macphail woods
ecological forestry project

Contact: Daniel McRae
Phone: (902) 651-2575
Email: danielmcrae@macphailwoods.org
Website: macphailwoods.org

Continuing Krummholz Preservation and Restoration

A PEI Forested Landscape Priority Place Project

April 15, 2023

Prepared by: Daniel McRae

Environment and Climate Change Canada
Environnement et Changement climatique Canada

Prince Edward Island
CANADA

Canada

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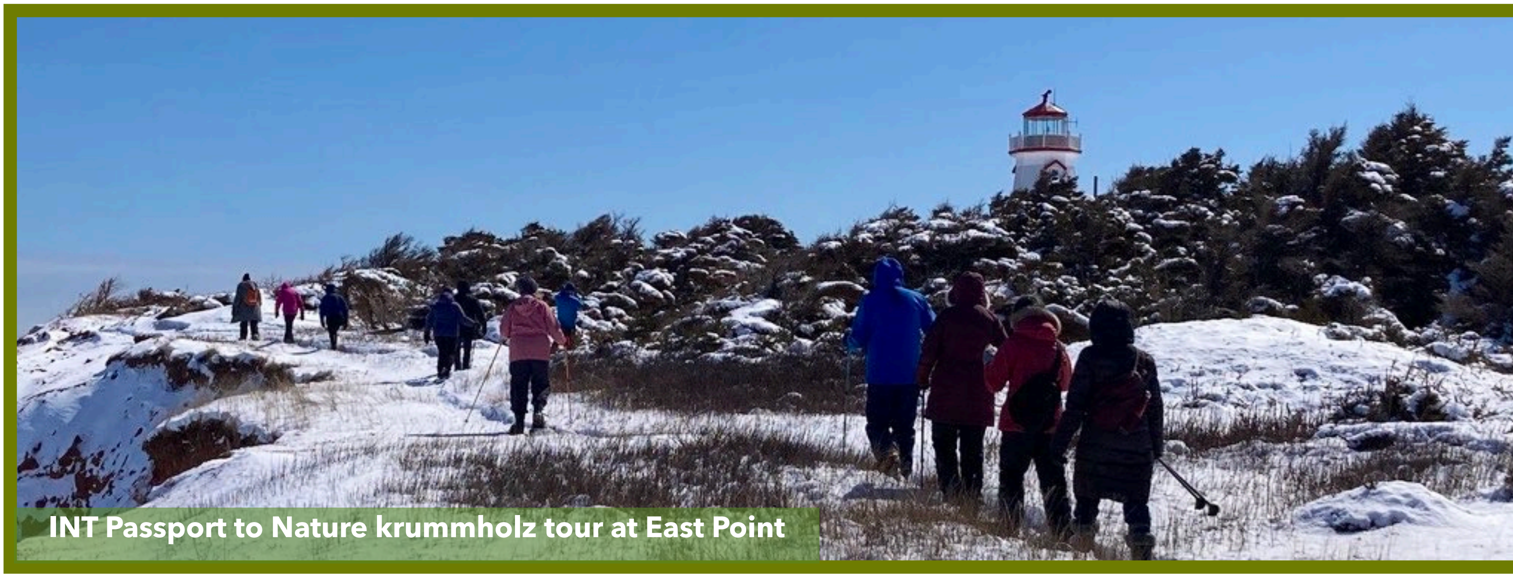
ACKNOWLEDGEMENTS



INT Passport to Nature krummholz tour at East Point

The Krummholz Project began in the winter of 2021, and has gradually grown in scope, scale and reach. There are many organizations and individuals, both near and far, who have provided an amazing amount of support for this project.

Thank you to both the Provincial Government of PEI and Federal Government of Canada, who's funding through the Forested Land Priority Places for Species at Risk Program made this project possible!

Thank you to Gary Schneider, Eric Edward, Becky Byrne and the rest of the staff at the Macphail Woods Ecological Forestry Project. They helped in so many ways, from fieldwork to propagation to editing. This project would be impossible without such a supportive group of amazing people!

Thank you to the many land stewards of PEI. From governmental groups like our Provincial Government and PEI National Parks to local conservation organizations like the INT and the NCC to private landowners. So many have worked hard to conserve our native habitats and graciously allowed me to access to their beautiful properties.

Thank you to Lennox Island First Nation for their assistance and permission in visited Hog Island and Georges Island. It was a magical experience each visit and such an amazing site to study.

