MONITORING OF DRIFT SEAWEED AND HARVEST
CENTRAL STRAIT OF GEORGIA 2014/15
FINAL REPORT
MONITORING OF DRIFT SEAWEED AND HARVEST
CENTRAL STRAIT OF GEORGIA 2014/15
FINAL REPORT

2015 PROJECT REPORT SUBMITTED TO:
BC MINISTRY OF AGRICULTURE

Date and Revision
May 22, 2015 Rev 3.1

Submitted to: Gary Caine, Senior Biologist
Food Safety and Inspection Branch
Ministry of Agriculture
2500 Cliffe Avenue, Courtenay, BC Canada V9N 5M6

Project Contact: Brian Kingzett, M.Sc., Deep Bay Field Station Manager
Centre for Shellfish Research at Vancouver Island University
900 Fifth Street, Nanaimo, B.C. Canada V9R 5S5

Tel: (250) 740-6399 / Fax: (250) 740-6353
Email: brian.kingzett@viu.ca / www.viu.ca/csr/

Full Citation for this Document

Central Strait of Georgia 2014/15. Final Report. Vancouver Island University Centre for Shellfish Research. 70 pp +
app.

DISCLAIMER: The authors and Vancouver Island University do not assume any responsibility or liability for losses occasioned to any party as a
result of the circulation, publication, reproduction or use of this report. It is inappropriate to rely upon the conclusions and opinions,
or any section of this report, outside of the context of the report as a whole. The authors reserves the right to review all information
referred to in this report and, if we consider it necessary, to revise our analyses and opinions in the light of any information which
becomes known to the authors after the date of this report.
Executive Summary

Background
At the request of the BC Ministry of Agriculture, the Centre for Shellfish Research at Vancouver Island University (CSR-VIU) has documented the distribution and characteristics of beach wrack and the harvest activities during the 2014/15 harvest season. The goal of this project was to provide information that will help managers, community and harvesters assess the local environmental effects of this activity.

Since 2007, the British Columbia Ministry of Agriculture (BCMoA) has been issuing licenses that permitted commercial operators to remove beach-cast seaweed from beaches between Deep Bay and Bowser, on the central east coast of Vancouver Island. The target species is the non-native red algae Mazzaella japonica (MJ). MJ is a valuable source of carrageenans widely used to gel, thicken and stabilize processed foods, cosmetics and pharmaceuticals. Harvests are conducted by hand, using pitchforks to skim beach-cast seaweeds from the supratidal and intertidal zones of beaches within the harvest region. The seaweed is transported from the beach by tracked vehicle and then by truck to local drying facilities for processing. Bales of the dried seaweed are exported for industrial use. In the last few years a group of local residents have voiced concern about the harvest citing environmental and social issues. Many others in the community seem to be neutral or in favour of the harvest for its economic benefits as long as it is sustainable.

MJ is native to Korea, Japan, and Russia. This species was first recognized in our marine flora about 10 years ago although it may well have been here much longer than that. Reports of distribution have been concentrated in the area south from Deep Bay, south along the east coast of central Vancouver Island.

Detached macroalgae provide a significant spatial subsidy, transferred from marine to coastal and terrestrial ecosystems by oceanic currents, winds, tides and surf. Accumulations of these beach-cast seaweeds and other matter, collectively known as wrack, play an important and well documented role within the marine-terrestrial ecotone. The actual influence of wrack on community dynamics and ecosystem functioning, however, can vary greatly depending on its quantity, distribution and composition.

The removal of beach-cast seaweeds, for aesthetic or commercial purposes is increasing globally. Beach-cast seaweeds are also collected from coastlines world-wide for use in agricultural fertilizers, shellfish aquaculture and for human consumption. Literature on the impacts of harvesting beach-cast seaweed is limited. It is also important to note that other wrack studies should also be considered in light of seasonal and habitat differences.

The objectives of the project were to assess the biomass, distribution and composition of beach wrack accumulations in the MJ licensed harvest area south of Deep Bay, on the East coast of Vancouver Island British Columbia. Specific objectives of the project were as follows:

1) Collate existing information on beach wrack monitoring methods and the nature of wrack accumulations in Deep Bay to design an effective study based on international examples as well as local knowledge.

2) Quantify the biomass and distribution of beach-cast seaweeds present within the harvest region over the course of the harvesting season.

3) Provide a quantitative description of beach wrack macrophyte composition and biomass for harvested sites and un-harvested sites across the region.

4) Provide a preliminary description of the fate of beach-cast MJ within the harvest region.

The study area is located on the east coast of Vancouver Island and encompassed the marine foreshore licensed for harvest by the BC Ministry of Agriculture for seaweed harvesting in 2014/15. This area extends along the approximately 4.24 km. The area upland of the harvest/survey area is known as the communities of Deep Bay and Bowser (Regional District of Nanaimo).
Methods

External data collection included weather event data obtained from the Department of Fisheries and Oceans website. Harvest data was obtained directly from the license holders. In order to quantify the biomass and distribution of beach-cast seaweeds present within the harvest region over the course of the harvesting season the entirety of the harvest region was walked weekly until February 5th, and bi-monthly after the harvest was finished. At randomly established locations along the walk samples were taken including location, number of discrete wrack bands as defined by age classes, depths and percent covers and average weights per volume. Photographs were taken at all sampling stations to document possible changes in the environment over the study period. From the data collected, the volume of wrack was calculated, and the weight of wrack present in the study area was estimated. The volume data are presented through ArcGIS map layouts in order to be more easily visualized.

Three permanent transects were established at six sites across the harvest region and monitored weekly to examine the biomass, distribution and macrophyte composition to provide a quantitative description of beach wrack band properties and macrophyte composition for harvested sites and un-harvested comparison sites over the harvesting season and beyond. Quadrat sampling was conducted on a weekly basis and representative samples of wrack were taken. Laboratory analyses of wrack samples included sorting of individual species of macrophytes. Macrofauna were also sorted and retained for future analysis. Species richness and diversity was calculated from these samples.

Two drift studies over the course of the monitoring period were conducted to provide a preliminary description of the fate of beach-cast MJ within the harvest region. Bundles of MJ were released on two occasions during the monitoring period. Individual bundles were composed of one naturally-formed bunch of MJ tied and labelled with a 10 cm long piece of highly visible, non-toxic, biodegradable flagging tape.

Opportunistic observations and photographs were recorded while in the field including sightings of birds and mammals, public interactions, vehicle tracks, disturbed vegetation and fauna etc. We maintained an active communications policy in response to public and media enquiries during the project.

Results

Winds greater than the 68th percentile of all wind data were chosen to indicate “significant” events which were more than 21.6 knots sustained. Data indicated that there are two predominant winter wind regimes: South — South-West, typically less than 10 knots and a wind that ranges from East-South-East through to South-East that created winds greater than the significant event threshold. Harvest data was provided by the three licensed companies. Harvesting began primarily at the Shoreline Drive location and then the majority shifted to The Deep Bay RV Park where the bulk of product was collected. In total 675 tonnes of the 900 tonne quota were harvested between October 5th and January 9th when harvesting ended. Deteriorating quality of beach-cast seaweeds was the reason that harvesters stated for discontinuing harvest activities.

Biomass sampling began November 7th and was carried out on a weekly basis until Thursday February 22nd, two weeks after the harvest was scheduled to end. The maximum volume of wrack (1268 tonnes) was noted on the first day of sampling on October 26th. This decreased rapidly to an estimated 587 and 608 tonnes during the following two weeks. Survey biomass averaged 212 tonnes per week through January 15th after which estimates dropped below 100 tonnes. Changes in the percent composition of wrack by relative age class indicated that fresh MJ wrack primarily came ashore during November with smaller events during January. Fresh wrack was gone by February which coincided with the cessation in harvesting activities by licensees. At the end of the sampling period total volume had decreased markedly and wrack “aging in place” was largely that which was in the supratidal region above normal high tide.

All of the six permanent transect sites experienced different levels of harvesting activity over the course of the 2014/15 harvesting season. Despite the removal of beach-cast seaweeds at the RV Park site throughout the monitoring period, the interquartile range and median biomass values for this site were similar to those of the un-harvested comparison sites suggesting that the harvesting activities were not reducing the available biomass between sites. Wrack biomass generally declined over time for all six sites. The rapid decline in biomass at
observed at the RV Park harvest and control sites began in the last two weeks of December, and first week of January. Declines in wrack biomass at RV Harvest transect coinciding with increasing biomass at RV Control transect may suggest the northward-movement of wrack through longshore drift. Biomass was consistently low at the southern sites during the monitoring period.

Macrophyte composition was analyzed for samples from 4 of the 15 collection dates. *MJ* accounted for the greatest proportion of the wrack macrophyte composition at all six of the sites. The proportion of degraded macroalgae ("Unidentifiable") was greatest at sites with higher wrack biomass. The mean proportion of degraded macroalgae in samples generally increased over the course of the monitoring period, suggesting that the proportion of fresh beach-cast materials was decreasing. The majority of the samples, however, were still primarily composed of identifiable specimens, suggesting that much of the decomposing macroalgae was either being mixed or moving, rather than entirely degrading in place. There was no evidence of spatial trends in total species richness from Southern-most to Northern-most sites, nor with harvesting pressure.

All macrofauna found in wrack samples analyzed for macrophyte composition were removed and stored for later analysis. Macrofauna samples collected in the fall appeared to have fewer specimens while greater activity was observed in the wrack as ambient temperatures rose near the end of winter leading up to spring. Our observations suggest that wrack provides a dynamic, habitat for macrofauna within the harvest region.

The results of the dispersal study indicate that storm-cast *MJ* within the supratidal zone can remain there for several weeks or even months, decomposing in place. All bundles placed within the intertidal zone, on the other hand, moved off the beach within a week. Rather than decomposing in place, wrack within this zone appears to be highly mobile. Storm-cast seaweeds within the supratidal and wrack deposits in the intertidal zone therefore have very different fates and unique ecological roles.

During the study period it was impressed upon the study team just how physically dynamic an environment the study area is with significant volumes of sediments, rock up to large boulders shifting through natural processes of wave movement, scour and longshore drift. We noted that in the mid to high intertidal that surface sediments could change from predominantly sand to large cobble to mixed gravels throughout the winter and that the slope and elevation of the beach could change significantly based on the frequency and strength of wave and tidal processes.

Photographs of wrack accumulations taken through the study illustrated rapid decreases in wrack volume that were observed independent of harvest volumes from the study area. Significant volumes of wrack were not observed in the later age classes of decomposition and additionally any long term impacts of the wrack build-up or harvest activities were not visible after wrack volumes decreased.

Anthropogenic changes to substrates as a result of harvesting activity appeared to be restricted to track depressions in soft and gravel sediments in the upper intertidal. These track depressions were not permanent and typically disappeared after the next series of high tides. The study area is primarily composed of upland subdivision settlement. A number of anthropogenic impacts on the study area were noted although the significance of these activities on the near shore environment has not been established. These included the removal of other intertidal plants by upland residents, "protest gardens" and extensive hardening of the upper intertidal. While formal survey protocols for wildlife were not employed, our observations suggest that there is little wildlife interaction with the wrack distributions.

**Summary**

A summary of the events during the harvest period are shown in the following figure. In this figure the harvest tonnage from the week prior is shown immediately below the volume estimate conducted at the end of the week. The total height of the area graph represents the estimated total biomass (harvested and remaining) during each week of the study (left axis).
Summary of wrack harvest, mean beach biomass estimate and mean wind speed over study period.

Average sustained wind speed during the week is plotted on the right axis of the graph. A clear relationship can be observed between storm events and increases in wrack volume.

It is important to note that the first biomass sampling estimate was completed on November 7, approximately three weeks after the start of harvesting activities. As a result, the onset of significant wrack biomass accumulating in the study and the total biomass prior to the start of the project is not known. The wind data suggests that the storm events during the middle of October may have brought the largest biomass observed during the season ashore.

Throughout the study period during the active harvest period, the amount of wrack removed ranged from 2-47% of the available biomass with an average of 16.5% (stdev +/- 0.12%) on a weekly basis. The maximum estimate of wrack in the study area was on October 26 with 1268 tonnes estimated by volume + 91 tonnes harvested or approximately 6.7% of total biomass. The next week volume dropped by 667 tonnes although only 101 tonnes (15.2 %) was removed by harvesters. The missing 562 tonnes cannot be accounted for by possible sampling error estimates during biomass surveys.

By November 30th, an estimated 544 tonnes had been removed by harvesters without exceeding more than 21.8 % of the total biomass calculated to be present in the study area in any given week. The following week, an estimated 46.6% of the weekly biomass was removed after which the harvest rate did not exceed 17% of weekly biomass for the rest of the harvest season. Both the biomass survey data and the results of the permanent transects suggest that harvesting does not appear to have a detectable effect on MJ biomass or macrophyte diversity over the course of this study.

Based on the data collected and ancillary observations, it appears that it is simplistic to interpret that wrack is coming ashore during storm events and then being harvested, eaten by macrofauna or decomposing in place as has been previously suggested.

Our working hypothesis is that wrack that remains below the high tide is continually moved northwest by a process of longshore drift, although it may temporarily accumulate in very high volumes in areas such as fronting the RV.
park. Only small amounts of wrack that is deposited onto the very high tide or above the high tide (supratidal) remains in place and decomposes fully. If this hypothesis is true, beach-cast MJ is brought ashore by wind events in the fall when the plants are weakened due to reproductive stress or other factors. Normal sediment processes of longshore drift in the intertidal rapidly move accumulations of wrack through the study area with rates determined by the combination of wave action and tidal heights. This has significant implications on the understanding of the role of MJ in the local ecosystem and its harvest management. Firstly, it would suggest that the instantaneous biomass estimates calculated on a weekly basis could grossly underestimate the total biomass coming ashore or moving through the 4.2 km harvest area. Secondly, this could mean that the ultimate fate of the MJ might have a significant subtidal component in the deeper portions of Baynes Sound with undetermined consequences on benthos and fauna.

Currently, we do not know how valuable MJ is to the function of this ecosystem; therefore it is not possible to determine if the impact of its removal is positive or negative. Regardless, this study suggests that the amount of seaweed removed is small relative to the amount that accumulates over the winter season. Most other wrack studies have focussed on wrack that has entered the intertidal during summer seasons when productivity is higher and supports larger infaunal and macrofaunal abundances (positive effects) but also potentially negative effects of decomposition. The local situation with MJ may be unique, occurring when temperatures and productivity is low and essentially dissipating out of the study area before biological productivity in the spring increases. A review of nutrient loading in the Strait of Georgia leads us to believe that the removal of MJ from the marine environment would not have a negative impact (limiting production) or significant positive impact (removal of excess anthropogenic nutrient inputs).

MJ has been present in our coastal ecosystems for a long period of time, potentially decades. It is unclear what has caused the perceived increase in abundance over the past decade and evidence is increasing that this species may be invasive. Exploring the drivers behind the localized increased abundance of this species would be valuable for understanding the impacts of this invasion, predicting how it may change in the future and if/how it may spread.

