated into the answers. Other pertinent information was added to provide further perspective and references. This additional information was selected by the first author of this report and must be viewed as limited, as a comprehensive literature search was not within the scope of the project. Material from the question and answer session for each presentation was consulted from notes taken at the meeting. Following the presentations, participants met in two small groups and discussed possible answers to the workshop questions. A note taker recorded the responses for each group and the notes were consulted. Finally, presentations from a related Workshop (DFO Nearshore Habitat Productivity Workshop and Gap Analysis, Pacific Science Enterprise Centre, February 22-23, 2018) were reviewed and relevant information has been cited.

2.1 What is the current knowledge of the structure and function of macroalgae communities in coastal British Columbia? In particular what organisms (invertebrates, fishes, and marine mammals) are dependent on these communities?

The structure of macroalgae communities in coastal British Columbia is only well known in a few locations where long term or intensive studies have been conducted. However, knowledge is accruing as there has been an increase in the number of projects in the past decade or so as coastal ecology has received more emphasis for conservation and fisheries management needs. Describing macroalgae communities in the region is complex. About 615 native species have been reported from the Pacific coast of Canada (Gabrielson and Lindstrom 2018). 340 species were found on Calvert Island, Central Coast (Martone, Appendix A). Comparisons of the structure of macroalgae communities in Washington State are instructive as the Salish Sea waters are contiguous. The intertidal marine algal flora of Washington is relatively well known. Less well known is the subtidal flora, especially crustose coralline algae (CCA) and fleshy crusts. Molecular taxonomy will continue to find cryptic species, but more importantly will allow us to study the cryptic life history phases (i.e. kelp gametophytes and other seasonal/annual species) and just small "macrophytes" (Mumford, Appendix A).

Both subtidal and intertidal macroalgae community structure have been described in detail on the west coast of Vancouver Island, notably in Barkley Sound by researchers from the Bamfield Marine Science Centre (e.g. Neufeld, Appendix A). Recent detailed studies of the bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*) ecosystem on the outer coasts have also been conducted on Haida Gwaii (Trebilco et al. 2014a), Calvert Island (Martone, Appendix A), and in synoptic surveys in several areas in the region (Lessard, Appendix A). In recent years fewer studies have been conducted in the Strait of Georgia/north Salish Sea. Exceptions are the detailed studies in Howe Sound where the complex sunflower sea star (*Pyncopodia helianthoides*)-green sea urchin (*Strongylocentrotus franciscanus* .)-fringed sieve kelp (*Neoagarum fimbriatum*) interactions are being studied (Borden, Appendix A). There are also decade-scale data on invertebrates and macroalgae from surveys in Howe Sound maintained by the Vancouver Aquarium Marine Science Centre and these are ongoing. In the 1970s, Dr. Ron Foreman initiated several detailed studies of bull kelp and algae communities on Bath Island, one of the northern Gulf Islands [1].

There have been relatively few investigations of invasive (alien) species of macroalgae on coastal British Columbia. Lindstrom (1999, summarized in Levings et al. 2002) listed 22 species of alien or cryptogenic species from the Strait of Georgia. The invasive red algae *Mazzaella japonica* is now a dominant species in Baynes Sound (Holden et al. 2017; Pawluk, Appendix A). Several studies have been conducted on the ecological effect of the Japanese wire weed (*Sargassum muticum*) which is widespread on outer and inner coasts (e.g. Barkley Sound; White and Shurin 2011). Shellfish aquaculture is thought to be major vector for invasive macroalgae in the Salish Sea (Mach et al. 2017) but other sources such as ships' ballast water cannot be discounted.

There has been some research in selected localities in coastal BC where functional relationships between macroalgae and invertebrates have been described. A complete literature search on this topic is beyond the scope of this report; however, a brief overview is given below.

As well as providing structure and habitat for invertebrates, macroalgae is one of the key basal foods for animals, with giant kelp for example providing 670 – 1300 $g \cdot m^{-2} \cdot y^{-1}$ (global estimate from Reed and Brzezinski, 2009). Macroalgae is directly grazed by invertebrates such as northern abalone (*Haliotis kamtschatkana*) (Sloan and Breen 1988), red sea urchins (*Strongylocentrotus droebachiensis)* (Breen et al. 1982), chitons (Martone presentation), and a myriad of other invertebrates. Macroalgae detritus can also subsidize pelagic-based productivity in the near field coastal zone (Ramshaw et al. 2017). The detrital food pathway is facilitated by heterotrophic bacteria on kelp detritus (Lemay et al. 2018). Grazing on kelp may affect the whole ecosystem in a trophic cascade when various predators are involved (e.g. sunstar-green sea urchin-fringed sieve kelp in Howe Sound - Schultz et al. 2016).

Habitat provision for invertebrates is a key ecosystem function of kelp and macroalgae beds along the coast, as emphasized by several speakers (Appendix A). As an example, early life stages (newly settled juveniles) of spot prawns (*Pandalus platyceros)* in Howe Sound use fringed sieve kelp as habitat (Borden, Appendix A). Volunteer divers from the Pacific Marine Life Surveys developed a unique database for the Salish Sea that showed the overlapping distributions of seaweed and invertebrates in numerous areas (Lamb et al. 2011).

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[1] [1] After the Workshop agenda was developed a report and reference list on the extensive macroalgae research and monitoring conducted by Dr. Ron Foreman in the 1970s, (with updates to the 1990s and 2000s) at Bath Island, Salish Sea - Strait of Georgia was kindly provided to the organizers by Dr. Sandra Lindstrom, Botany Department, University of British Columbia. Entitled the History of Bath Island surveys by Ron Foreman and Associates this report is available by contacting Dr. Lindstrom (Sandra.lindstrom@botany.ubc.ca).

There have been relatively few studies on the direct relationships between fish and macroalgae in British Columbia but clearly a wide variety of fish species are reliant on the kelp ecosystem, using the plants as habitat and a feeding locale (Trebilco et al. 2014b). An early study by Leaman (1980) found 44 species of fish in and around a bull kelp bed in Barkley Sound. The abundance of fish in a giant kelp bed in the same region declined when an *El Nino* event decreased the number of understory algae species in the bed (Lessard, Appendix A and presentation). Rockfishes are indirectly affected by the red sea urchin-kelp-sea otter interaction, as documented by Markel and Shurin (2015) in their study areas on the west coast of Vancouver Island. More rockfish species were present in areas where sea otter (*Enhydra lutris*) controlled urchin populations and thus allowed giant kelp growth. Use of bull kelp beds by salmonids is an area which is currently in progress in a study in the Gulf Islands. Preliminary results by Schroeder and Nahirnick (2017) showed that Chinook salmon (*Oncorhynchus tshawytscha*) smolts were found in bull kelp beds, mainly around the periphery of the beds. Recent listing of Puget Sound rockfish species (*Sebastes* spp.) has highlighted the importance of kelp beds. Linkages to forage fish and salmonids are being studied in Puget Sound (Mumford, Appendix A).

As currently understood the relationships between marine mammals and macroalgae are mainly mediated through invertebrate food supplies but kelp can provide habitat for some marine mammal species. The interaction between red sea urchin grazing on kelp and the trophic cascade resulting from predation by the urchins by sea otter is a trophic interaction which has received considerable attention since sea otters were reintroduced into BC waters in 1978 (e.g., Breen et al. 1982; Watson 2000). Recently in California, it was reported that kelp beds provide refuge from shark predation to sea otters (Nicholson et al. 2018).

2.2 What is the current state of macroalgae mapping along coastal British Columbia? Have macroalgae communities in coastal British Columbia changed in the past few decades and if so what is current thinking on reasons why? What is the magnitude of the change in terms of spatial coverage?

Some of the earliest bull kelp mapping in the Strait of Georgia was conducted by Cameron in 1916, who observed 125 beds on the southeast side of Vancouver Island between Victoria and Nanaimo (cited in Levings and Thom 1994). Although there have been no systematic surveys of the beds over the past century, there is evidence from citizen scientist groups that strongly suggest bull kelp beds have decreased in extent over the past few decades in the Strait of Georgia. This may be due to increased seawater temperatures (Heath, Appendix A). Green sea urchin grazing is also responsible for decreases in bull kelp beds as documented near Gabriola Island (Foreman 1977) and Howe Sound (Borden, Appendix A). The magnitude (areal extent) of these changes is not known. Studies are now underway with satellite imagery to map and monitor bull kelp bed changes in the Salish Sea and this technique has great promise improving our understanding of temporal changes (Costa and Schroeder 2018). There are challenges to mapping kelp in major harbours such as Vancouver harbour due of area congestion and development creating limitations to shoreline access (Ogston, Appendix A).