Thank you to the ACCDC and other regional scientists, botanists, geographers, meteorologists who were patient with my many, many questions, who provided their publications, and who collected wonderful data which has greatly aided this study. Thank you to staff from the ACCDC for their time and support in identifying species and providing training in the field.

Thank you to my partner, Mille, for her patience and support with many long days of field work and a big thank you to my son, Henry, who helped on several field excursions.

PROJECT HISTORY

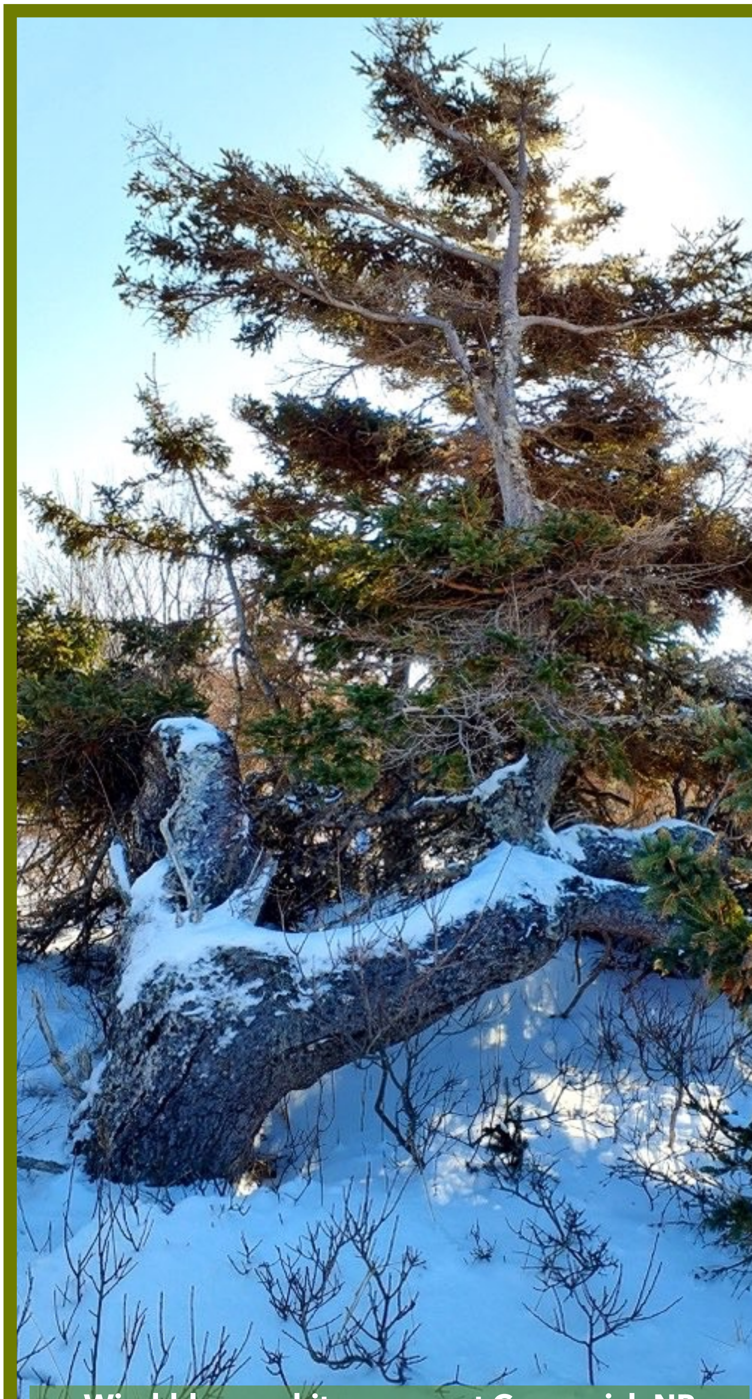
The 2022-23 season of the Krummholz Project, is a direct continuation of two previous studies.

The project was initially inspired by the aftermath of Hurricane Dorian which landed on PEI, September 7th, 2019. Macphail Woods director, Gary Schneider, was called to consult on the overwhelming windfall amongst the aging white spruce at Cavendish campground. Upon inspection, Gary noticed that the gnarled, wind-shaped spruce growing adjacent to the campground fared through the high-wind event with minimal damage. Our perspective on these unique areas shifted, looking past their deformities to truly appreciate their integral and resilient role in our Island's ecology, protecting our shores and inland habitats.