**Recommendations**

We recommend that further study is required including: continued monitoring of beach cast seaweed and harvests; determination of wrack transport patterns and final fate, the distribution changes of the population including a comparison sites along a gradient of MJ; the community structure of macrofauna within the wrack; further processing of samples taken during this study; interactions with forage fish spawning and; further genetic barcoding to differentiate with native species.
# Table of Contents

1 **Introduction** ....................................................................................................................................... 1  
   1.1 Project description and goals ..................................................................................................... 1  
   1.2 Background ................................................................................................................................ 1  
   1.3 Project Objectives ...................................................................................................................... 7  
   1.4 Limitations .................................................................................................................................. 8  

2 **Methods** .......................................................................................................................................... 10  
   2.1 Study Area ................................................................................................................................ 10  
   2.2 Data Collection ......................................................................................................................... 11  
   2.3 Biomass Survey ........................................................................................................................ 11  
   2.4 Biomass Data Analysis and Mapping ....................................................................................... 15  
   2.5 Interpolation ................................................................................................................................ 17  
   2.6 Drift Study ................................................................................................................................ 24  
   2.7 Opportunistic observational notes .......................................................................................... 24  
   2.8 Communication activities ......................................................................................................... 25  

3 **Results** ............................................................................................................................................. 26  
   3.1 Weather Data ........................................................................................................................... 26  
   3.2 Summary of Harvest Activities ................................................................................................. 29  
   3.3 Wrack biomass measurements ................................................................................................ 32  
   3.4 Permanent transect sampling .................................................................................................. 37  
   3.5 Macrofauna ................................................................................................................................ 47  
   3.6 Drift study results ..................................................................................................................... 48  
   3.7 Forage Fish ............................................................................................................................... 49  
   3.8 General Observations .............................................................................................................. 50  
   3.9 Use of wrack by wildlife ........................................................................................................... 57  

4 **Summary** .......................................................................................................................................... 58  
   4.1 Total abundance and harvest rates .......................................................................................... 58  
   4.2 Study area as a seaweed “conveyor belt” ................................................................................ 59  
   4.3 Summary observations on the ecological role of *Mazzaella japonica* in the study area ....... 61  

5 **Recommendations for further study** .............................................................................................. 64  
   5.1 Continued monitoring of wrack volume distribution ............................................................... 64  
   5.2 Determining wrack transport patterns and fate ..................................................................... 64  
   5.3 Monitoring distribution of *Mazzaella japonica* .................................................................... 64  
   5.4 Comparison sites along a gradient of *Mazzaella japonica* distribution .............................. 64  
   5.5 Macrofauna community structure ......................................................................................... 64  
   5.6 Analysis of February samples ............................................................................................... 65  
   5.7 Forage fish ............................................................................................................................... 65  
   5.8 Mazzaella DNA barcoding ...................................................................................................... 65  

6 **Literature Cited** ................................................................................................................................. 66
List of Tables and Figures

TABLES

Table 1. Example of how age class data was simplified: ................................................................. 13
Table 2. Wrack age classes used to categorize wrack samples .......................................................... 14

FIGURES

Figure 1. Harvest of wrack south of Deep Bay, November 2014 ........................................................ 1
Figure 2. Energy flow associated with faunal and microbial processing of kelp detritus in sandy beach ecosystem .......................................................................................................................... 2
Figure 3. The isomorphic, triphasic lifecycle of a red algae ................................................................ 3
Figure 4. Subtidal bed of Mazzaella japonica in fronting study area .................................................... 4
Figure 5. The two stages of invasion .................................................................................................. 5
Figure 6. Satellite photo of study area. Survey area indicated by green line. .......................................... 10
Figure 7. Example of bands of wrack in study area ........................................................................... 13
Figure 8. Study area showing permanent transect sites and harvester access points ......................... 19
Figure 9. Diagram of permanent transect set-up ............................................................................. 20
Figure 10. Wind Speed and Bearing over the study period (Oct. 1, 2014 to Feb. 22, 2015) ...................... 26
Figure 11. Wind data summary for Halibut Bank Weather Buoy, October 2014 .................................... 27
Figure 12. Wind data summary for Halibut Bank Weather Buoy, November 2014 ............................... 27
Figure 13. Wind data summary for Halibut Bank Weather Buoy, December 2014 ............................... 28
Figure 14. Wind data summary for Halibut Bank Weather Buoy, January 2015 ................................. 28
Figure 15. Wind data summary for Halibut Bank Weather Buoy, February 2015 ................................. 29
Figure 16. Percentage of harvest by quota holder ............................................................................. 30
Figure 17. Percent harvest by month ................................................................................................. 30
Figure 18. Total tonnes of wrack harvested by loading location and month. ........................................... 31
Figure 19. Wrack harvested (tonnes) per week as recorded by harvesters ............................................ 31
Figure 20. Example 5 km volume transect showing location of randomly established measurement points and interpolated volumes .................................................................................................. 32
Figure 21. Total wrack biomass estimate by for all age classes ............................................................ 33
Figure 22. Interpolation of wrack biomass within study area October 27, 2014 ...................................... 34
Figure 23. Interpolation of wrack biomass within study area November 27, 2014 .............................. 34
Figure 24. Interpolation of wrack biomass within study area December 31st, 2014 ............................ 35
Figure 25. Interpolation of wrack biomass within study area January 26, 2015 .................................... 35
Figure 26. Interpolation of wrack biomass within study area February 22, 2015 ............................... 36
Figure 27. Changes in wrack decomposition class by week ............................................................... 37
Figure 28. Boxplot of mean wrack biomass for all six permanent transect sites over the monitoring period .......................................................................................................................... 38
Figure 29. Boxplot chart of mean area covered by wrack per meter-wide transect extending from landward boundary to the water line. .................................................................39
Figure 30. Line chart of mean wrack biomass per meter-wide transect extending from the landward boundary to the waterline. ...........................................................................40
Figure 31. Line chart of mean area covered by wrack per meter-wide transect extending from landward boundary to waterline. .....................................................................................41
Figure 32. Mean proportion of Macrophyte species or groups in samples from all 4 of the analyzed collection dates. .................................................................42
Figure 33. Mean proportion of species or groups in samples divided by sampling date .........................43
Figure 34. Macroalgae species accumulation curve for all samples by site............................................44
Figure 35. Total number of macroalgae species identified in samples from all collection dates combined. Sample size for each site indicated in parentheses along x-axis..............................................................................45
Figure 36. Box plot of Shannon diversity index of macroalgae composition per sample across all six sites...46
Figure 37. Sites clustered by Jaccard distance calculated from mean macroalgae composition across all dates......................................................................................................................47
Figure 38. Northwest view changes in beach substrates between November and December 2014 ..........50
Figure 40. Thick layer of decomposing MJ mixed with large gravel under layers of storm cast rock and fresh wrack........................................................................................................52
Figure 41. Photographs of wrack accumulation fronting RV Park during study. ........................................53
Figure 42. Example of harvester tracks in upper intertidal........................................................................54
Figure 43. Tracked harvester vehicle stored on private property access across upper intertidal..............54
Figure 44. Removal of American Sea Rocket (Cakile edentula) from upper intertidal by upland residents....55
Figure 45. Protest Garden established at RV Park access site ...................................................................56
Figure 46. Example of hardening of the upper intertidal through use of cement blocks........................57
Figure 47. Summary of wrack harvest, mean beach biomass estimate and mean wind speed over study period..........................................................................................................................58
Figure 48. Accumulations of MJ at northern end of Deep Bay Spit, November 18, 2014 ....................60

List of Appendices

Appendix 1 – Shorezone Categorization Tables
Appendix 2: Press release and Poster regarding Drift study
Appendix 3: List of Communication Activities
Glossary

Anoxia: a total depletion in the level of oxygen

Beach-cast seaweeds: detached seaweed that does not grow on the beach, but has been cast there by surf, tides and/or wind.

Biomass: refers to the mass of biological material derived from living or recently living organisms.

Carrageenan: a polysaccharide extract from various red algae used typically as a gelling, thickening or clarifying agent in food, cosmetics and pharmaceuticals

Carposporophyte: first stage of the diploid (2n) sporophyte in red algae, formed by the union of haploid gametes. Produces carpospores which develop into trasporophytes.

Comparison sites: sites included in our permanent transect monitoring program from which no beach-cast seaweeds were removed for commercial purposes.

Dead zones: hypoxic (low-oxygen) areas in oceans or lakes that arise from the decomposition of plant or algal material following eutrophication events. When the plant or algal material eventually dies, it sinks and is decomposed by bacteria. As these bacteria work, they consume oxygen, ultimately causing the development and spread of “dead zones”—areas where the dissolved oxygen levels are too low to support aerobic (oxygen-requiring) life.

Dendrogram: a tree diagram used to illustrate the relationships of similarity among a group of samples, sites or other entities.

Effective number of species: the number of equally-common species required to yield a given species diversity index score.

Epifauna: animals living on the surface of the seabed or a riverbed, or attached to submerged objects or aquatic animals or plants.

Eutrophication: the ecosystem response to the addition of excessive nutrients (typically phosphates or nitrogen), be they artificial or natural. For example, “blooms” of phytoplankton in a lake, as a response to increased nutrients from fertilizers or sewage.

Food chain: describes a single linear pathway within a food web, starting from a primary producer species (such as trees or macroalgae) and ending at an apex predator or decomposer (such as cougars or bacteria).

Food web: refers to the complex network of food chains, describing which organisms are eaten by what within an ecological community.

Gametophyte: the haploid (1n, one set of chromosomes) multicellular stage that produces male or female gametes (sperm and eggs respectively)

Hypoxia: low-oxygen conditions, detrimental to aerobic organisms (organisms that require oxygen to respire) within the system.

Infauna: animals that live within the substrate (sediment)

Intertidal: area above the mean low tide and below the mean high tide mark. This zone is frequently both exposed and submerged by ocean water.

Introduced species: (or non-native): a species living outside of its native distributional range. It may have been introduced intentionally (e.g. Pacific oysters for shellfish aquaculture) or accidentally (e.g. zebra mussels from ballast water).

Invasive species: a non-native species, whether introduced intentionally or unintentionally, that spreads rapidly and has negative effects on the recipient environment.

Jaccard distance: measures dissimilarity between samples, is obtained by subtracting the Jaccard coefficient from 1.
Jaccard similarity coefficient: a statistic used for comparing the similarity and diversity of a given set of samples

Longshore drift: waves that hit the beach at an angle carry sand and gravel up the beach face at an angle. When the water washes back the sediment is carried straight back down the beach face. Individual particles are moved along the beach in a zig zag pattern.

Macroalgae: algae that is practically visible with the naked eye and does not require the aid of magnifying devices. Marine macroalgae are commonly referred to as seaweeds.

Macrofauna: a term applied to macroscopic animals that can be seen with the naked eye (larger than microfauna) but are smaller than megafauna. Includes primarily invertebrates such as insects.

Macrophytes: conspicuous freshwater or marine plants (macro algae and sea grasses) that grow near, below, or on the water.

Megafauna: a term applied to the relatively large animals of a given region, time period, and/or habitat

Point-contact transects: a method used for measuring the quantity and distribution of something by recording the first and last position for every point at which it is in contact with the transect.

Propagule pressure: a combination of the number of introduced individuals, and the number of introduction events. The stronger the propagule pressure, the more likely an introduced species will become established, spread and, in turn, become invasive (having negative ecological effects).

Quadrat: a small plot used to isolate a standard unit of area for study. Usually square or rectangular in shape.

Quantitative: relating to or involving the measurement of quantity or amount

Qualitative: relating to or involving the measurement of a quality of something, as opposed to a measurement of quantity.

Seaweed: multicellular marine algae visible with the naked eye (macroscopic). Includes members of the red, brown and green algae.

\[ H' = - \sum_{i=1}^{R} p_i \ln p_i \]

Shannon index: defined as: Where \( p_i \) is the proportional abundance of species \( i \)

Spatial subsidies: inputs of materials or organisms that originate from outside the habitat patch of interest. Wrack, for example, is typically composed of material from the marine environment, such as seaweeds, cast onto beaches (our habitat of interest in this case), and often benefit terrestrial ecosystems via food webs as well.

Species accumulation curves: graphs of the cumulative number of species detected in a particular site or unit of environment as a function of the cumulative effort spent looking for them. Plotting the curve enables comparisons of species richness between sites or environments with uneven sampling efforts. The number of species that would be discovered with further effort can be estimated from these graphs, given that the discovery of new species will slow down with increasing effort, reaching an asymptote.

Species richness: the number of different species within a given region, environment or community of interest. It does not take into account the abundances of these species.

Species evenness: refers to how equal species abundances are within a given region, environment or community of interest. It quantifies how close in numbers each of the resident species are to one another.

Species diversity index: a quantitative measure that takes into account both species richness and species evenness of a given community. There are several different diversity indices, two common ones being the Shannon index and the Simpson index.
**Sporophyte:** the diploid (2n, two sets of chromosomes) multicellular stage that develops from the fusion of male and female gametes. Sporophytes, in turn, produce haploid spores which develop into gametophytes.

**Standard deviation** is a measure used to describe the amount of variation in a set of values. A small standard deviation indicates that the data points tend to be close to the mean (i.e. there is little variation) while a greater standard deviation is indicative of a wider range of values.

**Supratidal zone:** the area above the mean high tide line, on coastlines and estuaries, that is regularly splashed, but not submerged by ocean water.

**Tetrasporophyte:** Second stage of the diploid (2n) sporophyte in red algae, develops from carpospores. Produces haploid (1n) spores which develop into a gametophyte.

**Transect:** a sample area, usually a straight line, path, or narrow section, along which observations are made and/or measurements are taken.

**Wrack bands:** the distinct bands of wrack, typically running parallel to the water line, that have been deposited by surf, tides and/or wind. These can be distinguished by their distribution (e.g. large gaps between bands), their depth, or level of decomposition.

**Wrack:** collective term for organic material, including seaweeds, sea grass and terrestrial debris, that washes up onto the beach by surf, tides and wind.
Acknowledgements

This project was funded by a Service Agreement from the BC Ministry of Agriculture. We are very grateful to Gary Caine and Wayne Sparanese for their support and advice.

This project also received non funded support in the form of Jessica Holden, Graduate Student at University of Victoria – co supervised by Dr. Sarah Dudas and Robert (Wes) Smith during a seven week practicum in the VIU Advanced GIS Diploma supervised by Brian Kingzett.

Jessica Holden assisted with literature review and study design and led the permanent transect field work and has initiated additional sample collection that will form part of her M.Sc. thesis and has volunteered several weeks of her time to contribute to project deliverables.

Wes Smith took it upon himself to manage and provide quality assurance on a complex data set and provided data summaries as well as impressive GIS products as evidenced in the report. We also received significant field assistance from a variety of VIU undergraduate student volunteers some of whom only know the study area by what they have observed by headlamp.

We have additionally received the generous additional support of a number of individuals on the project including:

- Contributions and advice of Stakeholder Advisory Committee (Ian Birtwell, Michael Recalma and Jason Rose) on the study design.
- Advice from Bill Veenhof, Area H Director Regional District of Nanaimo regarding community concerns and consultation.
- Peer reviews of sampling design by Kylee Pawluk and Dr. Caroline Fox. Ms. Pawluk has graciously contributed information regarding her thesis research throughout the study.
- BCMoA Fisheries Inspectors have kept the project team up to date on harvest activities.
- Rick Harbo (Retired DFO Biologist and invertebrate expert) joined project team for transect sampling and provided advice.
- Dr. Michael Hawkes (UBC Phycology Professor) joined project team for transect sampling and provided instruction of algal identification.
- Harvesters have assisted the investigations by keeping project team notified of harvest activities and providing on site information.
- A number of waterfront land owners have provided anecdotal information and observations to project team during volume surveys as well as use of driveways and properties for project access.
- Ms. Ramona deGraaf provided information on previous forage fish work, assisted with initial forage fish sampling, provided a training session on forage fish ID.
1 Introduction

1.1 Project description and goals

At the request of the BC Ministry of Agriculture, the Centre for Shellfish Research at Vancouver Island University (CSR-VIU) has documented the distribution and characteristics of beach wrack and the harvest activities during the 2014/15 harvest season. The goal of this project was to provide information that will help managers, community and harvesters assess the local environmental effects of this activity.

1.2 Background

1.2.1 Seaweed Harvesting on Central Vancouver Island

Since 2007, the British Columbia Ministry of Agriculture (BCMoA) has been issuing licenses that permitted commercial operators to remove beach-cast seaweed from beaches between Deep Bay and Bowser, on the central east coast of Vancouver Island.

The target species is the non-native red algae Mazzaella japonica \( (MJ) \). \( MJ \) is a valuable source of carrageenans widely used to gel, thicken and stabilize processed foods, cosmetics and pharmaceuticals. In 2011, investor interest increased, which led to an increase in licensed harvests. In 2012, the Ministry issued licences to commercially harvest up to 5,000 tonnes of from the Deep Bay region although this quota was not fully harvested. A harvest of 600 tonnes was approved for the 2013/14 harvest season and 900 tonnes of quota over 3 licenses was approved in 2014/15 under strict conditions of licence \(^1\).

Harvests are conducted by hand, using pitchforks to skim beach-cast seaweeds from the supratidal and intertidal zones of beaches within the harvest region. The seaweed is transported from the beach by tracked vehicle and then by truck to local drying facilities for processing. Bales of the dried seaweed are exported for industrial use.

Figure 1. Harvest of wrack south of Deep Bay, November 2014
In the last few years a group of local residents have voiced concern about the harvest citing environmental and social issues. Many others in the community seem to be neutral or in favour of the harvest for its economic benefits as long as it is sustainable. Drift seaweed can be an important part of the intertidal ecosystem, supporting intertidal organisms and cycling nutrients from the ocean to the land and back\(^2\). The physical activity of removing wrack from the beach could have negative impacts as well.

![Figure 2. Energy flow associated with faunal and microbial processing of kelp detritus in sandy beach ecosystem.](image)

Figure 2. Energy flow associated with faunal and microbial processing of kelp detritus in sandy beach ecosystem

Note: from Krumhansl and Scheibling (2012)

To date information has largely been the result of literature reviews and discrete observations during the harvest\(^3\).

### 1.2.2 Natural History of *Mazzaella japonica*

Native to Korea, Japan, and Russia, *MJ* was first recognized in our marine flora about 10 years ago although it may well have been here much longer than that. Reports of distribution have been concentrated in the area south from Deep Bay, south along the east coast of central Vancouver Island.