Macroalgae maps for the entire BC coast were prepared under the auspices of the British Columbia Marine Conservation Analysis group (BCMCA) following protocols recommended by a group of marine plant specialists who met in 2007 (Mason, Appendix A; Ban et al. 2013). These maps do represent baseline data for assessment of change, at least for presence or absence of species. Maps were generated from a variety of sources (e.g. UBC herbarium records, Province of BC kelp bed surveys, information from experts) and are online at https://bcmca.ca/journal. The BCMCA operated 2006-2013 and the maps are hosted by the Community Mapping Network. Except for kelp “bioband” data from the Province of BC (Cook 2018), no new map data have been added to the maps since 2013 and there are only volunteer initiatives to systematically update the maps (Mason, Appendix A). An exception is the recently started project on habitat mapping in Howe Sound (Fiona Beatty, Ocean Wise Conservation Association, pers comm).

A few localized studies have examined temporal changes in bull kelp beds on the west coast of Vancouver Island but these projects did not consider broad scale areal changes. *El Nino* events were related to algal community changes on the west coast of Vancouver Island (Milligan et al. 1999; Lessard, Appendix A). Using the excellent baseline data on macroalgae communities near Bamfield developed by Louis Dreuhl, Neufeld (Appendix A) showed that temporal change analyses has to include habitat considerations, especially exposure.

The comprehensive ecological programs recently launched by the Hakai Institute at their Calvert Island study area offer great potential for assessing canopy kelp changes on the Central Coast of BC and methods developed there are applicable elsewhere in the region. Satellite imagery from Landsat and World View sources is used and results are ground-truthed by SCUBA and UAV (unmanned aerial vehicle) surveys (Reshitnyk and Hessing-Lewis, Appendix A). Although the current emphasis is on canopy kelps, major intertidal species (e.g. rockweed (*Fucus* spp.)) could be able to be mapped as well if their texture is sufficiently different from the other species to be detected by these methods. Important baseline studies on macroalgae community structure at the detailed taxonomic level on Calvert Island provide valuable data for future comparisons (Martone, Appendix A), including physical (voucher) specimens for future comparisons. In the long term, results are to be scaled up to provide information on spatial and temporal changes coast-wide (Hessing-Lewis et al. 2018).

Kelp bed mapping usually focuses on the species with floating fronds because the perimeters of their beds can be mapped directly from the surface or from aerial/satellite data (see above). There are many other important taxa in the intertidal zone and shallow subtidal which are important invertebrate habitats. The DFO scheme for habitat mapping includes observations on percent cover for canopy, understory, turf and encrusting algae, using SCUBA in the low intertidal to 20 m depth (Lessard, Appendix A).

The geographic distribution of kelp in Puget Sound is better known relative to British Columbia and there are several untapped data sources in Washington State. Mapping of floating canopy-forming species of kelp (*Macrocystis pyrifera/Nereocystis luetkeana*) has been done since the late 1800's. Changes in the abundance of these two seem to correlate to the distance from the open ocean. The more urbanized areas in Central and South Puget Sound are experiencing the greatest losses. Little is known about the distribution and abundance of the remaining 21 (or so) species of kelp, especially in the subtidal. Hence the changes in the contribution of biogenic habitats and productivity are not known. There are many studies, especially in the Washington area of the Friday Harbor Laboratories that have not been well analyzed for historical data. Sources include herbarium specimens, student reports, environmental impact surveys, Washington Department of Fish and Wildlife herring rake data as well Traditional Ecological Knowledge from Native Americans and other fishers (Mumford, Appendix A).

2.3 What are the implications for nearshore ecosystems and food webs (involving invertebrates, fishes, marine mammals) of the macroalgae changes?

<u>Ecosystems and food webs</u>: The implications of the macroalgae changes for BC coast ecosystems are understudied at present, except for several studies on the sea otter-urchin-kelp interaction (see above). The implications of changes for coastal food webs were described by a breakout group at the Workshop as "huge". There are important baseline studies available for several areas on the coast (e.g. Indian Arm, Druehl 1965; northeast coast of Vancouver Island, Scagel 1961; Juan de Fuca Strait, Widdowson 1965) Strait of Georgia (see footnote 1) and further work is needed to identify other historical studies. However

except for a few areas such as Bamfield and Howe Sound and southwest Vancouver Island (Harley 2018) there have been no long term time series and only a few experimental studies to examine the implications of macroalgae changes. Recent biodiversity baseline studies and monitoring programs initiated by the Hakai Institute at Calvert Island (Hessing-Lewis et al. 2018) will be very useful in this regard. As well, given the importance of physical and chemical variables such as temperature, salinity, light, nutrients and pH there is a need to link the dynamics of macroalgae communities to regional oceanographic programs (Reshitnyk and Hessing-Lewis, Appendix A).

Invertebrates: Although there has been limited comprehensive food web study of kelp or other macroalgal communities in British Columbia (but see Trebilco et al.'s 2014 summary of baseline kelp forest community surveys in Haida Gwaii) the critical importance of these marine plants in nearshore food webs can be inferred from the numerous studies done in other temperate oceans. The comprehensive studies at Calvert Island by researchers at the Hakai Institute (Hessing-Lewis et al. 2018) will provide important data for the region.

There have been a number of local studies that have looked at some key food web connections. In addition to investigations of the direct grazing links to macroinvertebrates such as urchins and northern abalone (referred to above), there have been ecological studies of small grazers such as limpets (Saltspring Island, Kordas et al. 2017) and marine snails (Bamfield, Heaven and Scrosati 2004) in British Columbia. These smaller grazers mainly feed on gametophytes or sporeling stages of bull kelp but some crustacean amphipods feed on kelp detritus or after kelp blades have been grazed by other invertebrates (e.g. gastropods, see Chess 1993). Food web linkages via algae detritus are increasingly recognized using stable isotope analyses (Miller et al. 2018; Romanuk and Levings 2005). Decaying kelp and macroalgae (wrack) also contribute to the beach food web. Richards (1984) study at Bamfield of staphyilined beetles feeding on amphipods which in turn feed on decaying kelp and investigations of food web connections between wrack, invertebrates, and shorebirds in California (Dugan et al. 2003).

Fishes: There are many habitat-related connections to kelp and macroalgae. The seaweeds can provide cover from predators as well as provide food via invertebrates associated with them (e.g. Lessard, Appendix A). Thus changing macroalgae habitat could affect fish productivity. Trebilco et al. (2014b) found that bull kelp canopy density was related to fish biomass (greenlings and rockfish) in studies on the east coast of Haida Gwaii. Preliminary data suggest juvenile salmon were more abundant in kelp beds relative to non-kelp areas in the Salish Sea Gulf Islands (Schroeder and Nahirnick 2017). Other functional values include provision of spawning habitat for herring (*Clupea pallasii*) kelp, rockweed and a variety of other macroalgae (Lessard, Appendix A) as well as intertidal fish such as the sharpnose sculpin (*Clinocottus acuticeps*) (Marliave 1981). Louis Dreuhl (1967) noted in recent years about 20 tonnes of kelp were harvested in the herring roe on kelp fishery, as licensed by the Province of BC. There is some evidence that certain intertidal fish feed directly on algae or perhaps ingest algae in when feeding on epifaunal invertebrates. Green algae (likely *Ulva* spp) were found in about one-third of the coxcomb prickleback stomachs (*Anoplarchus purpurescens*) examined by Peppar (1965) from a study area at Second Narrows, Burrard Inlet. Intertidal macroalgae such as rockweed (*Fucus distichus*) also provide cover and protection from desiccation for littoral fish such as the cockscomb prickleback in Howe Sound (Maniwa 1997).

The relationships between marine mammals and macroalgae are mainly mediated through invertebrate food supplies and possibly habitat (Nicholson et al. 2018). As with other animals, change in macroalgae has implications for survival and productivity.