The first study, ***Exploring the Importance of Krummholz Forests***, took place between January 2021-March 2021. With lots of long winter drives, this study focused on surveying shores across the Island in search of wind-blown coastal habitats. This study resulted in the selection of 8 sites for deeper study, as well as a host of other potential sites. A variety of data was collected across the study sites over the winter, and an ecological assessment rubric began to develop.

The second study, ***Increasing our Awareness of Krummholz Forests***, ran from March 2021-March 2022. It saw the addition of five new sites, including Hog Island, for a total of 13 sites across the province. Sites were chosen to represent the diversity of coastal habitats found in PEI. From cliffs to dunes to salt marshes, our provincial coastlines have been heavily shaped by a number of natural, historic and present-day forces, resulting in a high variance across these priority places. This study focused on understanding the floral and faunal communities that coalesce into the diverse array of krummholzing habitats found on our Island. It also included seed collection and propagation of these integral native coastal species.

Both of these previous reports are available for free on the Macphail Woods website.



Wind-blown white spruce at Greenwich NP

INTRODUCTION

The 2022-23 season of krummholz research, ***Continuing Krummholz Preservation and Restoration,*** aimed to build off the previous studies, continuing a number of the same activities such as ecological assessment, biodiversity surveys and seed collection. Several new goals were added as well, which were focused on understanding natural krummholz succession & restoration. These goals included examining the role of wind & salt, community outreach to raise awareness about these habitats as well as creation of a virtual video tour of these krummholzing coasts. Additionally, two restoration trials sites were chosen with small plantings planned for early October of 2022. In late August, there was a field trip to northern Cape Breton to investigate several krummholzing coastal sites for comparison.

Hurricane Fiona arrived September 23rd, 2022, causing Island-wide damage resulting in power-loss, blocked roads, coastal flooding & erosion as well as large-scale blowdown across many Island forests. This historic storm also changed a variety of the previously planned actions for this stage of the krummholz project. As a result of hurricane Fiona, the two restoration trials were postponed until 2023, the large scale of damage limited access and site safety and delayed possible planting times until it was too late in the season.

Although initially seen as a set-back, negatively affecting the study, Fiona was eventually seen as an incredible learning opportunity. As previously mentioned, the krummholz project was initially inspired by hurricane Dorian and now there was a chance to see how our study sites fared during the historically powerful Fiona. Post-Fiona fieldwork began by early October 2022, assessing a number of previously established study sites as well as adding an additional 15 study sites. The results of this post-hurricane assessment were surprising, most of the krummholzing habitats not only survived the storm, but came through will much less damage compared to more inland sites.

Included in the analyses of survey data in this report, are two rudimentary indices created to quantify qualitative assessment data for the purposes of analysis and comparison. The Ecological Disturbance index (ED index) and Fiona index (F index) both range from low-to-high, with higher values indicating greater scope and scale of each variable respectively.

HIGH-WIND HABITATS


Phantom point lighthouse krummholz in Cape Breton

As mentioned in preceding reports, krummholzing flora and their associated habitats have been found and studied all over the globe. Historically, krummholzing alpine environments have been more commonly studied than those found in coastal conditions. Although they each face their own unique challenges, both of these types of krummholzing areas share a number of similar conditions, most specifically high mean annual winds.

While the interaction of high winds and tree growth-form have been extensively studied, this has historically been examined with the purpose of finding suitable sites for wind farms. E.W. Hewson and others published two significant reports in 1979 which summarize much of the research focusing on using vegetative growth patterns to estimate local annual wind speeds. The first publication, *A Handbook on the Use of Trees as an Indicator of Wind Power Potential,* includes descriptions of three methodological indices of deformity for estimating mean annual wind speeds. It also details more specific examples of growth form and damage which can indicate wind direction as well as the seasonality of strong winds. The second publication, *Vegetation as an Indicator of High Wind Velocity,* is a supportive document to the other. It provides more detailed explanations of previous studies as well as species-specific indices of deformity. Sadly, our primary native krummholzing species are lacking from their species-specific information although it does mention planned balsam fir (*Abies balsamifera),* studies, which have not yet been obtained. That being said, the report does include the generalized Griggs-Putnam deformity index (GP index), which is based on averages of species studied up to that time. While this is more than likely inaccurate, it does provide a starting point for analysis of field data and perhaps an opportunity to create our own regional and species-specific indices.