*MJ* (RHODOPHYTA, GIGARTINACEAE) is a flattened and dichotomously to irregularly branched red algae. It grows from the low intertidal down into the upper subtidal. Little is known about its reproduction. Eleven species of red algae belonging to the genus *Mazzaella* have been reported in British Columbia\(^4\). Members of this genus, however, can be difficult to distinguish due to tremendous phenotypic plasticity and convergent evolution\(^5\). The appearance of *M. splendens* and *M. linearis*, for example, in areas of intermediate wave exposure has been described as forming a seemingly continuous grade between the two species\(^6\). Saunders and Millar (2014) successfully assigned *Mazzaella* specimens to discrete species groups using COI-5P barcodes, and confirmed the presence of *MJ* on the east coast of Vancouver Island.\(^7\)
MJ likely has an isomorphic triphasic life history, typical of many red algae. Red algae with such life histories display three separate phases: one gametophyte phase (either male or female) and two sporophyte phases (carposporophyte and tetrasporophyte). All individuals are isomorphic (indistinguishable) until reproductive when phases and genders can be identified based on surface texture. Male gametophytes are smooth, while female gametophytes have large, rough bumps and the tetrasporophyte has many small bumps.

Observations from the field suggest that MJ is reproductive throughout the year, while an extensive basal crust suggests that it likely also propagates vegetatively.

Though there are many means by which non-native macroalgae can be introduced, aquaculture, particularly shellfish transfers, is considered to be one of the most important. Given the region’s extensive shellfish aquaculture activity, MJ may have been introduced to Deep Bay with shipments of oyster seed from Japan more than 80 years ago and is now becoming abundant.
Kylee Pawluk, a Ph.D. student in the Dept. of Geography at the University of Victoria, has documented extensive subtidal beds of this species south of Baynes Sound. At the Salish Sea Conference in 2014 she presented some of her field work which showed that MJ appears to be out competing local species, at least over short time scales, and may therefore be invasive.

The distinction between introduced and invasive is significant. Biologists typically refer to an alien (non-native) species as ‘introduced’ until it starts doing harm in the ecosystem at which point it is termed ‘invasive’. In the aquatic environment the Canadian Council of Fisheries and Aquaculture Ministers defines Invasive Species as: fish, animal, and plant species that have been introduced into a new aquatic ecosystem and are having harmful consequences for the natural resources in the native aquatic ecosystem and/or the human use of the resource.

An introduced species (or non-native) is a species living outside of its native distributional range. It may have been introduced intentionally (e.g. Pacific oysters for shellfish aquaculture) or accidentally (e.g. zebra mussels from ballast water).

An invasive species is defined as a non-native species, whether introduced intentionally or unintentionally, that spreads rapidly and has negative effects on the recipient environment.

Figure 4. Subtidal bed of Mazzaella japonica in fronting study area
Photo courtesy of Kylee Pawluck, UVIC
Macroalgae growing on rocky shores, such as those found in the study area, experience substantial and repeated wave-induced hydrodynamic forces. While individual waves are typically not forceful enough to account for breakage, damage accumulating over time can contribute to the eventual fatigue failure (fracture) of a macroalgae specimen. Fatigue failure in the genus *Mazzaella* can also vary with life history phase. In *Mazzaella splendens*, for example, male gametophytes endure more wave cycles than tetrasporophytes, which in turn endure more cycles than female gametophytes. Varying breakage rates could therefore be a reflection of changes in hydrodynamic forces (e.g. strong winter storms), seasonal reproduction patterns of the algae resulting in weakening of holdfasts or a combination thereof. A study looking at losses in *Fructellaria lumbricalis*, another red algae in the NE Baltic Sea found that beach casts (~5000 tonnes wet weight per year) represented only ~3% of the community standing stock in the summer.

### 1.2.3 Ecological role of beach-cast seaweeds

Detached macroalgae provide a significant spatial subsidy, transferred from marine to coastal and terrestrial ecosystems by oceanic currents, winds, tides and surf. Accumulations of these beach-cast seaweeds and other matter,
collectively known as wrack, play an important and well documented role within the marine-terrestrial ecotone\textsuperscript{19, 20, 21}. The decomposition of beach-cast materials, for instance, releases nutrients such as nitrogen and phosphorous, contributing to nutrient cycling\textsuperscript{22}. These nutrient inputs further enhance macroalgae and bacterial growth within intertidal and riparian ecosystems\textsuperscript{23}.

Additionally, wrack deposits provide a refuge from desiccation and predation for many species of macrofauna\textsuperscript{24, 25, 26} while for other upper-shore and terrestrial invertebrates it is a main source of food\textsuperscript{27, 28}. The benefits of wrack accumulations even extend to terrestrial ecosystems via food webs, including birds and terrestrial mammals\textsuperscript{29, 30}. The actual influence of wrack on community dynamics and ecosystem functioning, however, can vary greatly depending on its quantity, distribution and composition\textsuperscript{31}.

The biomass of wrack accumulations not only influences the magnitude of the deposit’s effect, but whether it benefits or harms organisms within the recipient environment. Macrofauna abundances, for instance, are typically positively correlated with the biomass of beach-cast seaweeds, with reported densities of more than 1000 animals per kg of wrack\textsuperscript{32}. Some species of macrofauna are even reported to time reproductive output to coincide with peaks in wrack biomass\textsuperscript{33}. Greater bird densities and abundances, in turn, have also been associated with greater quantities of beach-cast seaweeds\textsuperscript{34}. Referred to as "seaweed tides", mass stranding events of macroalgae as a result of eutrophication, however, can have profound ecological and economic consequences\textsuperscript{35}.

The decomposition of very high volumes can lead to the creation of hypoxic or anoxic zones. Such decreases in oxygen levels have adverse effects on infauna communities\textsuperscript{36, 37}. Additionally, hydrogen sulphide gas produced during the decomposition process not only has detrimental effects on the coastal ecology but can pose a health-risk for terrestrial wildlife and humans\textsuperscript{38}.

The spatial distribution of wrack on a beach influences the length of time it spends there and the nature of its interactions. The higher on the beach wrack is deposited, the longer it presumably remains there\textsuperscript{39}. The length of time beach-cast seaweeds spend on shore has implications for nutrient cycling and incorporation into terrestrial food webs. Wrack within the lower intertidal, on the other hand, is more likely to be driven by waves, tides and sediment movement, instead of undergoing dehydration and decomposition in one place. These detached seaweeds are typically incorporated into near-shore food webs and influence nutrient cycling in marine systems\textsuperscript{40}.

The macrophyte composition of beach wrack also influences its role within the ecosystem. Taxonomic groups or species of seaweeds differing in their physical structure (thickness, degree of branching etc.), for example, create unique microclimatic conditions within the wrack, varying in qualities such as temperatures and humidity\textsuperscript{41}. Nutritional values\textsuperscript{42} and decomposition rates\textsuperscript{43} are also known to differ between macrophyte species. These properties, in turn, influence macrofauna communities, determining their composition, abundance and turnover\textsuperscript{44}. The introduction of non-indigenous species can have profound consequences for recipient communities and ecosystems\textsuperscript{45, 46}. In marine systems, non-native macroalgae significantly reduce density, biomass, diversity and evenness of native primary producers, influencing their
availability to consumer communities. Furthermore, some species reportedly cause physiological damage to generalist herbivores, or water anoxia. Owing to differences in their physical structure, decomposition rates and nutritional values, non-native species can alter carbon, nitrogen and phosphorus provision, modifying nutrient cycling and benthic communities. How introduced macroalgae affects communities within wrack deposits, however, is still not well understood.

The removal of beach-cast seaweeds, for aesthetic or commercial purposes is increasing globally. Mechanical beach cleaning, also known as “grooming” is common on public and resort beaches in the US, Australia and New Zealand where the presence or smell of wrack impedes beach enjoyment. Beach-cast seaweeds are also collected from coastlines world-wide for use in agricultural fertilizers, shellfish aquaculture and for human consumption.

Literature on the impacts of harvesting beach cast seaweed is limited. One of the only review papers on beach-cast seaweed harvesting identifies several knowledge gaps that need to be addressed to make management decisions on this resource. These included wrack biomass, distribution and composition and form some of the key objectives of this study. Other knowledge gaps relate to those identified at the end of this document and include wrack residence time on the beach, relationship between beach-cast and offshore algal stands and the fate of beach-cast seaweeds.

It is also important to note that other wrack studies should also be considered in light of seasonal and habitat differences such as wrack accumulation during summer months and in nutrient limited sandy beach habitats. Temporal and environmental differences may further limit comparisons.

1.3 Project Objectives

1.3.1 Overall objective

The objectives of the project were to assess the biomass, distribution and composition of beach wrack accumulations in the MJ licensed harvest area south of Deep Bay, on the East coast of Vancouver Island, British Columbia.

Specific objectives

Specific objectives of the project were as follows:

1) Collate existing information on beach wrack monitoring methods and the nature of wrack accumulations in Deep Bay to design an effective study based on international examples as well as local knowledge.

2) Quantify the biomass and distribution of beach-cast seaweeds present within the harvest region over the course of the harvesting season.

3) Provide a quantitative description of beach wrack macrophyte composition and biomass for harvested sites and un-harvested sites across the region.

4) Provide a preliminary description of the fate of beach-cast MJ within the harvest region.
1.4  Limitations

There were several important factors limiting the study design, the timing of its implementation, and the conclusions we can draw from this study:

1.4.1  Project timeline

The duration of the contract was five months from announcement to the report submission deadline. This was a very short timeline for the design, implementation, and synthesis of such a project. We stress that 5 months of monitoring constitutes a short-term study. These results should be viewed as preliminary findings which can be used to inform the design and implementation of future, more extensive, research.

1.4.2  Timing of project implementation

Ideally, the sampling methods outlined below would have been implemented prior to any harvesting activities. Timing of project funding and approvals, announced October 22, 2014, resulted in the project beginning after wrack had already begun washing ashore and the harvest was underway. Consequently, we can make no comparisons with conditions prior to the harvest and were unable to make observations for the first 2-3 weeks of the harvesting season.

1.4.3  Permanent transect site selection

Six permanent transects sites were selected for this study at the beginning of the monitoring period. Three of these were placed at locations deemed likely to be harvested, and the remaining three sites were to serve as comparison sites from which no beach-cast seaweeds would be removed. Due to the accumulation of large volumes of wrack at the RV Park, beach-cast seaweeds were harvested at this single location for all but 2 days during the monitored period. Thus, instead of having three harvested sites we had only one primary harvest site, which limits our ability to detect the impact of harvesting activities and differences between harvested and un-harvested sites.

1.4.4  Tides

Although we tried to be as consistent as possible, monitoring was strongly constrained by the tides. Due to the timing of winter tides and the length of time required to complete such detailed sampling at several sites kilometres apart, permanent transect monitoring was performed over a range of hours beginning at 12:30 pm and ending at 6:40 am. The majority of the sampling was performed in the dark, with the aid of headlamps, limiting our ability to make opportunistic observations of beach- or wrack-use by local mega fauna. This also limited our use of the camera during permanent transect monitoring, as even with the flash, pictures showed very little of the beach.

1.4.5  Sample processing

Individual wrack samples from transect processing took anywhere from 20 minutes to 1.5 hours to process, depending on their condition and the abundance of macrofauna. Given the time restraints of this report we could process samples from four collection dates only. We settled on four dates, spread evenly three weeks apart, collected by the same two individuals at a similar time of evening.

Not surprisingly, given the conditions to which wrack is subjected both before and after washing up onto the beach, samples contained macrophyte
specimens that were either too small or too degraded for proper identification based on their morphology and colouration. Because we did not feel these could be identified with confidence they were classified as "Unidentifiable". As a result, there could be additional species of macrophytes in the wrack that we were unable to detect, requiring DNA barcoding or histological sectioning for proper identification.
2 Methods

2.1 Study Area

The study area is located on the east coast of Vancouver Island and encompassed the marine foreshore licensed for harvest by the BC Ministry of Agriculture for seaweed harvesting in 2104/15. This area extends from a point east of the community of Deep Bay (49.465911 N, 124.723283 W), south east approximately 4.24 km to a point at 49.445017 N, 124.680917 W. The area upland of the harvest/survey area is known as the unincorporated communities of Deep Bay and Bowser (Regional District of Nanaimo).

Figure 6. Satellite photo of study area. Survey area indicated by green line.
2.2 Data Collection

2.2.1 External data collection:

Weather conditions

Weather event data was downloaded in CSV format from the Department of Fisheries and Oceans website. The Halibut Bank Weather buoy was chosen for its location (open water in the Strait of Georgia) and its abundance and consistency of data. With few exceptions, hourly data records were available. The data from Halibut Bank was received in CSV format, converted to XLSX format and cleaned by removing the data not used in the analysis. For this study, wind speed (m/s converted to km/hr) and direction (bearing degrees from true North) were of interest.

In Microsoft Excel, the mean wind speed and direction for each day in the study period was calculated and grouped together into weeks and weather events were identified. A weather event was defined as a value above the 68th percentile: for this study period 21.6 km/hr. Weather events that occurred within three days prior to the collection day were of primary interest since any events greater than three days would be less likely to be on the beach for the collection day.

Both wind speed and direction were analysed for data within the study period, and these data were compared to note any differences that would add to the wrack analysis.

Contribution of the harvesters

We obtained the following information from harvester logs and interviews:

- Which license holder(s) was/were harvesting
- Number of baskets hailed and estimated weight of harvested seaweed for each day of harvesting
- Location of harvest activities for each day of harvesting and loading point

2.3 Biomass Survey

2.3.1 Objective:

The objective of the biomass surveys was to quantify the biomass and distribution of beach-cast seaweeds present within the harvest region over the course of the harvesting season and beyond.

2.3.2 Sampling locations and data collection

The entirety of the harvest region was walked weekly until February 5th, and bi-monthly after the harvest was finished (February 5th), recording measurements of wrack biomass and distribution during a medium to low tide. Surveys took place on Mondays (unless unable due to tide/daylight restraints) in order to allow the 4.2 km harvest area two days to accumulate wrack unaffected by harvest activities, as harvest licences did not permit weekend collection.
The walk started at the southern end of the harvest region, Buccaneer Beach Road, ending at the Deep Bay RV Park. At the outset of each volume walk we recorded:

- Date, time
- Current weather conditions
- Height of tide at time of sampling, as estimated from tidal charts

Over the course of this walk, we recorded the following information (listed below) at random intervals of paces ranging between 50 to 125 paces, determined using a random number generator. This approach was chosen to ensure that the entire area was sampled during the walk while still ensuring that specific stations were randomly selected and that an approximate 30 samples per survey were made to provide statistical significance.

At the beginning of the project we noted that high wrack volumes and the difficulty of wading through them inhibited the use of our “paces” unit. We therefore adjusted the random selection bounding range to between 75 to 150 paces in October/November. As volume decreased and walking became easier, pace range was adjusted accordingly in order to keep near the target number of 30 sampling stations within the study area survey.

- Latitude and Longitude, using handheld GPS (Garmin GPSMAP 78s), and GPS enabled camera (Nikon COOLPIX AW120) as secondary unit.
- Number of discrete wrack bands, as defined by age class (Appendix Table 1). Noting whether bands are clean or mixed with sand/gravel.
- The width of each discrete wrack band.
- The depth of each discrete wrack band using a measuring stick driven down into the wrack until it hits the ground, but is not pushed into sediment. Done at a minimum of 3 intervals ¼, ½ and ¾ of the width of the band and used to calculate average depth.
- Percent cover of each discrete band, recording both the Macrophyte coverage of bottom sediment and the sand/gravel coverage of wrack.
- Age class of wrack band according to classification scheme (Table 1).

At opportune locations throughout the survey a 19 L bucket was filled to the brim with wrack from multiple depths to form a representative sample. The filled bucket was weighed using a hand-held Rapala 50LB/25KG digital spring scale. This was repeated a minimum of three times for each distinct band of wrack present at the final sample site. This was used to develop a daily volume conversion to weight value for each age class band. Field recorded data was entered into an Excel template.

2.3.3 Determination of Wrack Age classes

During initial investigations prior to project start we observed that wave action tended to “sort” the MJ into bands of relatively consistent age or
decomposition classes. We also noted that as the wrack decayed the weight per volume increased significantly and that the harvesters only removed “fresh wrack” from the intertidal area (Age classes 1-2). To account for this we established a subjective age (decomposition) class categorization as shown in the following figure. This classification system was modelled after a Large Woody Debris classification by Wooster & Hilton\(^5^3\).