2.4 What does the future hold for macroalgae communities in coastal British Columbia? If their structure and function is reduced relative to earlier decades is restoration required and if so is it feasible?

It is highly likely that macroalgae communities will change their structure and function owing to; climate change (e.g. Wernberg et al. 2018), invasive species (Pawluk, Appendix A), sea level rise (Harley et al. 2012) anthropogenic effects such as environmental contaminants (e.g. Marsden et al. 2003); and habitat loss from conversion of rocky shorelines to wharves and docks (Ogston, Appendix A). Temperature increases are probably a major driver, notably for bull kelp in the Salish Sea where prolonged periods (over 30 days) of surface temperature > 17 º C are limiting to this species (Heath et al., Appendix A; Bisgrove and Schiltroth, Appendix A). In general however, there is critical need for more detailed data on the limiting factors for macroalgae, especially the intermediate (gametophyte) life history stages. Effects are likely to be cumulative.

In areas such as the Salish Sea where bull kelp beds have decreased in extent in past few decades citizen scientists are involved in major projects to restore these habitats, for example off Comox (Heath et al., Appendix A). The restoration of kelp as salmon habitat is the rationale for the latter work but wave dampening and erosion control are other reasons. Restoration appears to be feasible using "floating rope and anchor" technology and other methods practiced by commercial kelp growers (Dreuhl, Appendix A). However there can be specific problems (e.g. kelp crab (*Pugettia gracilis*) grazing on young plants (Heath presentation)and further testing is needed. Looking more broadly, long term data in particular are required, notably on the role of green sea urchin "outbreaks" for subtidal macroalgae productivity and biodiversity. As temperatures warm in the northern part of the Salish Sea, it may be necessary to use sori ("seed") from southern areas (Gulf Islands) for the restoration experiments (Heath et al., Appendix A). Genetic aspects of restoration projects are recognized as a key component (Wernberg et al. 2018). Thus, to move forward with restoration projects there is a need for basic research on algal ecology to improve our understanding of limiting factors.

2.5 What research is required to address these issues?

Although multiple areas of shortfalls in knowledge were described in the questions and answer sections above, the following were identified as research priorities in the breakout groups (not in order):

- Natural limiting factors (e.g. urchin outbreaks as a factor for kelp restoration)
- Anthropogenic effects, especially multiple stressors (e.g. contaminant mixtures with temperature) and cumulative effects
- Research on early life history stages (gametophytes)
- Critical habitat linkages and maintaining connectivity within and between macroalgae ecosystems
- Research on forage fish ecology (e.g. herring) and their relations to macroalgae
- Investigate use of Traditional Ecological Knowledge
- Intensify efforts to educate citizens about the importance of ecological integrity, using macroalgae ecosystem as an example
- Research on alternate productivity measures for macroalgae (i.e. in addition to carbon fixed) (fatty acids, stable isotopes) and information on amounts and timing for the measures to connect with consumer organisms
- Establish and/or maintain long-term monitoring programs and perform retroactive analyses on existing data as appropriate
- Investigate genetic diversity of macroalgae communities

- Research effect of oceanographic regimes changes on nearshore ecosystems, particularly macroalgae.

3.0 DISCUSSION OF PACIFIC SCIENCE ENTERPRISE CENTRE OPPORTUNITIES

Participants agreed there were numerous opportunities at the Pacific Science Enterprise Centre for collaborative research on nearshore macroalgae ecology. Other local laboratories are limited to small-scale tank experiments to test, for example, effects of oil and other contaminants on macroalgae at various life stages (Bisgrove and Schiltroth, Appendix A). Experiments could be scaled up or expanded to whole life-cycle tests at the Pacific Science Enterprise Centre because of the availability of ample seawater to run large tank experiments, artificial tide pools, or other mesocosm-type experimentation.

The Pacific Science Enterprise Centre could also facilitate collaboration between macroalgae researchers in British Columbia by establishment of a clearinghouse or “knowledge hub” for information – there is a lot of related work underway in different labs and projects and better progress might be made if annual workshops were held to bring people together. Initially, a summary and comprehensive review of the existing literature is necessary. It would be important to secure long-term funding to ensure continuity. A focus on the Salish Sea or a component of the area already relatively well known such as Howe Sound might complement the long term macroalgae studies on the Central Coast by the Hakai Institute. As well there are opportunities for student research projects at the high school and university/college levels. Citizen scientists could also be involved to help increase awareness of macroalgae for coastal ecology and conservation. In the long run, it is the local communities that will help maintain ecological integrity of the coastal ecosystem.

A linkage between the nearshore habitat working group established by the Pacific Salmon Foundation for the Salish Sea Marine Survival Program was also suggested as a component of the knowledge hub. Collaborations with professional societies such as the Pacific Estuarine Research Society and the Phycological Society of America are other possibilities. There are also possibilities to work more closely with First Nations, given the importance of macroalgae as food and as a cultural item, and benefit of insights of First Nations traditional ecological knowledge. There is a great scope for collaborative research on macroalgae between BC and Washington scientists, possibly in a cross-border study.

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5.0 REFERENCES

Ban, N.C., Bodtker, K.M., Nicolson, D., Robb, C.K, Royle, K., and C. Short. 2013. Setting the stage for marine spatial planning: Ecological and social data collation and analyses in Canada's Pacific waters. Marine Policy 39: 11-20.

Breen, P., Carson, T., Foster, J., & Stewart, E. 1982. Changes in Subtidal Community Structure Associated with British Columbia Sea Otter Transplants. Marine Ecology Progress Series, *7*(1), 13-20.

Chess, J.R. 1993. Effects of the Stipe-boring Amphipod *Peramphithoe Stypotrupetes* (Corophioidea: Ampithoidae) and Grazing Gastropods on the Kelp *Laminaria setchellii* J Crustacean Biology 13: 638-646.

Cook, S. 2018. The shorezone nearshore imaging and habitat mapping system in BC…and beyond. Presentation at the DFO Nearshore Habitat Productivity Workshop and Gap Analysis. Pacific Science Enterprise Centre, February 22-23 2018.

Costa, M. and S. Shroeder. 2018. Detection of bull kelp in the Salish Sea using high resolution satellite imagery. Presentation at the DFO Nearshore Habitat Productivity Workshop and Gap Analysis. Pacific Science Enterprise Centre, February 22-23 2018.

Dugan, J.E., Hubbard, D.M.,McCrary, M.D. and M.O. Pierson. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. Estuarine, Coastal and Shelf Science 58S: 25–40.

Druehl, L.D. 1967. Vertical distribution of some benthic marine algae in a British Columbia inlet, as related to some environmental factors. Journal of the Fisheries Research Board of Canada 24:33-46.

Foreman, R. E. 1977. Benthic community modification and recovery following intensive grazing by *Strongylocentrotus droebachiensis*. Helgoländer wiss. Meeresunters. 30: 468-484.

Gabrielson, P.W. and S. C. Lindstrom. 2018. Keys to the Seaweeds and Seagrasses of Southeast Alaska, British Columbia, Washington, and Oregon. Phycological Contribution Number 9. Available from Sandra Lindstrom, Botany Department, University of BC.

Harley, C. 2018. Ecology of benthic invertebrates and seaweeds in a changing climate. Presentation at the DFO Nearshore Habitat Productivity Workshop and Gap Analysis. Pacific Science Enterprise Centre, February 22-23 2018.

Harley, C.D.G., K.M. Anderson, K.W. Demes, J.P. Jorge, R.L. Koras, T.A. Coyle, and M.H. Graham. 2012. Effects of climate change on global seaweed communities. Journal of Phycology, 48(5), 1064-1078.

Heaven, C. and R. Scrosati. 2004.Feeding preference of *Littorina* snails (Gastropoda) for bleached and photosynthetic tissues of the seaweed *Mazzaella parksii* (Rhodophyta) Hydrobiologia 513: 239-243.

Hessing-lewis, M and 33 others. 2018. Scaling-up Metrics of Nearshore Habitat Productivity; the Hakai Institute's Approach for Quantifying Change at B.C.s Coastal Margin. Presentation at the DFO Nearshore Habitat Productivity Workshop and Gap Analysis. Pacific Science Enterprise Centre, February 22-23 2018.