These reports are primarily compiled from studies of alpine krummholzing trees, as the aim was to locate sites for wind power production. Wind-prone coasts can be problematic for wind production due to a number of additional environmental variables, such as salt spray, increased turbulence and erosion. This has also reduced the accuracy of the previously mentioned deformity indices due to the additional abrasive agents from sand to ice to salt, which all contribute to the trees' reactionary growth patterns in high-winds as well as their site distribution and density.

MEASURING THE WIND

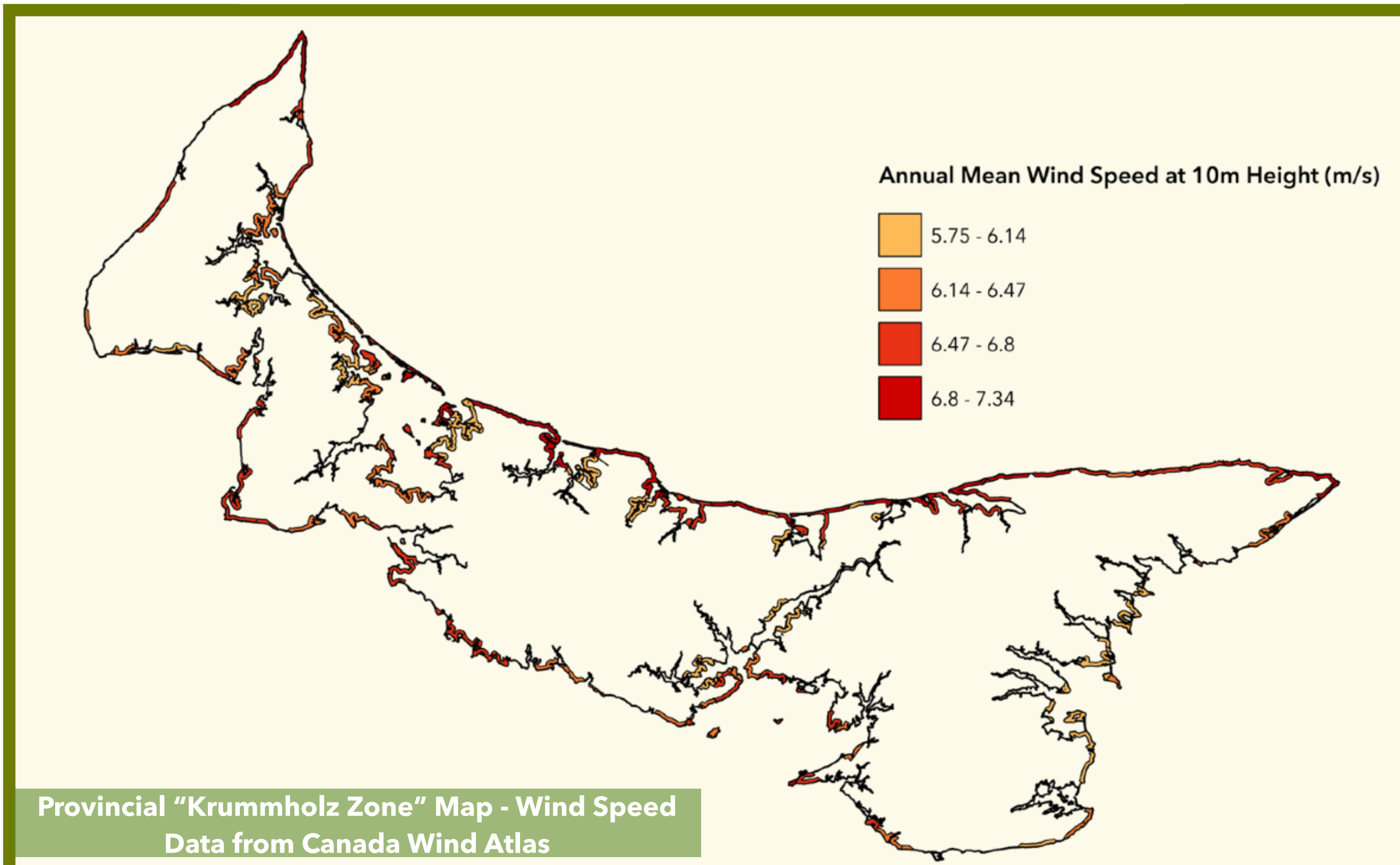
As part of this project, wind readings were taken at various locations across many of the sites. Each reading was taken for at least 2 minutes at each location in 3-second intervals. The goal of this method was to lengthen the data collection time compared to last year's singular 1-second wind measurements. This allowed for better averaging of wind speeds, smoothing the effect of our common coastal wind gusts. Although an improvement, this method does not allow for calculating site-specific annual mean wind speeds, a crucial piece of information concerning krummholzing habitats. That level of detailed data would require wind anemometers on each study site taking periodic readings over multiple years. Over the course of this project, relevant climate researchers have been contacted from organizations such as the UPEI Climate Lab, however no specific data has been shared as of yet.