**Figure 7. Example of bands of wrack in study area**

It was common to record two or three age classes within one band. In order to calculate the weight, the age classes of bands with wrack of multiple ages was simplified by averaging to either a rounded whole number or halfway between two whole numbers (e.g., 1.5). This allowed the data to be used in calculating the volume and subsequent weight of wrack. Typically, the simplification was to take an average of two classes that were observed to make up a discrete wrack band.

**Table 1. Example of how age class data was simplified:**

<table>
<thead>
<tr>
<th>Original Age Class Data</th>
<th>Simplified Age Class Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>1.5</td>
</tr>
<tr>
<td>2/3/4</td>
<td>3</td>
</tr>
<tr>
<td>2/3/5</td>
<td>3</td>
</tr>
<tr>
<td>Age Class 1</td>
<td>Characteristics</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------</td>
</tr>
<tr>
<td></td>
<td>Blades intact</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Class 2</th>
<th>Characteristics</th>
<th>Texture</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blades intact</td>
<td></td>
<td>Original colour, dark purple/brown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Class 3</th>
<th>Characteristics</th>
<th>Texture</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detached/missing blades</td>
<td>Slimy at frond tips/bleached portions</td>
<td>Patchy colouration fading to white</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Class 4</th>
<th>Characteristics</th>
<th>Texture</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detached/missing blades</td>
<td>Slimy at frond tips/bleached portions</td>
<td>Patchy colouration fading to white</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Class 5</th>
<th>Characteristics</th>
<th>Texture</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detached/missing blades</td>
<td>Slimy across entire thallus</td>
<td>Granular texture in areas of advanced decomposition</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Class 6</th>
<th>Characteristics</th>
<th>Texture</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detached/missing blades</td>
<td>Slimy across entire thallus</td>
<td>Granular texture in areas of advanced decomposition</td>
</tr>
</tbody>
</table>

Table 2. Wrack age classes used to categorize wrack samples
2.3.4 Standard photo stations
On every 4.2 km biomass (volume) survey, pictures were taken at all sampling stations looking up and down the beach to document possible changes in the environment over the study period. These stations were selected based on easily identifiable landmarks (individual boulders, headlands etc.). Each picture encompassed both the landward boundary of the beach and the waterline, unless made impossible by a particularly low tide. As mentioned previously our camera encoded GPS information onto each photo.

2.4 Biomass Data Analysis and Mapping

2.4.1 Analysis
From the data collected, the 2-dimensional (2D) area of wrack bands at each transect were determined. From this area value, the volume was calculated, and from the volume (m$^3$ per m of coastline) age class, and age class weights for a particular collection day, the weight of wrack could be estimated (tonnes per m$^3$).

2.4.2 GPS Data
Coordinates were recorded through two means: a Garmin GPS unit (Model # GPSMAP 78s) and a Nikon Camera with GPS capabilities (model # COOLPIX AW120). The Garmin was the primary unit for recording the coordinates. Each coordinate’s location was checked prior to running any analysis on the data.

2.4.3 Depth of wrack bands
A minimum of three depth measurements was taken from each band: many records were collected from wide bands, but a minimum of three depth records were collected at narrow bands (as narrow as 20 cm). The depth records of a band were used to determine the mean depth of that band.

2.4.4 Area
Once the mean depth of each band at a site was determined, the area of each band was calculated as follows:

\[ B_1\text{Area} = B_1\text{Width} \times B_1\text{Mean Depth} \]

The area calculated was multiplied by the percent cover values in order to determine a more accurate area, based on what was found at each band at each transect (see the example below).

\[ \text{Actual} B_1\text{Area} = B_1\text{Area} \times B_1\text{%Cover} \]

Since there could be many bands at each transect, the area of each band was then used to determine a weighted mean area of the transect with the following formula:

\[
\frac{(B_1\text{%Cover} \times (B_1\text{Width} \times B_1\text{Depth})) + (B_2\text{%Cover} \times (B_2\text{Width} \times B_2\text{Depth})) + (B_3\text{%Cover} \times (B_3\text{Width} \times B_3\text{Depth})) + (B_4\text{%Cover} \times (B_4\text{Width} \times B_4\text{Depth}))}{B_1\text{Width} + B_2\text{Width} + B_3\text{Width} + B_4\text{Width}}
\]
2.4.5  Calculating Biomass

With the mean depth and total width of the wrack at each transect, the volume could be estimated. The area of each band was used to calculate a volume measurement (m$^3$). Since there was typically little variation within one meter, it was assumed that the area (or slice of wrack) determined from the transect could be multiplied by 1 meter to determine the volume at the transect.

2.4.6  Calculations of Weight

On Beach

While the volumetric calculations are helpful in displaying the accumulation and movement of wrack, the wrack harvested from the shore is measured by weight; therefore, the volume values were converted to a weight value. This allowed a comparison to take place between the total weights of measured wrack with the weight of wrack harvested. Since older wrack is in an advanced state of decomposition and is thus denser, the age class recorded for each band at each transect was used to determine the weight per volume of wrack at each band.

For each data-collection-day, the weight of each age class was collected. These weights were applied to the volume of all bands of a matching class. From the gross weight, the bucket’s weight (0.62 Kg) was subtracted, and the net weight of the wrack was divided by the volume of the bucket (19 L or 0.019 m$^3$) to determine the weight per m$^3$ of a particular age class on that particular day.

At each transect, the weight of each band was determined by multiplying the age class weight (determined by the age class of each band) by the volume of each band. These values were added together to determine the total weight of wrack at that site. Below are the formulas:

\[
\text{Total Weight} = (B_1 \text{Vol}_1 \times B_1 \text{AgeClassWeight}_1) + (B_2 \text{Vol}_2 \times B_2 \text{AgeClassWeight}_2) + \ldots
\]

There were cases in which the wrack band was composed of multiple age classes; in this case, a mean wrack weight was determined from the weights of each age class recorded for that band.

Once the weight of wrack at each transect was determined, the mean weight for that collection day was calculated. The mean weight was then applied to every metre of the transect, the mean was multiplied by the length of the length of the study area. The shoreline study area was determined by merging all the spatial data to determine which point was furthest south and which was furthest north. These points became the farthest extent of the shoreline. In total, the intertidal study area was calculated as 4,235.5 metres in length.

Harvest Weights

In addition to the weight of the wrack on the beach, the total weight of harvested wrack was also calculated. The weights provided by the harvesters was compiled in an Excel spreadsheet and summarized by the week in which the harvests took place, the volume each company harvested, and the sum of the harvested weights (weight harvested that week). These weights were then added to the weights remaining on the beach in order to determine the total wrack weight for that week.
The data collection days were scheduled for Mondays; therefore, the harvest weights were calculated from Monday-Sunday.

2.5 Interpolation

The study area is a section of beach approximately 4.2 km in length, and the sampling points ranged from approximately 100-300 meters apart. In order to gain a more accurate assessment of the wrack accumulation, the use of interpolation was assessed. First the following questions were asked:

- Are the data spatially autocorrelated (that is, data from locations closer together are more likely to be similar).
- Are the data clustered?
- Are the data normally distributed (or can they be made so)?
- Are the data stationary?
- Are there trends in the data (global or local)?

After visual inspection of the data, the following answers to the above questions were arrived at:

- Data are autocorrelated.
- Data are not clustered.
- Data are not normally distributed, but a log transformation can be applied to make it so.
- Data are not stationary.
- There are local trends, and for some collection days, there are global trends.

Next a Moran’s I test was run with the datasets of four collection days in order to test the benefits of interpolation with the data itself. The first Moran’s I tests indicated that interpolation would be a helpful process; however, when a quality check was performed the Moran’s I test again after removing 4-5 clustered points with the highest weight values, the test indicated that the distribution was, in fact, most likely random. This same quality check was performed on the data from four collection days with the same results.

It was then concluded that instead of a sophisticated interpolation method, a mean weight of each collection day would be as effective a means of determining the total weight of wrack on a collection day.

2.5.1 Biomass Visualization

Map Layouts

The volume data are presented through map layouts in order to be more easily visualized. ArcGIS was used to digitize a polyline of the shoreline. The line feature loosely marks the data collection route. From this was created a “beach” polygon, which was used as a mask for each interpolated surfaces (one representing each data collection day); only the interpolated surface that falls within the mask is displayed. The beach polygon is not the width of the beach (although in some locations it may be close); nor does it represent the width or volume of the wrack.
The map layout displayed a masked interpolated surface with a classified symbology. Twenty classes were created and a colour spectrum was applied to help visualize the volume of wrack. Low volumes are represented with a blue colour (darker demarcates lower values), high volumes of wrack are represented with a red colour (darker demarcates higher values), and mid volume values are represented with a yellow colour. The study maximum and minimum volume values were determined from a review of the entire study period.

The following is an example of how the $B_1$ coefficient was determined:

\[
\frac{B_1 \text{Width}}{B_1 \text{Width} + B_2 \text{Width}}
\]

With a coefficient, the weight at a transect that has taken the age class into account

\[(B_1 \text{Co} \times B_1 \text{Weight}) + (B_2 \text{Co} \times B_2 \text{Weight})…\]

### 2.5.2 Permanent Transects

**Objective:** Provide a quantitative description of beach wrack characteristics (biomass, distribution and composition) for harvested sites and un-harvested comparison sites over the harvesting season and beyond.

**Methods:** Three permanent transects were established at six sites across the harvest region and monitored weekly to examine the biomass, distribution and macrophyte composition of distinct wrack bands. The six sites were selected based on their proximity to the harvest area and their biophysical similarities. The specific methods undertaken to meet this objective can be broken into 6 components:

1) Site selection  
2) Site characterization  
3) Establishment of permanent transects  
4) Permanent transect monitoring  
5) Sample analysis  
6) Data analysis

#### 2.5.3 Site selection

Six beaches along Deep Bay’s coastline were selected as permanent transect sites based on beach characteristics (their biophysical similarities), accessibility by foot and their potential exposure to harvesting activity.

The six permanent transect sites were located near access points at: Henry Morgan Road (HM), Buccaneer Beach Road (BC), Ocean Trail (OT), Shoreline Drive (SH), and two sites near the Deep Bay RV Park (RVC and RVH).
Three of these were ‘harvest’ sites, placed at locations deemed likely to be harvested (BC, SH, and RVH). Harvest sites were selected with the help of the licence holders, based on their experience in previous years. The three remaining locations were selected as comparison sites (HM, OT and RVC) which would not be subject to harvesting. The comparison sites were selected on the basis that they shared similar beach characteristics with the harvest sites, were accessible by foot, and would not be harvested. Comparison sites were established with the cooperation of the licence holders and harvesters who agreed that no beach-cast seaweeds would be removed from these regions.

2.5.4 Site characterization

The six sites were characterized according to the ShoreZone Coastal Habitat Mapping Protocol\textsuperscript{54}. This protocol is used by Alaska, British Columbia and Washington, to characterize coastal habitats for mapping, monitoring, and coastal marine resources planning purposes. Using this protocol allows our findings to be integrated with existing government agency and NGO programs utilising this system.

For each site we recorded the primary structuring process (Appendix 1 Table 1), the substrate type, the width of both the supratidal and the intertidal zones, the sediment composition of each zone (Appendix 1 Table 2), and three slope measurements within each zone (within the first 2 m, at the midpoint and last 2 m of the zone). Any anthropogenic modifications to the site were also noted (Appendix 1 Table 3). Using the characteristics outlined by the ShoreZone protocol we were able to assign each site a shore type (Appendix 1 Table 4). Following site classification we checked our results against previous classification records from the British Columbia Coastal Resource Information System\textsuperscript{55}.
2.5.5 Establishment of permanent transects

Three permanent transect were established at each of the six transect sites following the protocol established by Dugan et al.\textsuperscript{56}, which is used extensively for beach wrack monitoring studies\textsuperscript{57,58,59}.

The locations of the permanent transects were assigned randomly along a 50 m transect tape at the lowest edge of the terrestrial vegetation (landward boundary), running parallel to the water. The three locations were produced using a random number generator. A minimum distance of 10 meters was left between locations to minimize potential effects of monitoring activities on adjacent transects.

The coordinates of each site were recorded with a hand-held GPS and corroborated with pictures from a GPS-equipped Nikon Coolpix AW110 digital camera. A piece of rebar, tied with highly visible flagging tape, was hammered into the sediment at the landward boundary of each permanent transect site, serving as the point 0 marker. A nearby land mark was also flagged in the event that the marker became buried or washed away.

2.5.6 Permanent transect monitoring

At each site we ran a transect tape from the point 0 marker to the water line (Figure 9). For each of these point-contact transects we recorded the first and last position of any beach wrack bands that intersected the transect tape as well as the position of any gaps. The total length of a band therefore represented the distance from the start of the band to the end of the band (excluding any gaps) as measured perpendicular to the water line.

![Diagram of permanent transect set-up.](image)

A random number generator was used to select one point within each band. If the band was greater than two meters wide, one meter was excluded from either end of the band’s range in order to minimize edge effects. If the band was less than two meters wide, the center point of the band was selected. A 0.0625 m\(^2\) quadrat was placed directly next to the transect tape at the selected point. For each quadrat we recorded:

- Visual estimate of percent wrack cover of the beach substrate
- Level of wrack decomposition (Table 1.)
Three wrack depth measurements: one from the landward edge of the quadrat, one from the center, and one from the edge nearest the water. Depths were measured with a meter stick pushed into the wrack until it came into contact with the sediment, but no further.

Within each quadrat we also collected a representative sample of the wrack. A 1 litre tin was filled to the brim with wrack from the center of the quadrat and weighed using a hand-held spring scale. If there was an insufficient amount of wrack within the quadrat to fill the tin, wrack from directly outside the quadrat was also used. If the depth of the wrack within the quadrat was greater than the depth of the tin, one full tin was taken from the top layer of the wrack band, another from the center depth and a final tin from the bottom. These were mixed in a tote, from which a single full tin subsample was taken.

Each sample was transferred to a labeled Ziploc bag, sealed, and frozen for later analysis.

**Sample analysis**

Macrophyte composition was analyzed for samples from four of the fifteen collection dates, each three weeks apart:

- November 27th
- December 18th
- January 8th
- January 29th

Samples from these dates were all collected by the same two individuals and at a relatively similar time of evening.

Samples were rinsed under fresh water in a 1 mm sieve, and transferred to a tray for sorting. Within the tray, samples were suspended in fresh water and macrophytes were removed piece by piece and sorted into groups. Where possible, macrophytes were identified to species. Terrestrial plant material was grouped collectively as “Terrestrial debris”, and macrophyte fragments too small and/or degraded to identify with confidence were grouped collectively as “Unidentifiable”. Groups of macrophytes from each sample were dried individually at 70°C in a drying oven until they reached a constant weight. Dried macrophyte groups were weighed to the nearest 0.01g.

Concurrent with macrophyte sorting, all macrofauna within each sample was carefully removed using forceps. Macrofauna from a given sample was stored collectively in a vial of 75% ethanol for later analysis beyond the timeline of this study.

Because *MJ* is a non-indigenous species, we took precautions during this study to prevent its further spread. The above processing was done at the Deep Bay Marine Field Station, which is located within *MJ*’s known distribution on Vancouver Island.

**2.5.7 Data analysis**

All data was entered in Excel 2013. Basic calculations of wrack area, volume, biomass and macrophyte proportions per band were done in Excel, while the
remaining calculations and analyses were performed using the statistical program R.  