Holden, J.J., Kingzett, B.C., MacNeill, S., Smith, S., Juanes, F., and S. Dudas. 2017. Beach-cast biomass and commercial harvesting of a non-indigenous seaweed, M*azzaella japonica*, on the east coast of Vancouver Island, British Columbia. J Applied Phycology 30: 1175-1184 https://doi.org/10.1007.

Kordas, R.L., Donohue, I. and C.D.G. Harley. 2017. Herbivory enables marine communities to resist warming. Science Advances 3, Issue 10, e1701349.

Lamb, A., Gibbs, D. and Gibbs, C. 2011. Strait of Georgia Biodiversity in Relation to Bull Kelp Abundance. Pacific Fisheries Resource Conservation Council, Vancouver BC. 117 p.

Leaman, B.M. 1980. The ecology of fishes in British Columbia kelp beds. I, Barkley Sound *Nereocystis* beds. Province of British Columbia, Marine Resources Branch, Ministry of Environment. Fisheries Development Report No. 22.

Lemay, M. A., Martone, P. T., Keeling, P. J., Burt, J. M., Krumhansl, K. A., Sanders, R. D. and Wegener Parfrey, L. 2018. Sympatric kelp species share a large portion of their surface bacterial communities. Environ Microbiol, 20: 658-670. doi:10.1111/1462-2920.13993.

Levings, C.D. and R.M. Thom. 1994. Habitat changes in Georgia Basin: implications for resource management and restoration. p. 330-351. in Wilson, R.C.H., Beamish, R.J., Aitkens, F., and J. Bell (Eds.). Review of the Marine Environment and Biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait. Proc. BC/Washington Symposium on the Marine Environment, January 13-14 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948. 390 p.

Levings, C.D., Kieser, D., Jamieson, G.S., and S. Dudas. 2002. Marine and estuarine alien species in the Strait of Georgia, British Columbia. P. 111-131 In Claudia, Renata, Nantel, Patrick and Elizabeth Muckle-Jeffs (Eds). Alien invaders in Canada's Waters, Wetlands, and Forests. Natural Resources Canada, Canadian Forest Service, Ottawa.

Mach, M.E., Levings, C.D., and Kai Chan. 2016. Nonnative species in British Columbia eelgrass beds spread via shellfish aquaculture and stay for the mild climate. Estuaries and Coasts 40(1):187-199.

Maniwa, T. 1997. Densities of *Anoplarchus purpurescens* in the intertidal areas of Howe Sound in relation to the discharge of mine waste water. Coop Student Report, Simon Fraser University, Burnaby, BC, August 29 1997, 20 pp.

Markel, R.W., Shurin, J.B. 2015. Indirect effects of sea otters on rockfish (*Sebastes* spp) in giant kelp forests. Ecology 96, 2877–2890.

Marliave, J. B. 1981. High intertidal spawning under rockweed, *Fucus distichus*, by the sharpnose sculpin, *Clinocottus acuticeps*.Can. J. Zool. 59:1122-1125.

Marsden, A.D., Robert E. DeWreede, R.E., and C.D. Levings. 2003. Survivorship and growth of *Fucus gardneri* after transplant to an acid mine drainage-polluted area. Marine Pollution Bulletin 46:65-73.

Miller, R., Page, H.M. and C. Yorke. 2018. Kelp as a trophic resource to reef food webs. Presentation at the DFO Nearshore Habitat Productivity Workshop and Gap Analysis. Pacific Science Enterprise Centre, February 22-23 2018.

Milligan, K. L.D., Levings, C.D. and R.E. DeWreede. 1999. Data compilation and preliminary time series analysis of abundance of a dominant kelp species in relation to the 1997/1998 El Nino event. Proceedings 1998 Science Board Symposium on the Impacts of the 1997/98 El Nino Event on the North Pacific Ocean and its Marginal Seas. 7th Annual PICES meeting, Fairbanks, Alaska October 14-15 1998 p. 69-72.

Nicholson, T. E., Mayer, K. A., Staedler, M. M., Fujii, J. A., Murray, M. J., Johnson, A. B., Tinker, M. T. and Van Houtan, K. S. 2018. Gaps in kelp cover may threaten the recovery of California sea otters. Ecography doi:10.1111/ecog.03561.

Peppar, J.L. 1965. Some features of the life history of the cockscomb prickleback: *Anoplaruchus purpurescens* Gill. MSc thesis, Dept of Zoology, University of British Columbia, Vancouver , BC.

Ramshaw,B.C., Pakhomov, E.A., Markel, R.W. and S. Kaehler. 2017. Quantifying spatial and temporal variations in phytoplankton and kelp isotopic signatures to estimate the distribution of kelp-derived detritus off the west coast of Vancouver Island, Canada. Limnology and Oceanography 62: 2133-2153.

Reed, D.C. and M.A. Brzezinski. 2009. Kelp Forests. P 31-37 in Laffoley D.A.. & Grimsditch, G. (eds). 2009. The management of natural coastal carbon sinks. IUCN, Gland, Switzerland. 53 pp.

Richards, L.A. 1984. Feeding activity patterns of an intertidal beetle. Journal of Experimental Marine Biology and Ecology 73: 213-224.

Scagel, R. F. 1961. The distribution of certain benthonic algae in Queen Charlotte Strait, British Columbia, in relation to some environmental factors. Pacific Science 15: 494-539.

Schroeder, S. and N. Nahirnick. 2017. Distribution of kelp beds and their use by juvenile salmon. Poster presentation at the Salish Sea Marine Survival Project. Sponsored by the Pacific Salmon Foundation. November 21-22 2017. Nanaimo BC.

Schultz JA, Cloutier RN, Côté IM. 2016. Evidence for a trophic cascade on rocky reefs following sea star mass mortality in British Columbia. PeerJ 4:e1980 https://doi.org/10.7717/peerj.1980.

Sloan N.A and P.A. Breen. 1988. Northern abalone, *Haliotis kamtschatkana*, in British Columbia. Strait of Georgia, British Columbia. Can Spec Publ Fish Aquat Sci 103. 46 p.

Romanuk, T.N and C.D. Levings. 2005. Stable isotope analysis of trophic position and terrestrial versus marine carbon sources for juvenile Pacific salmonids in nearshore marine habitats. Fisheries Management and Ecology 11: 113-121.

Trebilco, R., Demes, K, Lee, K.W., Keeling, B.E, Sloan, N.A., Stewart, H.L. and A.K. Salomon. 2014a. Baseline kelp forest surveys within and adjacent to Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site, Haida Gwaii, British Columbia, Canada. Canadian Data Report of Fisheries and Aquatic Sciences 1252.

Trebilco R, Dulvy NK, Stewart H, Salomon AK. 2014b. The role of habitat complexity in shaping the size structure of a temperate reef fish community. Mar Ecol Prog Ser 532:197-211. https://doi.org/10.3354/meps11330.

Watson, J. 2000. The effects of sea otters (*Enhydra lutris*) and abalone (*Haliotis* spp.) populations. In Workshop on Rebuilding Abalone Stocks in British Columbia. Edited by A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci. 130:123-132.

Wernberg, T., Coleman, M.A., Bennett,S., Thomsen, M.S., Tuva, F. and B.P. Kelaher. 2018. Genetic diversity and kelp forest vulnerability to climatic stress. Scientific Reports 8, Article number: 1851

White, L. F. and Shurin, J. B. 2011. Density dependent effects of an exotic marine macroalga on native community diversity. J. Exp. Mar. Biol. Ecol. 405: 111–119.

Widdowson, T.B. 1965. A survey of the distribution of intertidal algae along a coast transitional in respect to salinity and tidal factors. Journal of the Fisheries Research Board of Canada 22 (6):1425-1454.

TABLES

Table 1. Workshop agenda: titles of presentations, speakers, and times.