The Federal Government of Canada, through their department of Environment and Climate Change, provides an excellent online resource in the Canada Wind Atlas (http://www.windatlas.ca/index-en.php). It provides downloadable GIS data about national, regional and local winds down to a scale of 16 km squares. Each of the gridded squares contains a variety of data, including the annual average wind speed as well as more seasonal data. Although the wind atlas is incredibly useful, its 16 km scale creates challenges in our small province. Our coastlines are narrow, with krummholzing effects generally ranging from 100-400 m from shore. The Wind Atlas data is often averaged over areas which include both coastal and inland conditions, decreasing the specificity of the data in relation to study sites. Coastal winds also tend to be more volatile with more localized variance than inland sites, particularly on PEI, with its largely flat topography. This further distorts the Wind Atlas data in relation to study sites.

Furthermore, the mathematical formulas used to calculate these averages require a derived number based on the "roughness" of land cover, reflecting the frictional effects of vegetation and structure on wind-flow. This value, often called the "roughness-length", is approximately equal to one-tenth of the average height of land-cover in the 16 km section. To more accurately estimate annual average wind speeds along our coasts, a smaller coastal-specific grid must be created with vegetative roughnesses more accurate to our coasts. As your will see below, there are a number of common processing techniques and data-sets that would allow for such a coastal specific map to be made.

Measuring the wind at Meat Cove, Cape Breton

PROVINCIAL KRUMMHOLZ ZONE



Provincial "Krummholz Zone" Map - Wind Speed Data from Canada Wind Atlas

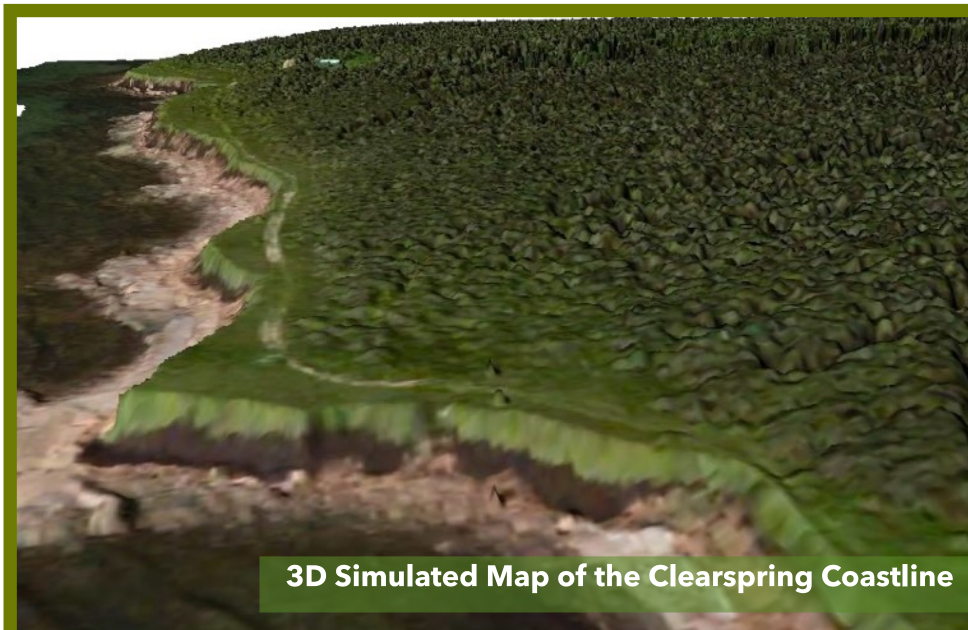
Despite these limitations, the Wind Atlas data was extensively used and processed to determine potential coastlines where krummholzing habitat should be present. Specifically, a prototype map of the provincial "krummholz zone" was created to help target new sites as well as understand the historical and present-day distribution of these habitats across the Island.