**Area, volume and biomass calculations**

Wrack area of a given band ($B_i$Area) was calculated for each band of wrack at a given site on a given sampling day by multiplying the band’s total length ($B_i$Length) in meters, excluding gaps, by the visual estimate of percent cover for that band ($B_i$%Cover). This value represents the area (in $m^2$) of substrate covered by each band of wrack within a 1 meter-wide (Width) transect running perpendicular to the water.

$$B_i\text{Area} = B_i\text{Length} \times B_i\%\text{Cover} \times \text{Width}$$

The mean depth ($B_i$MeanDepth) of each band was calculated from the three depth measurements per band and expressed in meters.

$$B_i\text{MeanDepth} = (B_i\text{Depth}_1 + B_i\text{Depth}_2 + B_i\text{Depth}_3) / 3$$

Wrack volume for a given band ($B_i$Volume) was calculated by multiplying the band’s total length by its mean depth and a standard 1 meter width. This value represents the volume of wrack (in $m^3$) within a 1 meter-wide transect running perpendicular to the water.

$$B_i\text{Volume} = B_i\text{Length} \times B_i\text{MeanDepth} \times \text{Width}$$

Wrack biomass per band ($B_i$Biomass) was calculated using the estimated volume of each band and the weight of the 1 L sample recorded in the field. Band volume in $m^3$ ($B_i$Volume), was multiplied by the weight of the 1 L wrack sample in kilograms ($B_i$Weight), and divided by the known volume of the sample in $m^3$ (1 L = 0.001 m$^3$).

$$B_i\text{Biomass} = B_i\text{Volume} (m^3) \times B_i\text{Weight} (kgL^{-1}) / (0.001 m^3 \text{L}^{-1})$$

Wrack area, volume and biomass were determined for each transect by calculating the sum of these values for all bands within the transect (e.g. $T_i$) (i.e. wrack area, volume and was aggregated by transect number, site and date).

$$T_i\text{Area} = B_1\text{Area} + B_2\text{Area} + B_3\text{Area}$$

$$T_i\text{Volume} = B_1\text{Volume} + B_2\text{Volume} + B_3\text{Volume}$$

$$T_i\text{Biomass} = B_1\text{Biomass} + B_2\text{Biomass} + B_3\text{Biomass}$$

The average for each site (e.g. $S_i$) on a given sampling day was then calculated across each of the three transects. These site values reflected the mean area ($m^2$), volume ($m^3$) and wet weight biomass (kg) of wrack per meter-wide transect running perpendicular to the waterline.

$$S_i\text{Area} = (T_1\text{Area} + T_2\text{Area} + T_3\text{Area}) / 3$$

$$S_i\text{Volume} = (T_1\text{Volume} + T_2\text{Volume} + T_3\text{Volume}) / 3$$

$$S_i\text{Biomass} = (T_1\text{Biomass} + T_2\text{Biomass} + T_3\text{Biomass}) / 3$$

Area, volume and biomass values for each site were used to generate descriptive figures of beach wrack properties across sites and sampling dates. Figures were generated using the statistical program R and the ggplot2 package.
**Macrophyte proportions**

The mean dry weight of each macrophyte group within a sample was calculated for each site. These mean dry weights were calculated first using values from all four collection dates pooled, then for each collection date separately. The mean proportion of each macrophyte group within a sample \((M_{i,\text{Proportion}})\) was calculated by dividing the macrophyte group’s mean dry weight \((M_{i,\text{Weight}})\) by the sum of mean dry weights for all macrophyte groups \((S_{i,\text{DryWeight}})\).

\[
M_{i,\text{Proportion}} = \frac{M_{i,\text{Weight}}}{S_{i,\text{DryWeight}}}
\]

Mean site macrophyte proportions were used to generate stacked bar plots describing the proportion of each sample represented by each macrophyte group within a given site and date, or across all four analyzed collection dates.

**Macroalgae species accumulation curves**

Using the dry weights of only the identifiable macroalgae (i.e. excluding terrestrial debris and unidentifiable specimens) the R package Vegan\(^63\) was used to generate species accumulation curves for each site. Given that the number of samples collected at each site depended upon the number of wrack bands, sites differed in sampling effort. Generally, increased sampling effort will lead to the detection of more species, thereby increasing reported species richness and diversity. The resulting species accumulation curves were therefore used to compare the completeness of macroalgae inventories for each of the sites.

**Macroalgae species richness**

The total species richness of each site was calculated from its mean species composition, spanning all four collection dates. This represented the total number of species detected at each site over the entire monitoring period.

**Macroalgae species diversity**

Shannon diversity index values were calculated from macroalgae dry weights for each individual sample using the Vegan package in R\(^64\). Mean diversity index values per sample were then determined for each site.

The Shannon index values were calculated as follows:

\[
H' = -\sum_{i=1}^{R} p_i \ln p_i
\]

Where \(p_i\) is the proportional abundance of species \(i\).

A cluster dendrogram of Jaccard similarity was generated using the Vegan\(^65\) package in R, based on the mean dry weights of macroalgae species for each of the six sites.
2.6 Drift Study

Objective: Provide a preliminary description of the fate of beach-cast MJ within the harvest region.

Methods: We performed two drift studies over the course of the monitoring period, using naturally-formed bundles of MJ collected from the monitoring region, and marked with biodegradable flagging tape. Marked bundles allowed us to monitor the time beach-cast MJ spends within the wrack and its movement between sites.

Bundles of MJ were released on two occasions during the monitoring period: once on December 21st, 2014 and a second time on January 18th, 2015. Individual bundles were composed of one naturally-formed bunch of MJ. A 10 cm long piece of highly visible, non-toxic, biodegradable flagging tape was secured to the center of each bundle using a metal twist-tie. Each piece of flagging tape was labeled in permanent marker with an alpha numeric code representing the release site and date of the bundle. Additionally, the colour of the flagging tape was unique to each combination of release site and date.

100 bundles were prepared for each release date. On both occasions these bundles were divided between two sites: Shoreline Drive and Ocean Trail. These sites were chosen because they are located near the center of the monitored region, and detection of the bundles would therefore be equally likely regardless of whether they moved North or South. At each site the 50 bundles were divided between the three permanent transect locations and placed at even intervals from the landward boundary of the first band of wrack to the bottom of the last band.

Both releases were performed the day before a volume walk (refer to specific objective 2), so that only one high tide passed between the release and first potential detection. The location of marked bundles was recorded during all subsequent monitoring activities until March 5th. Additionally, we ran an article in the local newspaper and put up signs at beach access points requesting that locals report any found bundles (Appendix 2). As of March 5th, we began collecting any marked bundles that we found remaining on the beach.

2.7 Opportunistic observational notes

The following observations were recorded while performing the components of this study outlined above, using either a camera or notebook. For all observations date, location, start time and end time of were recorded

- Photographs and notes of anything out of place/interesting/concerning
- Record sightings of birds and mammals (number and behaviour)
- Public interactions
- Tracks: photograph vehicle tracks.
- Photographic evidence of increased human traffic, disturbed vegetation and fauna etc.
2.8 Communication activities
During the project we maintained an active communications policy in response to public and media enquiries. These are detailed in Appendix 3.
3 Results

3.1 Weather Data

Frequencies of winds in the study area are shown in the following radar chart for the entire study period. Winds greater than the 68th percentile of all wind data were chosen to indicate “significant” events which were more than 21.6 knots sustained. From the plot it is apparent that there are two predominant winter wind regimes South-South-West, typically less than 10 knots and a wind that ranges from East-South-East through to South-East that created winds greater than the significant event threshold.

The wind speeds were classified as above or below 21.6 km/hr: the red lines represent strong winds, and the blue represent weaker winds.

Strongest winds (above 21.6 km/hr) blow from the ESE or SE, and during the study period, these winds blew from these directions approximately 13% and 10% of the time, respectively. But the weaker winds blew from a wider variety of directions, the highest percentages blowing from the SE and SSW, both

Figure 10. Wind Speed and Bearing over the study period (Oct. 1, 2014 to Feb. 22, 2015)

Wind speed is recorded in km/hr and was converted from m/s (the original data from the buoy). The above chart was created from the mean speed and bearing. Each day’s mean wind bearing datum was, first, classified within the cardinal direction class in which it fell, and then, second, the wind speed was classified as greater than or less than the 68th percentile of the study period’s wind speeds. The 68th percentile was chosen as a “wind event” marker since it was one standard deviation above the mean wind speed for the study period.

A radar chart was chosen to display this data because of the number of variables used in the analysis (i.e., 16 classes representing bearing degrees to North along with two classes of wind speed). Since the multivariate data shared a starting point and were evaluated against the same axis (percentage), it allowed a chart that displayed in two-dimensions. Each line originates in the centre of the chart and radiates outward in the wind bearing’s direction. The actual data points are demarcated by an angle in the line (or end of a line) and represent the percentage of days that the wind came from that direction over the course of the study period—a point further from the centre (often marked by a longer line) indicates a higher percentage of days with wind from that bearing; and points closer to the centre (often marked by a shorter line) demarcates a lower percentage of days with wind from that direction. The wind speeds were classified as above or below 21.6 Km/hr: the red lines represent strong winds, and the blue represent weaker winds.
As an example, in the above chart, the strongest winds (above 21.6 km/hr) blow from the ESE or SE, and during the study period, these winds blew from these directions approximately 13% and 10% of the time, respectively. But the weaker winds blew from a wider variety of directions, the highest percentages blowing from the SE and SSW, both approximately 13% of the time.

Figure 11. Wind data summary for Halibut Bank Weather Buoy, October 2014.

Figure 12. Wind data summary for Halibut Bank Weather Buoy, November 2014
Figure 13. Wind data summary for Halibut Bank Weather Buoy, December 2014

Figure 14. Wind data summary for Halibut Bank Weather Buoy, January 2015
3.2 Summary of Harvest Activities

Harvest data was provided by the three licensed companies. Three locations were used for offloading wrack from the intertidal area:

- Deep Bay RV Park (accessed from Deep Bay Dr.)
- Shoreline Dr. (accessed from Shoreline Dr)
- Buccaneer Beach (accessed from Buccaneer Beach Rd.)

The majority of the beach-cast seaweed collected was removed from the area at the Deep Bay RV park. Harvesting began primarily at the Shoreline Drive location and then the majority shifted to The Deep Bay RV Park. Based on their observations, harvesters suggested that the bulk of the wrack appears to move north westward along the shore before the largest volumes accumulate on the south side of the Mapleguard spit.

In total 675 tonnes of the 900 tonne quota were harvested between October 5th and January 9th. Harvest breakdown by company is shown in the following graph. Data is presented anonymously to preserve confidentiality.
Figure 16. Percentage of harvest by quota holder

The majority of the harvest occurred between October and November with the harvest essentially concluded by January as shown in the following figure. The conditions of license allowed the harvesters to harvest up until February 15, 2015.

Deteriorating quality of beach-cast seaweeds was the reason that harvesters stated for discontinuing harvest activities. The harvesters indicated that they targeted $MJ$ in the first two stages of the wrack age categories that were established by the study team.

Figure 17. Percent harvest by month
Figure 18. **Total tonnes of wrack harvested by loading location and month.**

![Bar chart showing total tonnes of wrack harvested by location and month.]

<table>
<thead>
<tr>
<th>Location</th>
<th>October</th>
<th>November</th>
<th>December</th>
<th>January</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buccaneer Beach</td>
<td>10.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shoreline Dr.</td>
<td>127.0</td>
<td>12.8</td>
<td>96.3</td>
<td>0</td>
</tr>
<tr>
<td>Deep Bay RV Park</td>
<td>42.3</td>
<td>372.9</td>
<td>12.8</td>
<td>0</td>
</tr>
</tbody>
</table>

**Weight of Wrack Harvested (Tonnes)**

Figure 19. **Wrack harvested (tonnes) per week as recorded by harvesters.**

![Line chart showing wrack harvested per week by harvesters.]
3.3 Wrack biomass measurements

Biomass sampling began November 7\textsuperscript{th} and was carried out on a weekly basis until Thursday February 22\textsuperscript{nd}, two weeks after the harvest was scheduled to end. A total of 16 sampling days, spanning four months were conducted. The following figure presents the location of randomly assigned study points and the interpolated calculation of wrack biomass per linear metre on November 10, 2014.

**Figure 20.** Example 5 km volume transect showing location of randomly established measurement points and interpolated volumes.

The summary of total biomass estimates collected during biomass surveys for the entire study area and estimated 95% confidence intervals are presented in the following figure.
The maximum volume of wrack (1,268 tonnes) was noted on the first day of sampling on October 26th. This decreased rapidly to an estimated 587 and 608 tonnes during the following two weeks. Survey biomass averaged 212 tonnes per week through January 15th after which estimates dropped below 100 tonnes.

3.3.1 Changes in wrack location over time

Interpolation analysis of the biomass surveys were calculated and plotted for each week of the study. Wrack biomass was converted to tonnes per linear metre of coastline and expressed as (0 – 0.54 t/m) through to (0.497 – 1.54 t/m). These gave a general estimate of the relative accumulation of wrack within the study area.

The following five figures representing each month of the sampling follow (note a computer animation was also produced and will be available at www.viodeepbay.ca). In these figures it can be observed that on October 27th wrack was distributed throughout the study area and as months go by volume reduces from the south until the end of February when wrack has largely disappeared from the study area with the exception of a small pocket at the southern end.
Figure 22. Interpolation of wrack biomass within study area October 27, 2014.

Figure 23. Interpolation of wrack biomass within study area November 27, 2014.
Figure 24. Interpolation of wrack biomass within study area December 31st, 2014.

Figure 25. Interpolation of wrack biomass within study area January 26, 2015.
3.3.2 Changes in wrack decomposition class over time

The following figure illustrates changes in the percent composition of wrack by relative age class by week of observations. This figure demonstrated that fresh MJ wrack primarily came ashore during November with smaller events during January. Fresh wrack was gone by February which coincided with the cessation in harvesting activities by licensees. Wrack in the second age class was present through sampling and increased during December.

Figure 26. Interpolation of wrack biomass within study area February 22, 2015.
Note the increase in the older age classes in the final weeks of the study. The oldest classes of MJ were only occasionally evident on the beach when calculated as percentage of total biomass. The 5th class of decomposing MJ became predominant during February. Note that this graph may be misleading in that estimates of biomass in the final weeks of the study (Figure 21) indicated that total volume had decreased markedly and that wrack “aging in place” was largely that which was in the supratidal region above normal high tide.

3.4 Permanent transect sampling

3.4.1 Site characterization and harvesting activity

Site characterization indicated that all six sites shared similar shore type characteristics. Following the ShoreZone protocol for shore type classification we identified HM and BC as wide gravel flats (Class 21), while the remaining four sites were classified as wide gravel and sand flats (Class 25). All sites had a mean slope of <5°, a width of >30 meters and were composed of boulders, cobble, pebbles and sand (>10% sand = Class 25). Classification was largely consistent with records from the British Columbia Coastal Resource Information System, which identified the entire 5 km encompassing all 6 sites as wide gravel and sand flats (Class 25). Given their dynamic nature that we observed during the beach walks it is possible that shore type could change between Classes 21 and 25 throughout the year for some, or all of these sites.

We noted that the landward boundaries of all sites, with the exception of OT, had also been heavily modified. Anthropogenic modifications to the landward boundaries included rock walls, roads, houses and riprap.

Each of the six sites experienced different levels of harvesting activity over the course of the 2014/15 harvesting season, as shown in Figure 17. BC and SH were harvested prior to permanent transect monitoring, but the RV park

<table>
<thead>
<tr>
<th>Abbr.</th>
<th>Site</th>
<th>Harvest or comparison site</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVC</td>
<td>RV Park</td>
<td>Comparison</td>
</tr>
<tr>
<td>RVH*</td>
<td>RV Park *</td>
<td>Harvest*</td>
</tr>
<tr>
<td>SH</td>
<td>Shoreline Drive</td>
<td>Harvest</td>
</tr>
<tr>
<td>OT</td>
<td>Ocean Trail</td>
<td>Comparison</td>
</tr>
<tr>
<td>BC</td>
<td>Buccaneer Beach</td>
<td>Harvest</td>
</tr>
<tr>
<td>HM</td>
<td>Henry Morgan Road</td>
<td>Comparison</td>
</tr>
</tbody>
</table>
harvest site was the primary harvest site within the permanent transect monitoring period. The only other site harvested during the monitoring period was Shoreline Drive, from which beach-cast seaweeds were collected on two days. The comparison sites HM and OT were not harvested at all during the 2014/15 harvest. At the RV park comparison site the presence of vehicle track, however, suggests that harvesting activity may have encroached on the first transect of this site on two occasions.

3.4.2 Wrack biomass and distribution

Within the monitoring period from November 14th, 2014 through March 5th, 2015 there were 15 permanent transect sampling days. Wrack biomass in wet weight (weight recorded in the field) over the entire sampling period was greatest at RVC, RVH and BC, while lowest at HM and OT sites (Figure 28). HM, OT and SH sites experienced the lowest variability in wrack biomass, as indicated by their narrow ranges across a constant sample size. The range in biomass was greatest at RVH and RVC, indicating that these two sites experienced the greatest variability in wrack biomass. The large range in biomass across all sites, however, is a testament to just how variable wrack accumulations can be within the region.

Despite the removal of beach-cast seaweeds at RVH throughout the monitoring period, the interquartile range and median biomass values for this site were similar to those of the un-harvested RVC and BC (which was only harvested in October, prior to permanent transect monitoring). This suggested that the harvesting activities were not reducing the available biomass between sites.

**Figure 28.** Boxplot of mean wrack biomass for all six permanent transect sites over the monitoring period.

Note: Wet weight recorded in the field. Mean wrack biomass was calculated for each site from the biomass recorded along three transects (n=15 sampling days).

---

**Box plots are a useful tool for visualizing the range and overall patterns of response for a group.**

- **Outlier**: More than 3/2 times of upper quartile
- **Maximum**: Greatest value, excluding outliers
- **Upper Quartile**: 25% of data greater than this value
- **Median**: 50% of data is greater than this value; middle of dataset
- **Lower Quartile**: 25% of data less than this value
- **Minimum**: Least value, excluding outliers
- **Outlier**: Less than 3/2 times of lower quartile

**Range**: the spread of all the data, represented on a boxplot by the vertical distance between the smallest and largest values (including any outliers).