Title	**Speaker**	**Time**
Registration		0800-0815
Welcome Workshop Objectives Introductions	Elan Park Colin Levings Hannah Stewart	0815-0830
Status of marine plant mapping for the British Columbia Coast on the Community Mapping Network at CMNBC.ca including the British Columbia Marine Conservation Analysis project and other sources	Brad Mason Community Mapping Network	0830-0855
Kelp mapping in Burrard Inlet	Lindsey Ogston Tsleil-Waututh Nation	0855-0920
Hakai program and what is the current state of macroalgae mapping along coastal British Columbia	Margot-Hessing Lewis (speaker) Luba Reshitnyk, Hakai Institute	0920-0945
DFO kelp data – Putting the pieces together	Joanne Lessard, Fisheries and Oceans Canada, Science Branch, Pacific Biological Station, Nanaimo	0945-1010
Health Break		1010-1030
Kelp Productivity in Howe Sound	Laura Borden Vancouver Aquarium/ Botany Department, UBC	1030-1055
Macroalgal species diversity and monitoring efforts along the central coast of British Columbia	Patrick Martone, Botany Department, UBC	1055-1120
Habitat heterogeneity drives scale-dependent kelp biodiversity loss in Barkley Sound	Chris Neufeld, Bamfield Marine Science Centre (speaker) Samuel Starko, Botany Department, UBC	1120-1145

Ecological implications of introductions and invasions: the dominance of a novel introduced seaweed over a known invasive seaweed in the Salish Sea.	Kylee Pawluk, Department of Geography, University of Victoria	1145-1210
Lunch		1210-1315
The status of BC kelp cultivation and its potential for kelp forest preservation and restoration, and environmental remediation.	Louis Druehl, Canadian Kelp, Bamfield	1315-1340
Bull Kelp Restoration Research in the north Salish Sea 2011 - 2018 Part 1: Field study Part 2: Estimating the resiliency of bull kelp life stages to increases in ocean temperatures associated with climate change	William A. Heath (speaker), Robert C. Zielinski and Amanda J. Zielinski. Nile Creek Enhancement Society/Project Watershed Comox Sherryl Bisgrove and Braeden Schiltroth, Biological Sciences, Simon Fraser University.	1340-1355
Status and Priorities for research on kelp in Washington State	Thomas Mumford, Marine Agronomics, Olympia, Washington	1355-1420
Health Break		1420-1430
Discussion		1430-1545
Closing comments and adjourn		1545-1600

Table 2. List of participants, speakers, co-authors of extended abstracts and affiliations.

Name	Affiliation
Lindsey Ogston	Tsleil-Waututh Nation
Brad Mason	Community Mapping Network
Margot Hessing-Lewis	Hakai Institute
Luba Reshitnyk	Hakai Institute
Joanne Lessard	Fisheries and Oceans, Science Branch, Pacific Biological Station
Laura Borden	Vancouver Aquarium/Botany Department, UBC
Patrick Martone	Botany Department, UBC
Chris Neufeld	Bamfield Marine Science Centre
Kylee Pawluk	Department of Geography, University of Victoria
Louis Dreuhl	www.canadiankelp.com, Bamfield, BC
Bill Heath	Nile Creek Enhancement Society/Project Watershed Society of Comox Valley
Thomas Mumford	Marine Agronomics, Olympia, Washington
Gary Williams	G.L. Williams and Associates, Coquitlam
Bridget Doyle	Tsleil-Waututh Nation
James Mortimor	Fisheries and Oceans, Science Branch, Pacific Biological Station
Boone Barber	Fisheries Protection Program, Fisheries and Oceans
Sarah Schroeder	Department of Geography, University of Victoria
Kyle Demes	Senior Advisor, Strategic Initiatives, UBC
Elan Park	Pacific Science Enterprise Centre, Fisheries and Oceans
Chelsey Wierks	Pacific Science Enterprise Centre, Fisheries and Oceans
Herb Herunter	Pacific Science Enterprise Centre, Science Branch, Fisheries and Oceans
Hannah Stewart	Pacific Science Enterprise Centre, Science Branch, Fisheries and Oceans
Colin Levings	Pacific Science Enterprise Centre, Science Branch, Fisheries and Oceans (retired)

APPENDIX A

Extended abstracts, listed in order of speaker

Status of marine plant mapping for the British Columbia Coast on the Community Mapping Network at CMNBC.ca including the British Columbia Marine Conservation Analysis project and other sources

Brad Mason, Community Mapping Network

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The Community Mapping Network (CMN) assists community mapping of sensitive habitats and species distributions in British Columbia and Canada. Since 2000, the CMN has created over 60 community based atlases with customized data entry and reporting tools. The atlases integrate many different data sources from volunteers, local, regional and senior governments. Several atlases integrate coastal and marine resource information including an eelgrass atlas, forage fish atlas, the Pacific Region Coastal Resources Atlas, the Shorekeepers Atlas, and the British Columbia Marine Conservation Analysis (BCMCA) Atlas.

The BCMCA was a collaborative project designed to provide resource managers, scientists, decision-makers, and those with a vested interest in the marine environment with resources to inform coast-wide integrated marine planning and management initiatives. The overall purpose of the BCMCA project was to collaboratively identify marine areas of high conservation value and areas important to human use in Canada's Pacific Ocean.

The BCMCA Atlas provides public access to 300 map layers that can be viewed individually or by viewing multiple layers overlaid on one another. In addition, there is a link from each map layer to its metadata at *BCMCA.ca*. With the creation of a comprehensive atlas and in-depth analysis, tools were developed to help inform decisions about ocean management. To support the development of marine plants information, a marine plants expert workshop was held March 14, 2007 which was used to collaboratively identify areas of high conservation value for the coast of BC. Overall, 52 marine plant features were identified by expert participants (7 related to canopy forming kelps, 36 related to algae and 9 related to vascular plants) including features that should be included for which data are lacking. Data gaps, relative quality and consistency of data and assumptions about the data were documented in detailed metadata.

Since the development of the BCMCA atlas there have been no updates to the marine plant layers on the CMN except for a coast wide kelp layer from the province of BC. Updates from volunteers are compiled opportunistically for eelgrass and other community based atlases but there is no anticipated systematic inventory for large parts of the coast. The Community Mapping Network servers are actively maintained. Updates for marine plants and other natural resources information are encouraged and will be integrated as resources permit.

Kelp Mapping in Burrard Inlet

Lindsey Ogston, Tsleil-Waututh First Nation

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Tsleil-Waututh are 'the People of the Inlet' and have occupied and used the lands and waterways surrounding Burrard Inlet since time out of mind. Approximately 90% of the Tsleil-Waututh diet was derived from marine resources of Burrard Inlet, including shellfish and finfish. Development within the inlet has impacted fish habitat and many species of fin fish have experienced declines, or have become extirpated.

Kelp beds are an essential fish habitat, both for forage fish and for juvenile salmonids, and removal of kelp has been observed to result in fish population declines. In Burrard Inlet, both salmon and forage fish have experienced declines, and much of the kelp beds have disappeared. A key species in high productivity kelp beds is bull kelp (*Nereocystis luetkeana*), which has not been extirpated in Burrard Inlet. Bull kelp is visible from the seawall around Stanley Park, but a modern mapping effort of kelp bed presence and size is lacking.

Mapping kelp in an environment that is also a highly urbanized area and one of the busiest ports in Canada can be difficult. However, adjusting kayak-based protocols and using novel technology Tsleil-Waututh Nation conducted a successful kelp mapping of the south shores of Burrard Inlet.

Quantifying kelp forest dynamics in British Columbia; from regional biomass to coast wide trends

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The Hakai Institute conducts integrated observations of canopy-forming kelps in British Columbia using a combination of field-based measurements and remote sensing. We have partnered with DFO, Parks Canada and community groups to create an integrated approach for quantifying kelp dynamics in British Columbia, from local, bed-level assessments to provincial-scale kelp mapping using satellite imagery. At the Calvert Island Ecological Observatory on the Central Coast of British Columbia, we combine dive surveys with UAV imagery to model the seasonal dynamics of the two dominant canopy-forming kelp species (*Macrocystis* sp. and *Nereocystis* sp.). Dive surveys collect sub-surface metrics (e.g. stipe density, frond morphology & turnover, stipe length) to parameterize population models aimed at quantifying kelp net primary production. Additionally, kelp-associated communities, including sub-canopy macroalgae, invertebrates and fish are quantified seasonally and annually using adapted Reef Life Survey methods, a global standard employed by the MarineGEO network. We also measure potential drivers of kelp dynamics, including physical parameters (temperature, salinity, alkalinity) and sea otter foraging. This year (2018), surface cover of canopy forming kelps, in addition to surface biomass metrics, will also be collected at the bed level in order to develop a robust, spatially explicit model of kelp productivity for this region. To scale-up from individual beds to a regional (100-1000 km^2) analysis of kelp cover, WorldView 2 imagery has been collected for the Central Coast region. Using this high spatial resolution imagery (0.5-2.0m), we have developed techniques to classify kelp beds by dominant species, and quantify kelp extent with high spatial accuracy. To quantify kelp distribution and inter-annual dynamics at the scale of the province (~1000 km coastline), we have determined that Landsat imagery (30m spatial resolution) is an appropriate tool for long term change detection, annual reporting and hot spot assessments (areas of consistently high biomass). Going forward, we will be tasking WorldView-2 for select hot spot sites for more detailed analyses of species-level composition. We also aim to scale-up our local scale metrics of kelp biomass regionally and coast wide, supporting and training a network of community groups and institutions to collect data spanning the BC coast. We are harnessing the collective of engaged community groups coastwide, including of First Nations, community-based conservation groups and state-sponsored organizations to collect standardized data from boat-based and UAV surveys and to ground truth provincial kelp maps. Ultimately, a publically-accessible database will be used to determine where and why kelp extent and productivity is changing along the West Coast of North America, and to inform how best to manage, restore and plan for changes in kelp habitats forecast with climate change.