The map above was created by extracting 500m wide polygons using the provincial coastline GIS data in combinations with Wind Atlas data. These polygons, geo-referenced along our coast, contain the annual average wind speeds at 50m for each 16km stretch of coastline. Through the use of standard wind-industry mathematical formulas which can estimate average wind speeds at variable heights using surface roughness data provided by the Canada Wind Atlas, the 50m data can be converted to estimate annual mean wind speeds at other heights. Again, none of this is site specific, but should be broadly indicative of general trends. The map above shows annual average wind speeds at 10m calculated using this process.

Even with the previously mentioned challenges of this data-set, this process has yielded good initial results. All of the study sites are located in areas on the map above that are predicted to have high mean annual winds. Both of the south shore sites illustrate this well, the Enmore site is located in an area of much weaker winds compared to Cameron Island, and demonstrates much weaker krummholzing effects on its flora. All sites in the St. Peters area, which were added to the study recently, were chosen using the "krummholz zone" data-set. These include two additional sites in the PEI National Parks as well as a site stewarded by the INT. Rare native species and krummholzing vegetation were found at each site.

MAPPING WIND FLOW

Our constant coastal winds shape the vegetation throughout the "krummholz zone", influencing both their shape and local distribution in conjunction with other conditional variables, such as drainage and soil structure. As krummholzing woody species develop into scattered clusters or undulating fronts, they influence the flow and dynamics of wind, decreasing the wind's strength on other specimens located further inland, creating the typical inclining vegetative slope of Island krummholzing coasts.


3D Simulated Map of the Clearspring Coastline

Predicting these dynamic local wind patterns would required site-specific historic wind data as well as complex and expensive 3D wind flow simulation software, which Macphail Woods did not have access to. That being said using 2020 digital elevation models (DEM) from the Government of Canada, vegetative and structural heights can be ascertained with a 1 m resolution by subtracting the digital terrain model (DTM) values from the corresponding digital surface model (DSM) values. This process is similarly used in provincial forest inventory calculations. The resulting GIS data, representing surface cover height, can then be processed in a variety of ways providing insight into krummholzing conditions in 2020. For instance, both the direction and incline of sloping coastal vegetation can be calculated at a 1 m resolution, virtually estimating the krummholzing intensity and inclining angle of vegetative cover.

The resulting maps were tested at a number of different study sites, most throughly along the Clearspring coast. Field observations of krummholzing patterns, including direction and distribution, broadly corresponded with processed predictions. Even sites like Greenwich in the PEI National Parks, with its scattered back-dune krummholzing patches of white spruce, were approximately well-matched, as long as krummholzing clumps were larger than a half-meter in area.

While wind flow patterns through the krummholzing habitats were not possible to record, processing Wind Atlas data with the derived vegetation heights can create a snap shot of estimated annual wind speeds at the height of the canopy across the site. Although definitely inaccurate without proper 3D flow modelling, the resulting wind maps of coastal sites do illustrate the general trends of wind protection that krummholzing habitats provide.