**Interquartile range**: The middle half (50%) of the data set from the 1st (lower) quartile to the 3rd (upper) quartile. In a boxplot the interquartile range is represented by the vertical distance of the box.

**Skew**: if most of the observations are concentrated on the low end of the scale the distribution is said to be positively skewed (or right-skewed), and vice versa.

Similarly, the median values for the area of beach covered by wrack were also greatest at BC, RVH and RVC sites (Figure 29). Wrack area observations for RVH were concentrated within the upper values of the site’s range (positively-skewed). As observed in the boxplot, 75% of wrack area observations at RVH exceeded the median observations for HM, OT and SH. RVH had both the largest wrack area values observed during this study, and the largest range of observed values. Though BC and RVC had greater median wrack biomass, RVH had the greatest median wrack area of the three. This is consistent with observations made in the field where we saw narrower but deeper wrack bands accumulate at RVC and BC compared to the bands at RVH.

Figure 29. Boxplot chart of mean area covered by wrack per meter-wide transect extending from landward boundary to the water line.
Note: Mean wrack area was calculated from three transects per site for each sampling date (n=15 sampling days).

As suggested by the boxplot (Figure 28), wrack biomass tended to be greatest at RVC, followed by BC and RVH. This is consistent with findings from the total biomass estimates, wrack biomass generally declined over time for all six sites (Figure 30). The rapid decline in biomass at observed at RVH and RVC appears to have begun in the last two weeks of December, or first week of January.

Biomass was consistently low, however, at both HM and OT sites throughout the monitoring period. Declines in wrack biomass at RVH coinciding with increasing biomass at RVC may suggest the northward-movement of wrack (e.g. from November 20\textsuperscript{th} – December 4\textsuperscript{th} and December 22-December 29\textsuperscript{th}).
Figure 30. Line chart of mean wrack biomass per meter-wide transect extending from the landward boundary to the waterline.
Note: Biomass in wet weight recorded in the field. Graphs stacked from north to south. Mean wrack biomass was calculated for each site from the biomass recorded along three transects.

Though wrack biomass tended to be greatest at RVC, wrack area was generally greater at RVH until January (Figure 30). The January decline in wrack area also appears to have begun earlier and been at a greater rate at RVH compared to RVC (Figure 31). Meanwhile, wrack area was consistently low at HM and OT over the course of the monitoring period, while trends in area at SH and BC are less clear.

North-ward movement also appears evident in the patterns of coinciding declines and peaks in wrack area. As large peaks in area declined at RVH from November 20th to November 27th and from December 22nd to January 8th, wrack area increased at RVC. Similarly, a decline in wrack area at BC from November 11th to December 11th coincided with an increase in wrack biomass at OT (closest site North of BC).
3.4.3 Macrophyte composition

Macrophyte composition was analyzed for samples from 4 of the 15 collection dates, each 3 weeks apart: November 27th, December 18th, January 8th and January 29th, yielding a total of 103 samples.

Relative abundance of all macrophytes:

Using the mean dry weight of each macrophyte species or group across all sampling dates, it is clear that MJ accounted for the greatest proportion of the wrack macrophyte composition at all six of the sites (Figure 32). The proportion of degraded macroalgae (“Unidentifiable”) appears to have been greatest at sites with higher wrack biomass (BC, SH, RVH and RVC). This may also be a reflection of northward movement with age, given that SH, RVH and RVC are...
the three northern-most sites. The greater proportion of degraded material at BC is consistent with the presence of a large stationary band of old wrack that appeared to decompose in place over the course of the monitoring period and we suspect that this material may also be largely MJ.

The mean proportion of degraded macroalgae in samples generally increased over the course of the monitoring period (Figure 33), suggesting that the proportion of fresh beach-cast materials was decreasing. This is consistent with observations of decreasing biomass across sites in mid-December and from January onwards. The majority of the samples, however, were still primarily composed of identifiable specimens, suggesting that much of the decomposing macroalgae was either being mixed or moving, rather than entirely degrading in place.
Figure 33. Mean proportion of species or groups in samples divided by sampling date
Note panels from left to right represent samples from November 27th, December 18th, January 8th and January 29th. Mean proportions were calculated for each permanent transect site. All terrestrial macrophytes were grouped collectively as “Terrestrial debris”, macroalgae species representing a very small proportion of the wrack composition were grouped as “Other”, and macroalgae specimens too small or degraded to be identified with confidence were labeled as “Unidentifiable”.

Macroalgae species accumulation curves
Species accumulation curves for macroalgae species within individual samples indicated that the number of species detected leveled off very quickly with increasing number of samples. This was true for all six sites (Figure 34), which shared very similar accumulation curves. Species richness began to level off at 10 species, with >84% (±1.23%) of all species detected within the first 12 samples from a given site.
Figure 34. Macroalgae species accumulation curve for all samples by site.

Note: Samples selected randomly from all samples collected at a given site. 1000 permutations, >84% (±1.23%) of species detected within 12 samples across all sites.

Macroalgae species richness

Total species richness, based on the mean composition of all samples collected from a given site ranged from 11 species (HM and SH) to 13 (BC) (Figure 35). There was no evidence of spatial trends in total species richness from Southern-most (HM) to Northern-most (RVC) sites, nor with harvesting pressure.

Given the nature of our study design, there was an unequal number of samples from each site, depending on the number of wrack bands present on sampling days. While a greater sample size generally leads to better species detection and greater reported species richness, species accumulation curves indicated that species richness leveled off within the range of sample sizes collected. OT, for example, had the fewest samples (n=12) but the same species richness as RVC (n=24).
3.4.3.1.1 Macroalgae species diversity

The Shannon diversity index scores of macroalgae composition for individual samples were low across all sites (Figure 36). All median values were less than 0.3 and no sample surpassed 0.7, indicating that there was only one dominant species accounting for the majority of each sample. From the proportions in Figures 32 and 33 we know that this dominant species was MJ across all sites. Samples at HM had the greatest range in species diversity over the course of the monitoring period, while OT and RVH had the smallest range in values. Median species richness per sample was greatest for samples collected from RVC, while lowest for those from OT.

There did not appear to be any spatial trends in median diversity index scores or interquartile ranges. Shannon diversity indices initially decreased from Northern-most sites moving South then increased again South of OT. Harvest level did not appear to affect diversity (Figure 36.)
A species diversity index is a quantitative measure that takes into account both species richness and species evenness of a given community. There are several different diversity indices, two common ones being the Shannon index and the Simpson index.

The Shannon index is defined as:

\[ H' = -\sum_{i=1}^{R} p_i \ln p_i \]

Where \( p_i \) is the proportional abundance of species \( i \).

The effective number of species is the number of equally-common species required to yield a given species diversity index score.

---

**Figure 36.** Box plot of Shannon diversity index of macroalgae composition per sample across all six sites

**Similarity of macrophyte composition between sites**

The dendrogram produced from Jaccard distances between sites, based on their mean macroalgae compositions, revealed some interesting patterns in community similarities (Figure 37).

RVC and RVH were more similar to each other than they were to the other four sites. This is not surprising given their relative spatial proximity compared to other locations. More surprising however, is that the dissimilarity between these neighbouring sites (indicated by the height of the dendrogram’s branches) is greater than that between BC, SH and OT, which were much further apart from one another. SH and OT were the two most similar sites in terms of macroalgae composition, despite the fact that OT is actually located closer to BC than SH. BC, SH and OT were, in turn, more similar to one another than they were to the Southernmost HM.
Figure 37. Sites clustered by Jaccard distance calculated from mean macroalgae composition across all dates.

Macroalgae composition appears to be clustering across latitudes, with the central sites being the most similar to one another. Composition becomes more dissimilar towards the south (BC and HM), with the two north-west sites (RVC and RVH) being most dissimilar from the other four. The notable dissimilarity between RVC and RVH, despite their proximity, suggests that there may be other differences between these two sites influencing macroalgae composition.

3.5 Macrofauna

As outlined in Section 2.5.6 all macrofauna in samples from the 4 collection dates analyzed for macrophyte composition (103 samples) were removed and stored in ethanol for later analysis. While they have not yet been identified to specific taxonomic groups, these samples appear to contain several species of dipterans (flies), and beetles, at least one species of amphipod and spider, as well as an array of smaller invertebrates believed to be worms, mites and collembola and thrips.

Though it has yet to be confirmed with counts from the 103 samples, our experience in the field and in the lab suggest that time of year likely has the most significant influence on macrofauna abundance. Samples collected in the fall appeared to have fewer specimens while greater activity was observed in the wrack as ambient temperatures rose near the end of winter leading up to spring.

We suspect, however, that macrofauna communities also vary with wrack properties such as depth, distribution and age class. On November 14th, for example, the ambient temperature dropped to -4°C during our overnight sampling and we noticed that the deepest accumulations of wrack retained a great deal of heat due to decomposition. These deposits also contained a very active macrofauna community, likely taking refuge from the cold. Macrofauna abundance did not appear to be nearly as high in thinner accumulations of wrack that night. Deeper, decomposing bands found near the landward boundary also retained the most moisture throughout the sampling period. These bands appeared to contain the highest abundance of flies while having the lowest abundances of amphipods and beetles. Given the number of pupal
cases we observed while sorting samples, these older bands were also used most extensively by flies for reproduction and rearing. As temperatures began to rise in late January through early March, wrack deposits became smaller and began to dry out on the beach. During these later sampling dates we began to notice more amphipods, especially at the interface between the sand and the bottom of drying wrack deposits lower on the beach (as opposed to older bands near the landward boundary).

These observations suggest that wrack provides a dynamic, habitat for macrofauna within the harvest region. Proper identification and enumeration of macrofauna collected from these samples may confirm or reject suspected trends, allowing us to more thoroughly investigate the influence of wrack properties such as biomass, distribution and composition, time of year, and harvesting pressure on macrofauna communities using multiple regression and/or multivariate analyses such as principal component analysis.

3.6 Drift study results

3.6.1 First release: December 21st, 2014

Of the 50 bundles released at Shoreline Drive (SH), 24 were reported by a resident the following day (December 22) at 12:00 pm along the upper intertidal. When we returned to the site that evening at 8:00 pm for our scheduled permanent transect monitoring, 24 of 25 bundles were still present in the older band nearest the landward boundary (within 6 meters of the landward boundary), while only 9 of 25 bundles were found in the fresher lower band (33 meters from the landward boundary). All bundles were gone by the following monitoring evening, December 29th.

One harvester reported finding bundles from SH within seaweeds harvested from the RV park on December 23rd and December 26th. Both flags were discovered in the dryer, therefore did not remain on the beach and were not recovered by us. While we were unable to confirm the bundles ourselves, the reported colour of the flag, which was not shared with the public, corresponded to bundles released at SH.

Of the 50 bundles released at Ocean Trail (OT) only 8 were present when we returned the next evening (December 22nd) to perform our permanent transect monitoring. All 8 bundles were those that had been placed in an old band of wrack at the landward boundary. These bundles were not very visible from the beach due to a low-hanging tree branch. Bundles continued to be found within this small portion of wrack into early January.

A member of the community also reported finding these 8 bundles on December 25th, and 5 bundles were reported in the same location on January 2nd. There were no reports, however, of bundles from OT found elsewhere within the region. Though we hope bundles were simply swept out by the tide, we must also consider the possibility that this site had been tampered with. Signs describing the drift study that had been securely stapled to trees or stumps at access points to HM, BC, and the RV park were all missing the evening after the release (December 22nd) and there were fresh footprints along wrack bands at OT where the missing bundles had been placed.

Amphipods are malacostracan crustaceans with no carapace and generally with laterally compressed bodies are mostly detritivores or scavengers. Often known as sand or beach hoppers.

Springtails (Collembola) modern hexapods that are no longer considered insects. These are omnivorous, free-living organisms that prefer moist conditions. They are frequently found in leaf litter and other decaying material where they are primarily detritivores and microbivores, and one of the main biological agents responsible for the control and the dissemination of soil microorganisms. They do not directly engage in the decomposition of organic matter, but contribute to it indirectly through the fragmentation of organic matter.
3.6.2  Second release: January 18th, 2015

Of the 50 bundles released at SH on January 18th, 32 were still present on our next permanent transect date (January 22nd). All 32 bundles were found within 6.5 meters of the landward boundary. During subsequent monitoring, we continued to find bundles along the oldest band of wrack only (within 3.5 meters of the landward boundary) until the end of the monitoring period on March 5th, 2015. A member of the community repeatedly observed 15 SH bundles at this site from January 26th through February 3rd. After a high tide and winds on February 5th they reported only 8 bundles remaining.

At OT, 27 bundles remained on the beach on January 22nd, 15 remained on January 29th, and 14 were found within three meters of the landward boundary on February 5th. By the end of the monitoring period only 4 bundles remained, all within the same storm-cast patch of wrack at the landward boundary. No OT bundles from the second release were reported by the public. On March 13th, however, a bundle originally released at OT on January 18th was recovered just North of our last transect at SH.

3.6.3  Conclusions

The results of this small-scale dispersal study confirm that storm-cast MJ within the supratidal zone can remain there for several weeks or even months, decomposing in place. All bundles placed within the lower portion of the intertidal zone, on the other hand, moved off the beach within a week. Rather than decomposing in place, wrack within this zone appears to be highly mobile. Storm-cast seaweeds within the supratidal and wrack deposits in the intertidal zone therefore have very different fates and unique ecological roles.

All three of the bundles recovered at a different site than their release had moved north. Bundles from SH, for example, were found by harvesters at the RV park only 2 and 5 days after their release, indicating that this movement can be quite rapid. This supports our hypothesis that wrack is moving across the 4.2 km region from south to north over the course of the harvesting period. It also raises more questions as to the ultimate fate of this wrack, which may be accumulating somewhere in Baynes Sound.

3.7  Forage Fish

Detection of forage fish eggs within the sediment requires a great deal of training that was not possible within the limited time frame of this study. We collaborated with Ramona de Graaf, a regional expert in forage fish sampling and habitat assessment that has been studying and sampling this region for many years. Embryo surveys were conducted at several sites within the harvest area by Ramona de Graaf according to established protocols in BC and Washington. These are described in an unpublished report (to be available from R. de Graaf at a future date). Embryo surveys in 2014 were conducted on Nov 8, Dec 3, Dec 21, and Dec 22, 2014, and a total of 28 samples analyzed. Pacific sand lance embryos were detected on Dec 21 and 22, 2014 in six samples from sampling sites at Blue Heron Road, Shoreline Drive and Deep Bay Drive.
3.8 General Observations

3.8.1 Study area as a dynamic environment

During the study period it was impressed upon the study team just how physically dynamic an environment the study area is. Exposed to significant SE storm swell, we noted that from week to week significant volumes of sediments up to large boulders would move through these natural processes of wave movement, scour and longshore drift. We noted that in the mid to high intertidal that surface sediments could change from predominantly sand to large cobble to mixed gravels throughout the winter and that the slope and elevation of the beach could change significantly based on the frequency and strength of wave and tidal processes.

Examples of changes in in beach composition are shown in the following Figures 38-40. These photos demonstrate that the beach sediments are highly mobile during high water storm events.

![Northwest view changes in beach substrates between November and December 2014](image)

Figure 38. Northwest view changes in beach substrates between November and December 2014
Location: N 49d 27m 3.44s / W 124d 41m 31.53s
Figure 39. Southeast facing view near Buccaneer beach showing changes in Beach composition between November 14 to February 15. Note arrow indicates point of comparison reference. Location: N 49d 26m 53.51s / W 124d 41m 3.89s

We also noted that MJ wrack could become buried within the sediments after wind and high tide events (Figure 40). We were unable to quantify the volume of MJ that may have become permanently buried in this fashion but we believe it to be relatively insignificant.
Figure 40. Thick layer of decomposing MJ mixed with large gravel under layers of storm cast rock and fresh wrack.
Note October 27, 2014

3.8.2 Visual changes in wrack composition during study period

Photographs were taken along the study area to document the presence of wrack accumulation. The following figure with photographs taken looking west along the intertidal fronting the RV Park illustrates the changes in wrack composition and depth during the study period.
These photographs illustrate the rapid decrease in wrack volume that was observed independent of harvest volumes from the study area. It is interesting to note that the wrack was not observed in the later age classes of decomposition before disappearing from the harvest area. Additionally, any long term impacts of the wrack build-up or harvest activities were not visible after wrack volumes decreased.

3.8.3 Physical effects of Harvesting activities

Study personnel noted and photographed anthropogenic changes to substrates as a result of harvesting activity. While these were not quantified, we noted
that these appeared to be restricted to track depressions of up to 5-10 cm in soft and gravel sediments in the upper intertidal as shown in the following figures. These track depressions were not permanent and typically disappeared after the next series of high tides that covered them. Damage was noted at one point to surf grass where the harvester was moved across the high intertidal to access a private property for day to day storage.