References

Cavanaugh KC, Kendall BE, Siegel D, Reed DC, Alberto F, Assis J. 2013. Synchrony in dynamics of giant kelp forests is driven by both local recruitment and regional environmental controls. *Ecology*. 94(2):499-509. http://www.ncbi.nlm.nih.gov/pubmed/23691668.

Cavanaugh K, Siegel D, Reed D, Dennison P. 2011. Environmental controls of giant-kelp biomass in the Santa Barbara Channel, California. *Mar Ecol Prog Ser*. 429:1-17. doi:10.3354/meps09141

Cavanaugh K, Siegel D, Kinlan B, Reed D. 2010. Scaling giant kelp field measurements to regional scales using satellite observations. *Mar Ecol Prog Ser*. 403:13-27. doi:10.3354/meps08467.

Krumhansl KA, Okamoto DK, Rassweiler A, et al. 2016. Global patterns of kelp forest change over the past half-century. 2016:1-6. doi:10.1073/pnas.1606102113.

Reshitnyk, L.Y., Rubidge, E., Nijland, W. 2018. Multiscale satellite mapping of canopy forming kelp. In prep.

DFO kelp data – Putting the pieces together

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DFO-Science has been accumulating algae data since the late 70’s. However, very little analysis has been completed using these data. This presentation summarizes a few projects in which algae data were collected and layout the path we are following to make use of these datasets. In order to study the effects of El Niño events on the fish and algae communities off the coast of BC, a study was conducted to assess the abundance of fish and algae within *Macrocystis* kelp beds in both 1997 and 1998. Fifteen 50m transects were placed within kelp forests (location of the forests were the same for both year) and were surveyed for fish and algae communities. Video was used for fish and diver observations within 25 $1m^2$ quadrats for algae. Preliminary analyses showed that fish communities were predominately associated with % cover of understorey kelp. The El Niño event significantly decrease algae cover (particularly canopy and understorey) as well as both the total number of algae and fish species.

The Dive Program has been collecting algae data on many of their stock assessment surveys. In addition to those, in 2013, we developed a new method to collect more extensive invertebrate and algae data for the specific purpose of defining 'habitats and/or communities'. On the Habitat Mapping Survey, we collect presence/absence data for approximately 100 species of invertebrates and 50 species of algae as well as other habitat data like substrate and % cover for canopy, understorey, turf and encrusting algae. Cluster/community analyses have just been initiated on these data. Since 2004, the Nearshore Habitat WG has been working on developing methods to map the nearshore marine habitats. The first step was to create a dataframe or basemap which we call the Bottom Patches (BoPs). The BoPs is a seamless polygon layer created from depths and several sources of substrate data from 50m depth to the high intertidal. The BoPs are now complete for all of BC coast. We are now working on overlaying and attaching environmental variables to each polygon so that we can then produce species-environmental factors relationships which could then be use to predict potential habitat for those species.

Kelp Productivity in Howe Sound

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For over 35 years the Howe Sound Research Program at the Vancouver Aquarium has been monitoring seabed biodiversity in Howe Sound. Rocky reefs are amongst the most well-documented of the habitats and are dominated by four species of kelp, *Saccharina latissima*, *Costaria costata*, *Nereocystis lutkeana* and *Neoagarum fimbriatum*. However, following the mass mortality of sunflower sea stars in 2013 there was a significant decline in kelp in Howe Sound, notably *N. fimbriatum*, due to unprecedented increases in green urchins. Entire kelp beds have since been wiped out. These kelp beds are essential settlement habitat for juvenile spot prawns, which as adults are commercially harvest (Schultz et al. 2016). In order to address to concerns about kelp habitat loss, particularly the decline *N. fimbriatum*, we collected data about the baseline productivity of the species over a two-year period. Growth, light and temperature were monitored at three reefs in Howe Sound from 2015-2017 and were paired with historical information about kelp beds to understand seasonal and inter-annual patterns. Growth occurred throughout all months of year but was higher in 2015 than 2016, when temperatures were warmer. However, light proved to be the best predictor of growth. The importance of light on this subtidal species was evident with the impact of spring blooms greatly reducing growth. There was also significant site variability in patterns of growth. Despite consistent growth throughout the year grazers continue to dominate the shallower kelp reefs, effectively eliminating shallow reef habitat for important species of fish and crustaceans. Seabed topography has helped some reefs maintain multi-layered kelp beds, but a large proportion of reefs that have supported juvenile spot prawn settlement over the past 30 years have become urchin barrens. *Neoagarum fimbriatum* remains the most dominant kelp in Howe Sound but innovative techniques to repopulate barren reefs may be necessary to combat loss due to grazers since growth cannot outcompete grazer-related loss.

References

Marliave, J.B. and M. Roth. 1995. *Agarum* kelp beds as nursery habitat of spot prawns, *Pandalus platyceros*. Crustaceana. 68: 27-37.

Schultz JA, Cloutier RN, Côté IM. 2016. Evidence for a trophic cascade on rocky reefs following sea star mass mortality in British Columbia. Peer J 4:e1980 https://doi.org/10.7717/peerj.1980.

Macroalgal species diversity and monitoring efforts along the central coast of British Columbia

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Supported by cold nutrient-rich waters of the northeast Pacific, the central coast of British Columbia maintains rich and diverse assemblages of marine macroalgae. From lush subtidal kelp forests to dense intertidal stands, temperate macroalgae contribute significantly to global primary production and play central roles in the ecology of marine communities, generating food and habitat for invertebrates, fish, mammals, and sea birds. Because ecological interactions centered on seaweeds are often quite specific (e.g., due to food preferences, settlement cues, chemical defenses, habitat structure), understanding the biodiversity of macroalgae on the shore lends insight into the greater structure of marine ecosystems. Further, because they need to weather environmental conditions wherever they settle and grow, sessile macroalgae are indicator species of biological shifts that may occur as ocean temperature increases and pH decreases due to climate change.

Since 2010, our team has been surveying seaweeds along the coast of Calvert Island. Our goals have been twofold. First, we wanted to document and describe the marine flora of Calvert Island. This species catalogue will serve as a reference for all studies along the central coast of British Columbia. After seven years of intertidal surveys and two years of subtidal surveys, we have documented more than 340 species on Calvert Island. Our species determinations are from both morphological observation and DNA sequence data, which are needed to identify difficult specimens. In the course of our work, we have found several new species on Calvert Island, including the calcified coralline *Bossiella hakaiensis*, and over the years we have been working to describe these species. However, DNA sequence data demonstrate that many species on the central coast are new to science and need to be described, and clearly more work needs to be done. As a whole, the flora of Calvert Island represents an interesting blend of northern and southern species with, for example, Californian species *Mastocarpus agardhii* and *Grateloupia californica* found on the same shore as Alaskan species *Palmaria hecatensis* and *Tokidadendron bullatum*.

The second goal of our seaweed surveys has been to establish a long-term monitoring program to detect shifts in seaweed communities through time. The diversity of macroalgae on Calvert Island presents an excellent opportunity to observe the effect of climate change on marine communities. First, as global temperatures continue to increase, some models predict that southern species will move northward while northern species will retreat; other models have incorporated the timing of stressful mid-day low tides in the summer, predicting that hotspots may cause local extinctions instead of steady movements north or south. The mix of southern and northern species at Hakai is ideal for exploring these two hypothetical scenarios. Data analysis shows that seaweed communities are changing significantly through time with a clear decline in abundance of *Fucus* and some kelp species in the last few years. Additional work is required to characterize these changes and to link with fluctuating environmental parameters.

Habitat heterogeneity drives scale-dependent kelp biodiversity loss in Barkley Sound

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Kelps serve important ecological roles as primary producers and by providing habitat for other species. Although many of the world's kelp communities are made up of only a few species, the Northeast Pacific houses more than 30 species, many of which have species-specific associations with other taxa. Because kelps play such a fundamental role in nearshore ecosystems, accurately forecasting how kelps will respond to ongoing human impacts (including climate change) is an urgent need among scientists and managers alike. Some recent work shows that kelps are susceptible to large climate-related declines at their range edges, while other studies have shown highly variable changes in kelp abundance within and between regions over time. However, it is not clear why kelps appear to show these variable spatial responses to environmental change.

We tested a possible explanation for the variable responses of kelps that hinges on an interaction between local and regional stressors. In 2017 we resurveyed intertidal sites (n=49) in Barkley Sound and compared our data to the results of historical surveys conducted by Druehl and Elliot between 1993 and 1995. Across the study system, we found widespread declines in kelp species richness and abundance that were mediated by local variation in wave action. At wave-exposed sites kelp communities did not decline, while at wave-sheltered sites kelp species richness and abundance has been reduced to between zero and three species, regardless of their historical diversity. Patterns were also scale-dependent: the number of species in the regional kelp assemblage did not change, while local richness and average abundance declined markedly. We also found that wave-sheltered rocky shores, which saw the largest declines, make up nearly 57,000 km of shoreline from Oregon to Alaska.

This leads us to three conclusions. First, given the important ecological role of kelp, the declines that we documented are likely to have cascading effects on the diversity of other organisms and on ecosystem functioning of these intertidal communities. Second, the sheer amount of wave-protected habitat suggests that a majority of shoreline in the Northeast Pacific may be especially sensitive to similar climate-related losses of kelp habitat. Third, and perhaps most importantly, such losses are likely to be missed by studies not designed specifically to detect them. For example, the common approach of quantifying regional species richness change would have missed the localized losses, and assessing losses across sites that differ in wave action would have obscured the losses restricted to wave-protected sites. Our results highlight how local gradients may interact with global drivers to facilitate systematic nearshore habitat loss, and stress the need for appropriate sampling schemes to capture functionally-important changes in nearshore communities at the landscape scale.

Ecological implications of introductions and invasions; the dominance of a novel introduced seaweed over a known invasive seaweed in the Salish Sea

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Introduced macroalgae contribute to the decline in native seaweed diversity worldwide. However, to date there have been no studies which have examined the interactions or impacts of co-invading non-indigenous seaweeds in one recipient habitat. Baynes Sound, British Columbia hosts two non-indigenous seaweeds: the well-known and studied *Sargassum muticum* and the lesser-known *Mazzaella japonica*. Using a long-term removal experiment with three treatments and a control, I examined the interaction of the two non-indigenous seaweeds and how their removal impacted native seaweeds and motile marine invertebrates. The results suggest that *M. japonica* outcompetes both native seaweeds and the invasive *S. muticum* and is the dominant competitive marine algae in the ecosystem. Though *M. japonica* and *S. muticum* exhibit invasional interference, *M. japonica* has a greater impact on *S. muticum*. Exclusion of both non-indigenous seaweeds had the greatest impact on native seaweeds followed closely by removal of *M. japonica* alone. Resultant seaweed communities in control plots and where only *S. muticum* was removed were similar in composition. Additionally, the removal of *M. japonica* and *S. muticum* allow for increased abundance and diversity of benthic invertebrates. Gaps in our understanding of these non-indigenous seaweeds will be discussed along with potential management strategies.

References

Pawluk, K.A. 2016. Impacts and Interactions of Two Non-Indigenous Seaweeds *Mazzaella japonica* (Mikami) Hommersand and *Sargassum muticum* (Yendo) Fensholt in Baynes Sound, British Columbia.

Saunders, G.W. & Millar, K.R. 2014. A DNA barcode survey of the red algal genus *Mazzaella* in British Columbia reveals overlooked diversity and new distributional records: descriptions of *M. dewreedei sp. nov.*. and *M. macrocarpa sp. nov*. *Botany* 92:223–31.

The status of BC kelp cultivation and its potential for kelp forest preservation and restoration, and environmental remediation

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BC kelp beds are the major primary producers of our shallow coastal waters. Stresses of a changing environment and increasing demand for kelp products challenge this crucial ecosystem. Kelp cultivation provides a way to support wild beds and meet commercial demand. Thirty years of kelp cultivation by CKR have streamlined kelp "seed" production, demonstrated the cultivability of 6 kelp species, expanded the kelp farming season, introduced multi-kelp species farm systems, and initiated genetic selection of superior kelp strains. Presently, stands of cultivated kelp are being employed to restore environmentally diminished bull kelp beds, remediate shores impacted by coastal development, sequester carbon, thus reducing ocean acidification, and produce kelp biomass for industrial use. To meet the demand for kelp biomass, world-wide kelp cultivation has increased yearly 8-10% for the past several years. To meet this demand and preserve our highly diverse wild BC beds, Canada needs to develop an accommodating seaweed cultivation policy.

References

Shan, T.F, Pang, S.J. and S. Q. Gao. 2013. Novel means for variety breeding and sporeling production in the brown seaweed *Undaria pinnatifida* (Phaeophyceae):Crossing female gametophytes from parthenosporophyteswith male gametophyte clones. Phycological Research 2013, 61:154-161.

Druehl, L,D. R Baird, A Lindwall, KE Lloyd and S. Pakula. 1988. Longline cultivation of some Laminariaceae in British Columbia. Aquaculture Research 19: 253-263

Bull Kelp Restoration Research in the north Salish Sea 2011 - 2018

Part 1: Field study

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Bull kelp, *Nereocystis luetkeana*, has declined widely in recent decades in central Strait of Georgia (north Salish Sea) mainly due to herbivore grazing and prolonged periods of elevated temperatures (>17C). The Nile Creek Enhancement Society started a project in 2011 to study local ocean conditions at a natural kelp bed (south Denman I.) and at a kelp restoration site (Maude Reef, Hornby I.) where culture techniques are being applied to research and re-establish bull kelp. A kelp culture line grid (25m x 30m) was installed at the Maude Reef site. Four years of study on kelp growout and monitoring of the restoration site in comparison with the natural kelp bed were conducted with support from the Pacific Salmon Foundation (PSF) Community Salmon Program. Diver observations and data-logged temperature and light intensity measurements at two depths at each site have been recorded. In 2015, with support from PSF Salish Sea Marine Survival Program (SSMSP), the kelp project was expanded in collaboration with Project Watershed Society by adding a second experimental site in northern Baynes Sound. Additional environmental data from multi-parameter sonde casts have been collected at the study sites. The 2015 project was conducted during one of the warmest spring and summer periods recorded locally and provided an opportunity to study the effects of temperature stress and herbivore grazing as limitations to bull kelp distribution in an important area of the Salish Sea. An additional collaboration with the Bisgrove Lab at SFU Biosciences allowed investigation of stress resiliency of kelp life stages (see Part 2 below). Field work focused on further improvement of restoration techniques, especially in addressing the need for adaptation to warming conditions in the Salish Sea. The identification and propagation of bull kelp plants with tolerance of warm water (>17 C) is now a leading approach for our research. In 2016 we assisted the Alberto Lab of University of Wisconsin-Milwaukee in their coast wide population genetics study of bull kelp by collecting samples from N. Vancouver Island and the N. Salish Sea, including from a new experimental site at Cape Lazo shoal. In Fall 2016 we obtained sori and produced “seed” based on kelp from Sansum Narrows (S. Gulf Islands) to compare growth and survival with kelp originating from sori collected at Campbell River. During 2017 work we concluded that the Sansum Narrows stock was preferred for performance and reliability in obtaining excellent quality sori for seed production. Grazing pressure by sea urchins is also a major limiting factor for bull kelp abundance. In 2018 we are experimenting with sea urchin exclusion and/or thinning of densities as treatments on the sea bottom.