Figure 42. Example of harvester tracks in upper intertidal

Figure 43. Tracked harvester vehicle stored on private property access across upper intertidal
3.8.4 Other anthropogenic activities and impacts in study area

The study area is primarily composed of upland subdivision settlement and during the study period we observed a number of anthropogenic impacts on the study area. The significance of these activities on the near shore environment has not been established. We have included examples of our observations as these are important in understanding the study area and the potential for resilience as well as cumulative effects.

Removal of other intertidal plants

During early November we noted the removal of the plant American Sea Rocket by upland residents on various portions of the beach (Figure 44). Sea rocket, a non-native member of the mustard family, is a pioneer species, able to colonize areas of bare coastal sand where very few plants can survive. The sandy substratum is a very unstable medium for plant growth, and the lack of humus means that it's not only unable to retain moisture but is also nutritionally poor. Sea rocket puts down a long taproot that holds it in place. The root then branches into an extensive network that tends to stabilize the sand. We also noted that Sea Rocket may play a role in restricting how far up the beach that the wrack extends. We are not aware why large volumes of this species was being removed,

Figure 44. Removal of American Sea Rocket (Cakile edentula) from upper intertidal by upland residents
Location:  N 49d 26m 43.51s / Longitude: W 124d 40m 52.94s
“Protest gardens”

Prior to the harvest season, a group of individuals opposed to seaweed harvesting activities built a series of “Protest Gardens” at several of the normally used harvester access sites with the intent of physically preventing harvesters from accessing intertidal areas. Installation of these unapproved works involved moving intertidal sediments, rocks and debris with unauthorized machinery, the addition of off-site soils and non-native plants and “garden art” and signage (Figure 45).

While these beach modifications did not achieve the goals of restricting harvester access, they did have the unintended consequence of forcing the tracked harvest transport vehicle to travel up to four times farther along the beach to access harvest locations and potentially increasing any habitat impacts. Study personnel also noted that the installation at the RV Park limited public access to the popular beach, in particular those with mobility issues.

![Figure 45. Protest Garden established at RV Park access site](image)

Hardening of the foreshore

A large portion of the study area is settled with private residences and a recreational vehicle park. A significant portion of the area has been “hardened” with the use of cement blocks, cast walls or the addition of rip rap to prevent wave or upland erosion (Figure 46). While common within the Strait of Georgia, these installations are known to interfere with natural processes and presumably most were installed prior to information regarding potential effects became known. We note that programs to reduce the use of such beach hardening and bulk heading include programs such as “Green Shores”. 68
3.9 Use of wrack by wildlife

Observations of wildlife were noted and logged during beach biomass walks. This was constrained by the fact that most beach walks were conducted during night tides. Those walks that were conducted during daylight did provide limited observational opportunities.

A variety of overwintering sea ducks including scoters, golden-eyes, and harlequins were noted during surveys however these were immediately offshore and did not overlap with wrack. Few wading birds were observed present as most species are not present during the winter. Those that were included herons and oyster catchers and neither species was observed feeding within the wrack. Occasionally gulls, crows and other terrestrial birds were observed in the intertidal however none were observed actively foraging within the wrack. Deer and raccoons were occasionally noted on the beach but again not foraging in the wrack.

While formal survey protocols for wildlife were not employed, our observations during this season suggest that there is little wildlife interaction with the wrack distributions. This may be the result of the factS that: most small wading birds are not present during the winter season; temperatures during winter restrict the abundance of prey items such as amphipods; and most wrack has disappeared from the intertidal prior to herring spawn and the northward migration of most species.
4 Summary

4.1 Total abundance and harvest rates

A summary of the events during the harvest period are shown in the Figure 47. In this figure the harvest tonnage from the week prior is shown immediately below the volume estimate conducted at the end of the week. The total height of the area graph represents the estimated total biomass (harvested and remaining) during each week of the study (left axis).

![Figure 47. Summary of wrack harvest, mean beach biomass estimate and mean wind speed over study period.](image)

Average sustained wind speed during the week is plotted on the right axis of the graph. A clear relationship can be observed between storm events and increases in wrack volume.

It is important to note that the first biomass sampling estimate was completed on November 7, approximately three weeks after the start of harvesting activities. As a result the onset of significant wrack biomass accumulating in the study and the total biomass prior to the start of the project is not known. The wind data suggests that the storm events during the middle of October may have brought the largest biomass observed during the season ashore.

Throughout the study period during the active harvest period the amount removed ranged from 2-47% of the available biomass with an average of 16.5% (stdev +/- 0.12%). The maximum estimate of wrack in the study area was on October 26 with 1268 tonnes estimated by volume plus 91 tonnes harvested or approximately 6.7% of total biomass. The next week volume dropped by 667 tonnes although only 101 tonnes (15.2 %) was removed by harvesters. The
missing 562 tonnes cannot be accounted for by sampling error estimates during biomass surveys.

By November 30th, an estimated 544 tonnes had been removed by harvesters without exceeding more than 21.8% of the total biomass calculated to be present in the study area in any given week. The following week, an estimated 46.6% of the weekly biomass was removed after which the harvest rate did not exceed 17% of biomass for the rest of the harvest season.

Both the biomass survey data and the results of the permanent transects suggest that harvesting does not appear to have a detectable effect on MJ biomass or macrophyte diversity over the course of this study.

4.2 Study area as a seaweed “conveyor belt”

Based on the data collected and ancillary observations it appears that it is simplistic to interpret that the wrack is coming ashore during storm events and then either being harvested, eaten by macrofauna or decomposing in place as has been previously suggested.

Our working hypothesis is that wrack that remains below the high tide is continually moved northwest by a process of longshore drift, although it may temporarily accumulate in very high volumes in areas such as fronting the RV park. Only small amounts of wrack that is deposited onto the very high tide or above the high tide (supratidal) remains in place and decomposes fully.

This hypothesis is substantiated by the following observations:

- the volume of wrack on in the study area decreases quickly between wind events (rapidly in some cases) beyond which harvest removal can account for;
- no influence of harvest activity could be detected in wrack volume in permanent transects;
- rapid northward dispersal of tagged bundles of MJ;
- northward movement and accumulation observed in calculated interpolations of wrack biomass;
- observations of harvesters reported at outset of study, and;
- the fact that age classes of wrack did not sufficiently increase over the duration of the project to support an observation of aging in place.

Additionally we made observations during the study period that significant volumes of wrack made their way outside of the study area - for example the western end of the Deep Bay Spit and Ships Point in Baynes Sound. We also consistently recovered MJ on prawn traps set in the deepest portions of Baynes Sound in waters greater than 80 metres.
If this hypothesis is true, beach cast MJ is brought ashore by wind events in the fall when the plants are weakened due to reproductive stress or other factors. Normal sediment processes of longshore drift in the intertidal rapidly move accumulations of wrack through the study area with rates determined by the combination of wave action and tidal heights.

Wrack will move faster or slower depending on the direction of the beach relative to wave direction. This would account for the larger accumulations of wrack immediately south of the Mapleguard spit as long shore drift “slows down”. Once the wrack makes its way past the north end of Mapleguard spit it would then accelerate and essentially distribute and disappear northward into Baynes Sound.

The study area could be considered as a northward moving conveyor belt of macroalgae with additions of wrack being made along its entire length from the subtidal. This has significant implications on the understanding of the role of MJ in the local ecosystem and its harvest management.

Firstly, it would suggest that the instantaneous biomass estimates calculated on a weekly basis could grossly underestimate the total biomass coming ashore or moving through the 4.2 km harvest area. For an example, a preliminary calculation of the area under the curves of biomass using Reimann Sum suggested that total biomass could be greater than 39,000 tonnes. Revising the annual biomass estimate accurately would require more understanding of the rate at which the longshore drift of the algae is occurring.

Secondly, this could mean that the ultimate fate of the MJ might have a significant subtidal component in the deeper portions of Baynes Sound with undetermined consequences on benthos and fauna (see below).
4.3 Summary observations on the ecological role of *Mazzaella japonica* in the study area

4.3.1 Food web subsidy or negative impact?

Seaweed plays an important role both alive and as beach wrack. It can provide important habitat for invertebrate and vertebrate species and be an important subsidy (e.g., nutrients, food) for subtidal and intertidal zones. Not all seaweeds are created equal; some species may be more ecologically valuable than others. Currently we do not know how valuable *MJ* is to the function of this ecosystem; therefore it is not possible to determine if the impact of its removal is positive or negative. Regardless, this study suggests that amount of seaweed removed is small relative to the amount that accumulates over the winter season.

Further, our research shows that a significant portion of intertidal beach habitat is under a spatially extensive, deep ‘blanket’ of seaweed for variable periods of time. Potential smothering could drastically alter the physical environment and subsequently all of the native fauna and flora that inhabit and use this habitat.

Most other wrack studies have focussed on wrack that has entered the intertidal during summer seasons when productivity is higher and supports larger infaunal and macrofaunal abundances (positive effects) but also potentially negative effects of decomposition. The situation with *MJ* may be unique, occurring when temperatures and productivity is low and essentially dissipating out of the study area before biological productivity in the spring increases.

Both alive and dead, *MJ* could also play an important role in the functioning of this nearshore ecosystem. Algal invasions in other regions have resulted in increased invertebrate species diversity because of the added environmental structural complexity. Decomposition of *MJ* may increase nutrients which could improve conditions for other flora and organisms dependent on them or, if high enough, could result in eutrophication. It is important to understand the ecological role of *MJ* in order to understand the consequences of removing it.

In deeper waters the invasion of *MJ* may also have an impact. From our observations it appears that a large volume of *MJ* is washed off the beach and essentially ‘disappears’. Should the algae sink in near shore waters it could create low oxygen or hypoxic conditions at depth.

Overall our impression is that the nutrient subsidy within the study area may be low during the period that *MJ* is washing ashore. Similarly potential negative effects due to smothering of the intertidal or decomposition gases etc. are also low due to both the cold temperatures of the season and the dynamic wave forces in the study area at least within the study area.

4.3.2 Harvesting as removal of nutrients from the system

At the outset of the study it was our intention to attempt to calculate the nutrient removal from the ecosystem by way of harvest. Unfortunately, we were unable to find any published literature on the chemical breakdown of *MJ* that would allow us to make that calculation and the short nature of the study and budget did not allow us to make the chemical analyses ourselves.
We can infer however from studies examining the potential for eutrophication within the Georgia Basin, in particular a 1997 review by Mackas and Harrison. In this study, the authors stated that large-scale eutrophication of Georgia Basin marine waters is unlikely for two reasons. First, ambient nitrate + ammonia concentrations are high over much of the total area, so that total primary productivity is insensitive to incremental additions. Second, exchange of water by estuarine and tidal currents is rapid (approx. 1 year turnover time), and entering water carries naturally high nutrient concentrations.

Although anthropogenic nutrient-input rates from urban centres are large in absolute magnitude, the authors noted that they are small relative to natural inputs and do not accumulate. Furthermore total ‘natural’ nitrogen inputs by the estuarine circulation are very much larger than all other sources combined: 2600–2900 tonnes N per day for the entire system and 1400–1500 tonnes N per day for the inner basins (Strait of Georgia and Puget Sound).

From autumn through early/mid-spring, surface layer nitrogen concentrations are high (>20 μM) and non-limiting in all areas because of the combined effects of reduced stratification (solar heating and Fraser River runoff are at annual minima), sustained tidal and wind mixing, and relatively low phytoplankton productivity. The authors also calculated that the ~20x10^3 tonnes of finfish and ~30x10^3 tonnes of shellfish removed through commercial fisheries equated to nitrogen removal of only about 2 tonnes Nitrogen per day from the system and was inconsequential.

These observations lead us to believe that the removal of MJ from the marine environment would not have a negative impact (limiting production) or significant positive impact (removal of excess anthropogenic nutrient inputs).

4.3.3 Mazzaella as a marine invader?

MJ has been present in our coastal ecosystems for a long period of time, potentially decades. It is unclear what has caused the perceived increase in abundance over the past decade and there is speculation that the following factors could have contributed in some way:

- Increase in localized nutrient inputs from upland use and non-point source pollution;
- Climate change impacts such as increased warming of the Strait of Georgia and/or decreases in marine pH which might favour macrophytes;
- that the population of MJ has reached a point that the reproductive potential has allowed it to increase exponentially or;
- all or any combination of the above, or other factors.

Dr. Michael Hawkes (UBC) has now noted MJ as far southward as Nanaimo and we have anecdotal reports of MJ in beach wrack as far north as Campbell River. The work of Kylee Pawluck (UVIC) in the subtidal waters fronting the study region has suggested that MJ may outcompete local native seaweeds resulting in changes in marine habitat diversity and structure. The outcomes of this work will be important if for example it is found that MJ is used differently by grazers such as sea urchins or if outcompetes bull kelps which are believed to be important ecosystems for juvenile salmon survival.
Exploring the drivers behind the localized increased abundance of this species would be valuable for understanding the impacts of this invasion, predicting how it may change in the future and if/how it may spread.
5 Recommendations for further study

As stated in the limitations section of this report, the results of this study should be considered preliminary given the scope and duration of the project. Additionally we have identified a variety of factors which we believe to be important relating to the distribution, harvest and ecology of MJ on Vancouver Island. We believe that the presence of MJ on Vancouver Island will continue to have economic and ecological consequences and warrants further study. In particular we recommend that the following future studies are conducted.

5.1 Continued monitoring of wrack volume distribution

Wrack accumulations are highly dynamic and influenced by many factors such as macrophyte abundance, oceanic currents, and storm events. The biomass and distribution of beach-cast seaweeds could therefore differ from year to year. Long-term monitoring should therefore be implemented to truly characterize wrack accumulations and long term trends in the region.

5.2 Determining wrack transport patterns and fate

The current study proposed that long-shore drift has a considerable effect on the movement of wrack in the intertidal and that wrack was dispersed out of the study zone prior to final fate. This phenomenon has significant implications for stock assessment, establishment of harvest quotas and understanding the final ecological effects of the wrack in the local environment. Further studies should expand the preliminary drifter studies that we undertook and extend outside of the previous study area to further track the movement of wrack.

5.3 Monitoring distribution of Mazzaella japonica

As an introduced species, potentially exhibiting qualities of an invasive, it is important that the distribution of MJ on the East coast of Vancouver Island continues to be carefully monitored. Future research should focus on mapping the full extent of its distribution, monitoring the rate at which it is spreading, and characterizing the mechanisms by which it disperses and reproduces. Currently we do not know why it is so abundant along this particular portion of coastline although some speculate that nutrient addition from upland sources could potentially play a role. Understanding the factors that have contributed to its success in this region and its impact on local ecosystems will require further investigation and long-term monitoring of both its subtidal and beach-cast distribution.

5.4 Comparison sites along a gradient of Mazzaella japonica distribution

The wrack for all sites included in this study was composed primarily of MJ. Given the lack of baseline macroalgae/macrofauna composition and biomass records for the region, understanding the influence of this introduced species will require a similar study including comparison sites along a gradient of MJ abundance. This would improve our understanding of what macroalgae composition and macrofauna community structure looks like in the absence of the introduced red algae.

5.5 Macrofauna community structure

Given that macrofauna from analyzed wrack samples have already been collected and stored, we highly recommend that they be identified. Species identification and counts would enable us to investigate the associations
between macrofauna communities, wrack species composition, biomass and decomposition state, and time of year throughout the harvesting season. Funding for this task was outside the scope of contract. Future studies should enumerate and examine the role of macrofauna in the wrack. Laboratory studies should attempt to conduct grazing and preference studies both intertidally and subtidally.

5.6 Analysis of February samples
In addition to the samples from the four collection dates processed in this study, we have frozen wrack samples collected in February which could contribute to our understanding of how wrack composition and macrofauna communities change over time.

5.7 Forage fish
In 2014 forage fish embryo surveys showed positive results (i.e. eggs were found) at the Shoreline Drive harvest site. It is important to note that forage fish spawning areas are temporally variable and eggs have been found at Buccaneer Beach and the RV Parks in 2012. Forage fish embryos and eggs are likely to be damaged if driven over. However, given the dynamic nature observed of the intertidal sediments it is unknown how driving disturbance compares to natural disturbance from wave action and the movement or rocks and boulders beach (e.g. we observed large boulders dislodged in storm events). Further, it is unknown how forage fish embryos and eggs are impacted by seaweed burial. It is clear that the seaweed harvest areas overlap with appropriate forage fish habitat and that the forage fish use these areas for spawning. Understanding the relative impacts of harvest disturbance to natural storm disturbance and wrack burial requires further study.