Bull Kelp Restoration Research in the north Salish Sea 2011 - 2018

Part 2: Estimating the resiliency of bull kelp life stages to increases in ocean temperatures associated with climate change

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Rises in ocean temperature is a major factor associated with declines in kelp forests globally. Using data available from satellite imagery (NOAA), Braeden Schiltroth and Sherryl Bisgrove (SFU) found that since 2011 sea surface temperatures in the central Strait of Georgia are at and above those associated with major bull kelp die-offs on the coast of California (> 17 °C) for prolonged periods in the spring and summer months. The affected region includes the "salmon highway" stretching from Oyster River through Baynes Sound to Nile Creek. The timing of this exposure corresponds to the most productive months for bull kelp in terms of biomass accumulation and the formation of reproductive cells that produce the next year's crop. In contrast, temperatures in the Strait of Juan de Fuca throughout the growing season are 5-6 °C cooler than they are in the central Strait of Georgia, well below those associated with the California die-offs. To gain an understanding of whether and how rapidly ocean temperatures are changing in the region, Braeden will extend his analysis of sea surface temperatures to include historical conditions dating back 30 years available from online databases. This analysis will provide information on the rate at which ocean temperatures in the region have changed over time and enable projections related to the extent of stress that may be imposed on kelp in future years. Braeden is also analyzing the impacts of temperature stress on different life stages of bull kelp. He is currently collecting data on the production, viability, and development of early reproductive stages exposed to stressful warm and cooler temperatures.

References

tom Dieck (Bartsch). I. 1993. Temperature tolerance and survival in darkness of kelp gametophytes (Laminariales, Phaeophyta): ecological and biogeographical implications. Mar. Ecol. Prog. Ser. 100: 253-264. Available at: *https://www.int-res.com/articles/meps/100/m100p253.pdf.*

Wheeler W.N. 1990. Kelp forests of British Columbia: a unique resource. BC Ministry of Agriculture and Fisheries, 91 pp. Available at: ftp://ww4.dnr.wa.gov/aqr/SVMP/For%20Tom/Kelp%20Forests%20of%20British%20Columbia.pdf.

Status and Priorities for research on kelp in Washington State

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What is the current knowledge of the structure and function of macroalgae communities in coastal Washington State? In particular what organisms (invertebrates, fishes, marine mammals) are dependent on these communities?

- The intertidal marine algal flora of Washington is relatively well known. Less well known is the subtidal flora, especially crustose coralline algae (CCA) and fleshy crusts. Molecular taxonomy will continue to find cryptic species, but more importantly will allow us to study the cryptic life history phases (i.e. kelp gametophytes and other seasonal/annual species) and just small "macrophytes".
- The productivity and biogenic habitat provided by marine algae has profound and all-encompassing effects on almost all invertebrates, fishes, marine mammals. Recent listing of Puget Sound rockfish species in particular has highlighted the importance of kelp beds. Linkages to forage fish and salmonids is being studied.

- “It is hard to think of nearshore marine organisms that are not in some way dependent on or influenced by macroalgae or eelgrass habitats.” MaxCalloway, Graduate Student, The Evergreen State College, Olympia, WA. pers comm 2018.

What is the current state of macroalgae mapping along coastal Washington State? Have macroalgae communities in coastal Washington State changed in the past few decades and if so what is current thinking on reasons why? What is the magnitude of the change in terms of spatial coverage?

- Mapping of floating canopy-forming species of kelp (*Macrocystis/Nereocystis*) has been done since the late 1800’s. Changes in the abundance of these two seem to correlate to the distance from the open ocean. The more urbanized areas in Central and South Puget Sound are experiencing the greatest losses.
- Little is known about the distribution and abundance of the remaining 21 (or so) species of kelp, especially in the subtidal. Hence the changes in the contribution of biogenic habitats and productivity is not known.
- We have many studies, especially in the area of the Friday Harbor Labs, that have not been well analyzed for historical data. Herbarium specimens, student reports, environmental impact surveys, WDFW herring rake data, etc. are a gold mine. Nor has anyone systematically sought TEK from Native Americans and other fisherman.

What are the implications for nearshore ecosystems and food webs (involving invertebrates, fishes, marine mammals) of the macroalgae changes?

- As foundation species, changes in macroalgal communities affect not only the nearshore ecosystem, but also deep water and terrestrial ecosystems. We know now that not only macroalgal primary productivity moves, but many of the species dependent on these biogenic habitats also “move”, using these habitats for all or only portion of their life history. We are beginning to understand the role of macroalgae as larval traps, specific settlement areas, nursery areas, migratory paths, sources of epibenthic prey, and so forth.
- The effects are two-way- changes in invertebrates, fishes, marine mammal populations due to harvest, disease, invasive species, OA, and climate change affect macroalgal communities- there are top down trophic interactions as well as bottom-up.
- While we are beginning to understand the importance of “spatial subsidies”- the export of kelp detritus to not only the nearshore but also the deep water as well as terrestrial ecosystems, we do not have a good idea of the importance of the 30-50% of primary productivity in kelp that is dissolved organic materials (DOM)- how much, when, and where does that carbon go?
- We do not understand the implication of community shifts from kelp to turfs or CCA-dominated communities in relationship to the amount, timing, and composition of the biogenic habitats and productivity.
- We need to look carefully at the changes that have occurred in such places as northern California, Australia, South Africa and other places where dramatic changes in kelp forests have occurred and determine if similar changes are occurring here or if they are different. What lessons can we learn?
- We desperately need to gain a better understanding of the fate of nearshore productivity using such techniques as carbon isotopes.
- “It’s all connected”

What does the future hold for macroalgae communities in coastal Washington State? If their structure and function is reduced relative to earlier decades is restoration required and if so is it feasible? What research is required to address these issues?

1. Restoration of macroalgal communities is usually couched just in terms of *Nereocystis* restoration. These efforts have not been successful because we lack a fundamental understanding of what caused the losses in the first place and no efforts have been made to correct these underlying causes. We need to think about restoration more in terms of the ecosystem processes that support macroalgal communities.
2. In the case of kelp we lack an understanding of the gametophyte phase biology, distribution, ecology, and possible relationships to losses of the sporophytes. What pollutants, temperature changes, OA, and changes in herbivory affect the success of the WHOLE life history, not just the presence of sporophytes in the summer.
3. We do not know about or understand the ramifications of the multiple fisheries that have left the Puget Sound ecosystem greatly altered. Whales, salmon, steelhead, Pacific hake, Pacific cod, Walleye Pollock, spiny dogfish, urchins, Dungeness crab, sea cucumbers, herring, and Olympia oysters: these are only some of the species whose abundance has greatly decreased or are gone. How they depended on or interacted directly or indirectly with macroalgae is largely unknown.

References

Biela, V.R. Von, Newsome, S.D., Bodkin, J.L.,Kruse, G.H. and C.E. Zimmerman. 2016. Widespread kelp-derived carbon in pelagic and benthic nearshore fishes suggested by stable isotope analysis. Estuarine and Coastal Shelf Science 181: 364-374 https://doi.org/10.1016/j.ecss.2016.08.039.

Duggins, D.O., Gomez-Buckley, M.C., Buckley, R.M., Lowe, A.T., Galloway, A.W.E., and M.N. Dethier. 2016. Islands in the stream: kelp detritus as faunal magnets. Marine Biology 163: 10 https://doi.org/10.1007/s00227-015-2781-y.

Northwest Straits Commission. “SoundIQ”. http://www.nwstraits.org/our-work/soundiq/. Accessed March 12, 2018.

Pfister, C.A., Berry, H.D., and T. Mumford. 2017. The dynamics of kelp forests in the Northeast Pacific Ocean and the relationship with environmental drivers. Journal of Ecology 106:1175-1184 https://doi.org/10.1111/1365-2745.12908.

Washington Depart of Natural Resources, “Kelp Monitoring” https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/kelp-monitoring. Accessed January 24, 2020.

Washington Department of Natural Resources, “Washington Marine Atlas” https://www.dnr.wa.gov/programs-and-services/aquatics/aquatic-science/washington-marine-vegetation-atlas. Accessed January 24, 2020.