5.8 Mazzaella DNA barcoding
11 species of red algae belonging to the genus Mazzaella have been reported in British Columbia. Members of this genus, however, can be difficult to distinguish due to tremendous phenotypic plasticity and convergent evolution. The appearance of M. splendens ad M. linearis, for example, in areas of intermediate wave exposure has been described as forming a seemingly continuous grade between the two species. Saunders and Millar (2014) successfully assigned Mazzaella specimens to discrete species groups using COI-5P barcodes. Kylee Pawluk previously sent samples of Mazzaella and confirmed that the species present is M. japonica. Given the difficulty in differentiating species and the spatial and temporal variability in seaweeds it would be valuable to periodically use DNA bar coding to confirm that the species composition hasn’t changed.
6 Literature Cited

1 http://www.newsroom.gov.bc.ca/2014/07/mazzaella-japonica-harvest-licences-issued-for-2014-season.html


8 Dr. Michael Hawkes, University of British Columbia. personal communication December 11, 2014

9 https://seaweedindustry.com/seaweed/type/mazzaella-splendens

10 Kylee Pawluk, University of Victoria. personal communication December 16, 2014

11 Dr. Michael Hawkes, University of British Columbia .personal communication December 11, 2014


14 http://cedar.wwu.edu/cgi/viewcontent.cgi?article=1373&context=ssec


27 ibid


34 Bradley RA, and Bradley DW. 1993. Wintering shorebirds increase after kelp (Macrocystis) recovery. The Condor. 95: 372-376


42 Rossi F, Incera M, Callier M, and Olabarria C. 2011. Effects of detrital non-native and native macroalgae on the nitrogen and carbon cycling in intertidal sediments


52 Lenanton RCJ, Robertson AI, and Hansen JA. 1982. Nearshore accumulations of detached macrophytes as nursery areas for fish. Marine Ecology Progress Series, 9: 51-57


57 Dugan JE, Hubbard DM, McCray MD, Piersen MO. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. Estuarine, Coastal and Shelf Sciences, 58: 25-40


68 Stewardship Centre of British Columbia Green Shores Program: http://stewardshipcentrebc.ca/Green_shores/


MONITORING OF DRIFT SEAWEED AND HARVEST
CENTRAL STRAIT OF GEORGIA 2014/15
FINAL REPORT

1 Appendix

Table 1. General guidelines for assigning structuring processes in shore types from the ShoreZone Coastal Habitat Mapping Protocol¹.

<table>
<thead>
<tr>
<th>Structuring Processes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Energy Processes Dominant</td>
<td>• wave energy is the dominant process controlling shore morphology&lt;br&gt;• the dominance as a structuring process is evident from erosional shoreline landforms (e.g., cliffs, bluffs, or platforms) or accretional landforms (e.g., spits, barrier islands, swash bars, or berms) resulting from wave-generated sediment transport processes</td>
</tr>
<tr>
<td>Estuarine Processes Dominant</td>
<td>• freshwater input usually results in salt marsh and/or salt meadow areas in the upper intertidal and supratidal zones&lt;br&gt;• sediment input to the unit from fluvial sources often creates deltaic landforms and features&lt;br&gt;• substrates are commonly fine (e.g., muds) and also often includes organics such as peats&lt;br&gt;• freshwater input likely to create brackish water conditions&lt;br&gt;• usually an embayment with restricted wave fetch and a connection to the open sea</td>
</tr>
<tr>
<td>Anthropogenic Processes Dominant</td>
<td>• man-made structures, filled shoreline, shoreline armoring, or other modifications that comprise more than 50% of the intertidal zone area</td>
</tr>
<tr>
<td>Current Processes Dominant</td>
<td>• usually elongate channels with very restricted wave fetch&lt;br&gt;• salt water, high current channels caused by tidal flow&lt;br&gt;• often found between islands or at the constricted entrances to saltwater lagoons&lt;br&gt;• water movement is generally visible within the channel but not outside it&lt;br&gt;• intertidal zone widths are often narrow</td>
</tr>
<tr>
<td>Glacial Processes Dominant</td>
<td>• glacial ice fronts dominate the intertidal zone&lt;br&gt;• restricted to a few locations in SE Alaska, Kenai Fjords, and Prince William Sound</td>
</tr>
<tr>
<td>Lagoon Processes Dominant</td>
<td>• an enclosed water body that is connected to salt water by either a permanent inlet, ephemeral inlet, or storm overwash such that the water body is permanently or at least occasionally salty&lt;br&gt;• the tidal range is often restricted due to a sill height or narrow channel&lt;br&gt;• wave fetches are limited and wave exposure low (Protected or Very Protected)&lt;br&gt;• no significant fluvial input or landforms within the unit</td>
</tr>
<tr>
<td>Periglacial Processes Dominant</td>
<td>• permafrost and pore ice are dominant in controlling the shoreline morphology&lt;br&gt;• thermokarst or periglacial features such as ground ice slumps, thermo-erosional gullies, and thaw pits may be present&lt;br&gt;• degradation of permafrost resulting from thaw subsidence creates unique morphologies such as inundated tundra (e.g., submergence of the tundra surface below mean sea level)</td>
</tr>
</tbody>
</table>

Table 2. **Sediment texture (Simplified from Wentworth grain size scale) from the ShoreZone Coastal Habitat Mapping Protocol².**

<table>
<thead>
<tr>
<th>Sediment</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GRAVELS</strong></td>
<td></td>
</tr>
<tr>
<td>Boulder</td>
<td>&gt;25 cm</td>
</tr>
<tr>
<td>Cobble</td>
<td>6 to 25 cm</td>
</tr>
<tr>
<td>Pebble</td>
<td>0.5 to 6 cm</td>
</tr>
<tr>
<td><strong>SAND</strong></td>
<td>0.063 to 2 mm</td>
</tr>
<tr>
<td><strong>FINES</strong></td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td>0.0039 to 0.063 mm</td>
</tr>
<tr>
<td>Clay</td>
<td>&lt;0.0039 mm</td>
</tr>
</tbody>
</table>

Table 3. **Shore modifications, from the ShoreZone Coastal Habitat Mapping Protocol.**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Shore modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>WB</td>
<td>Wooden bulkhead</td>
</tr>
<tr>
<td>BR</td>
<td>Boat ramp</td>
</tr>
<tr>
<td>CB</td>
<td>Concrete bulkhead</td>
</tr>
<tr>
<td>LF</td>
<td>Landfill</td>
</tr>
<tr>
<td>SP</td>
<td>Sheet pile</td>
</tr>
<tr>
<td>RR</td>
<td>Riprap</td>
</tr>
</tbody>
</table>

Table 4.  Classification for wave-structured shore types from the ShoreZone Coastal Habitat Mapping Protocol.

<table>
<thead>
<tr>
<th>SUBSTRATE</th>
<th>SEDIMENT</th>
<th>WIDTH</th>
<th>SLOPE</th>
<th>SHORE TYPE</th>
<th>CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCK</td>
<td>N/A</td>
<td>WIDE (&gt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Rock Ramp, wide</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Rock Platform, wide</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NARROW (&lt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Rock Ramp, narrow</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Rock Platform, narrow</td>
<td>5</td>
</tr>
<tr>
<td>ROCK &amp;</td>
<td>SAND &amp; GRAVEL</td>
<td>WIDE (&gt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>6</td>
</tr>
<tr>
<td>SAND</td>
<td>GRAVEL</td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Ramp with gravel beach, wide</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Platform with gravel beach, wide</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NARROW (&lt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Ramp with gravel beach</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Platform with gravel beach</td>
<td>10</td>
</tr>
<tr>
<td>SAND</td>
<td>WIDE (&gt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Ramp with gravel &amp; sand beach, wide</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Platform with gravel &amp; sand beach, wide</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NARROW (&lt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Ramp with gravel &amp; sand beach</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Platform with gravel &amp; sand beach</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WIDE (&gt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Ramp with sand beach, wide</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Platform with sand beach, wide</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NARROW (&lt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Ramp with sand beach, narrow</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Platform with sand beach, narrow</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WIDE (&gt;30 m)</td>
<td>FLAT (&lt;5°)</td>
<td>Gravel flat, wide</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NARROW (&lt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Gravel beach, narrow</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Gravel flat or fan, narrow</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>SAND &amp;</td>
<td>WIDE (&gt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>SAND &amp;GRAVEL</td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Sand &amp; gravel flat or fan, wide</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NARROW (&lt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Sand &amp; gravel beach, narrow</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Sand &amp; gravel flat or fan, narrow</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>SAND &amp;</td>
<td>WIDE (&gt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>MUD</td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Sand beach, wide</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Sand flat</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>Mudflat</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NARROW (&lt;30 m)</td>
<td>STEEP (&gt;20°)</td>
<td>n/a</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>INCLINED (5-20°)</td>
<td>Sand beach, narrow</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FLAT (&lt;5°)</td>
<td>n/a</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>
Table 5. **Permanent transect site characterization and corresponding shore type classification based on the criteria of the ShoreZone Coastal Habitat Mapping Protocol.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Substrate</th>
<th>Sediment</th>
<th>Width</th>
<th>Mean Slope</th>
<th>Shore Type</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM</td>
<td>Sediment</td>
<td>Gravels: Boulder, cobble and pebbles, (&lt;10% sand content)</td>
<td>&gt;30</td>
<td>4.9</td>
<td>Gravel flat, wide</td>
<td>21</td>
</tr>
<tr>
<td>BC</td>
<td>Sediment</td>
<td>Gravels: Boulder, cobble and pebbles (&lt;10% sand)</td>
<td>&gt;30</td>
<td>3.88</td>
<td>Gravel flat, wide</td>
<td>21</td>
</tr>
<tr>
<td>OT</td>
<td>Sediment</td>
<td>Gravels and Sand: boulder, cobble, pebble and sand (&gt;10% sand content)</td>
<td>&gt;30</td>
<td>2.86</td>
<td>Sand and gravel flat</td>
<td>25</td>
</tr>
<tr>
<td>SH</td>
<td>Sediment</td>
<td>Gravels and sand: Boulder, cobble, pebble and sand (&gt;10% sand content)</td>
<td>&gt;30</td>
<td>2.7</td>
<td>Sand and gravel flat, wide</td>
<td>25</td>
</tr>
<tr>
<td>RVH</td>
<td>Sediment</td>
<td>Gravels and sand: Sand, pebbles, cobble and boulders</td>
<td>&gt;30</td>
<td>4.3</td>
<td>Sand and gravel flat, wide</td>
<td>25</td>
</tr>
<tr>
<td>RVC</td>
<td>Sediment</td>
<td>Gravels and sand: Sand, pebbles, cobble and boulders</td>
<td>&gt;30</td>
<td>3.6</td>
<td>Sand and gravel flat, wide</td>
<td>25</td>
</tr>
<tr>
<td>Site</td>
<td>Terrestrial vegetation of landward boundary</td>
<td>Anthropogenic modifications to landward boundary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------</td>
<td>-------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HM</td>
<td>Terrestrial vegetation including grass, a few shrubs transitioning into primarily trees growing up a steep ridge</td>
<td>Cabin located at sea level to the left of first transect site, homes at a greater distance on the top of the steep ridge above</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>Terrestrial vegetation including grass, a few shrubs transitioning into primarily trees growing up a steep ridge</td>
<td>Cabin located at sea level directly at landward boundary of first transect, some riprap at landward boundary of second transect, no anthropogenic modifications at third transect.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OT</td>
<td>Entirely trees with a narrow footpath leading to the access point</td>
<td>Narrow footpath within the trees leading to site, no other modifications to landward boundary of the site, though houses line the upper banks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH</td>
<td>Some grass, sparse trees and shrubs on an exposed bank of sediment – we observed many fallen trees and collapsing banks following a large storm in November</td>
<td>A cement road runs the length of the site along the top of the bank (~10 feet up, and only a few meters back from starting point of terrestrial vegetation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVH</td>
<td>No terrestrial vegetation</td>
<td>Rock wall with parking lot and viewing gazebo at the top of first two transects. Rock wall and house at top of third transect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVC</td>
<td>Some grasses, no other terrestrial vegetation</td>
<td>Rockwall, fence and homes line all three transects.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6. Natural characteristics and anthropogenic modifications to the landward boundaries of permanent transect sites.**
VIU NEWS RELEASE - VIU RESEARCHERS SEEK PUBLIC HELP WITH STUDY

VIU RESEARCHERS SEEK PUBLIC HELP WITH STUDY

Public assistance needed to monitor beaches in Deep Bay and Bowser

VIU RELEASE: 2014/092

FOR IMMEDIATE RELEASE: Friday, December 19, 2014

NANAIMO, BC: A team of researchers from Vancouver Island University (VIU) and the University of Victoria are studying the movement and fate of a seaweed called Mazzaella japonica (MJ), and they are asking for the public’s help.

Since 2007, the BC Ministry of Agriculture has been issuing licences for the harvest of beach-cast seaweed (wrack) between Deep Bay and Bowser. The target species in the study, MJ, is a Japanese red alga. Like many red seaweeds, MJ is rich in carrageenans, a compound used as a gelling and thickening agent in a variety of food, pharmaceutical and industrial processes.

“While this harvest has raised environmental concerns, the available information to date has been largely based on literature reviews and anecdotal observations,” says Sarah Dudas, a researcher in VIU’s Biology department.

“To investigate the fate and dispersal of this particular kind of seaweed, we are releasing small bundles of the seaweed tied with brightly coloured, non-toxic, biodegradable flagging tape at two sites in the Deep Bay/Bowser region. A total of 100 small bundles will be released at two beaches and the tape will be labeled with special identification numbers.”

Researchers will monitor the beaches on a bi-weekly basis between now and February 9 but if any member of the public happens to see the specially marked bundles while strolling local beaches, they are asked to email jjholden@uvic.ca

“We’d like to know the date, time and location of the sighting, as well as the colour of the flagging tape and identification numbers,” says Dudas. Information from the study will be used to develop a database and map of the distribution of the beach-cast bundles over time.

Tracking the movement of MJ will help researchers better understand the fate of this red algae within the ecosystem, Dudas adds. Understanding the dispersal patterns of beach-cast seaweed will also contribute to more accurate calculations of the volume of seaweed being washed ashore.

Dudas asks members of the public to leave seaweed bundles where they are found. After February 9, researchers will gather up any remaining biodegradable tape left on beaches.

-30-

MEDIA CONTACT

Marilyn Assaf, Communications Officer, Vancouver Island University
P: 250.740.6559  C: 250.618.4596  E: Marilyn.Assaf@viu.ca  T: @viunews
**Mazaella japonica Drift Study**

As part of an ongoing study on beach-cast *Mazaella japonica*, small bundles of the seaweed tied with brightly coloured, non-toxic, biodegradable flagging tape have been released at two beach sites within this region.

Since 2007, the British Columbia Ministry of Agriculture has been issuing licences for the harvest of beach-cast seaweed (wrack) from Deep Bay to Bowser targeting this species. *M. japonica*, is a Japanese red alga that was first reported in Deep Bay about 10 years ago. Like many red seaweeds, *M. japonica* is rich in carrageenans, a compound used as a gelling and thickening agent in a variety of food, pharmaceutical and industrial processes.

To investigate the fate and dispersal of beach-cast *M. japonica* within the ecosystem, small bundles of the seaweed tied with biodegradable flagging tape have been released at two beach sites. The colour of the tape is unique to both the site and the date of release. Additionally, each bundle has been marked with an identification number, for which there is a corresponding recorded weight. If a flagged bundle is found, the sighting can be reported according to the instructions below.

**How to report found bundles**

Email the following information to jjholden@uvic.ca

- Date and time of the sighting
- Location of the sighting (include as much detail as possible)
- Colour of the flagging tape
- Identification number marked on the tape

**We ask that the bundles are left where they are found until February 9th, 2015.** After February 9th, we will be collecting and disposing of any remaining flagging tape found on the beaches.
3 Appendix

The following further communication activities have been conducted during the course of the project:

1) Stakeholder advisory group meeting October 22nd


3) CTV News interview at harvest area about study November 7th - available on line at: http://vancouverisland.ctvnews.ca/video?clipId=487127&binId=1.1180928&playlistPageNum=1

4) Verbal Project update briefing with Gary Caine at Field Station – November 12th

5) Public photos from project on Field Station Flickr site at: https://www.flickr.com/photos/viucsr/sets/72157649377792181/

6) Community information blog post at www.viudeepbay.com

7) Press release regarding mark recapture study attached and at at www.viudeepbay.com

8) Radio Interview – 91.7 FM Nanaimo and online article.

9) Radio Interview – CBC Radio 15.01.08

10) Shaw TV – Video 15.01.28 http://youtu.be/QegEUMeHi1g


13) Provided information about study and potential narratives to “Seedy Saturday” organizers regarding potential boycott. 15.02.05