COASTAL WINDS

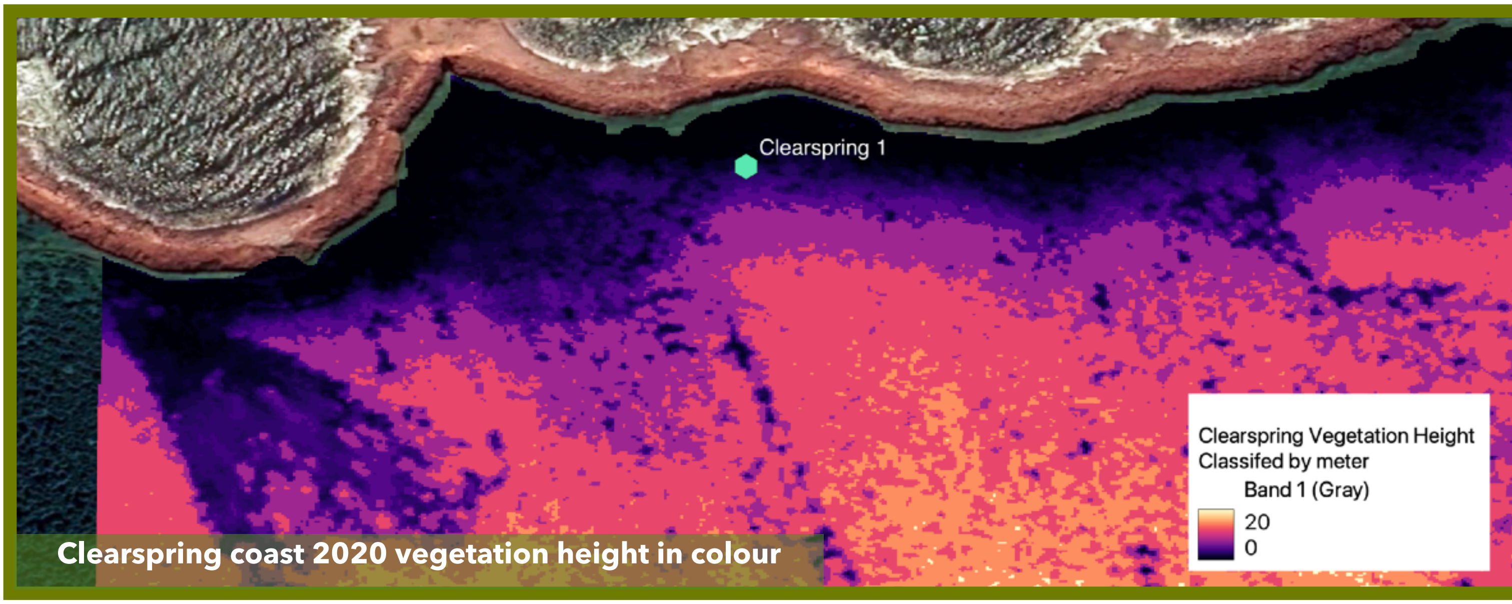
As previously mentioned, our coastal krummholzing habitats have generally been poorly studied, save for some excellent work in the PEI National Park, by local historians, and the ACCDC. That being said, most of these works focused on specific aspects or areas of our coasts, which only provide limited understanding of PEI's krummholz distribution and health, as well as the myriad of ecological services that they provide and challenges they face.

Salt-spray and sand play an unknown role in the krummholzing process along our coasts. Although indices like the Griggs-Putnam include correlations between tree-form and wind speed, it is unknown what proportional role our coarser agents add to the krummholzing effect. The reports of vegetation deformity in relation to wind from 1979 did not focus on coastal sites. Fieldwork included recording specific specimen and site-average levels of deformity based on the GP index. By categorizing sites by their top level of deformity, we can compare and contrast predicted average wind speeds as well as a variety of other indicators.

SITE DEFORMITY BY WIND SPEED AND OTHER VARIABLES

TOP DEFORMITY LEVEL	Total Surveyed	GP Index Avg Wind Speed Estimate	Lowest Wind Atlas Average Annual Wind Speed (m/s)	Average of Site Wind Atlas Average Annual Wind Speeds(m/s)	Avg F index	avg D index	Avg age
ALL Sites	**28**		**7.147**	**8.046**	**10.53**	**4.75**	**63.57**
Brushing	0	3.5	N/A	N/A	N/A	N/A	N/A
Slight_Flagging	2	4.5	7.147	7.554	14.0	3.5	82.5
Mod_Flag	3	5.5	7.345	7.522	7.0	4.7	75.0
Full_Flag	6	6.5	7.789	8.058	11.7	6.0	58.3
Part_Throw	11	7.5	7.767	8.176	10.4	4.7	53.2
Full_Throw	2	8.5	8.393	8.451	10.0	5.0	85.0
Carpet	4	10	7.633	8.104	10.0	3.5	71.3

As can be seen from the table above, estimates for average annual winds speeds at sites with extreme wind-shaped growth-forms, do not accurate account for the severity of deformity according the Griggs-Putnam index. Although some of this discrepancy might be due to species-specific variation as well as local site wind variance, our abrasive coastal agents might account for some of this difference between extreme deformity levels and wind speed averages. It stands to reason that the effect of abrasive materials such as sand and salt would proportionately increase with higher wind speeds as more and larger particles are lifted into the winds. The effects of coastal salt-spray have been studied, although most studies found were focused on its reach inland and effect on inland soils rather than its erosional effect on vegetaion along the coast.



Clearspring coast 2020 vegetation height in colour

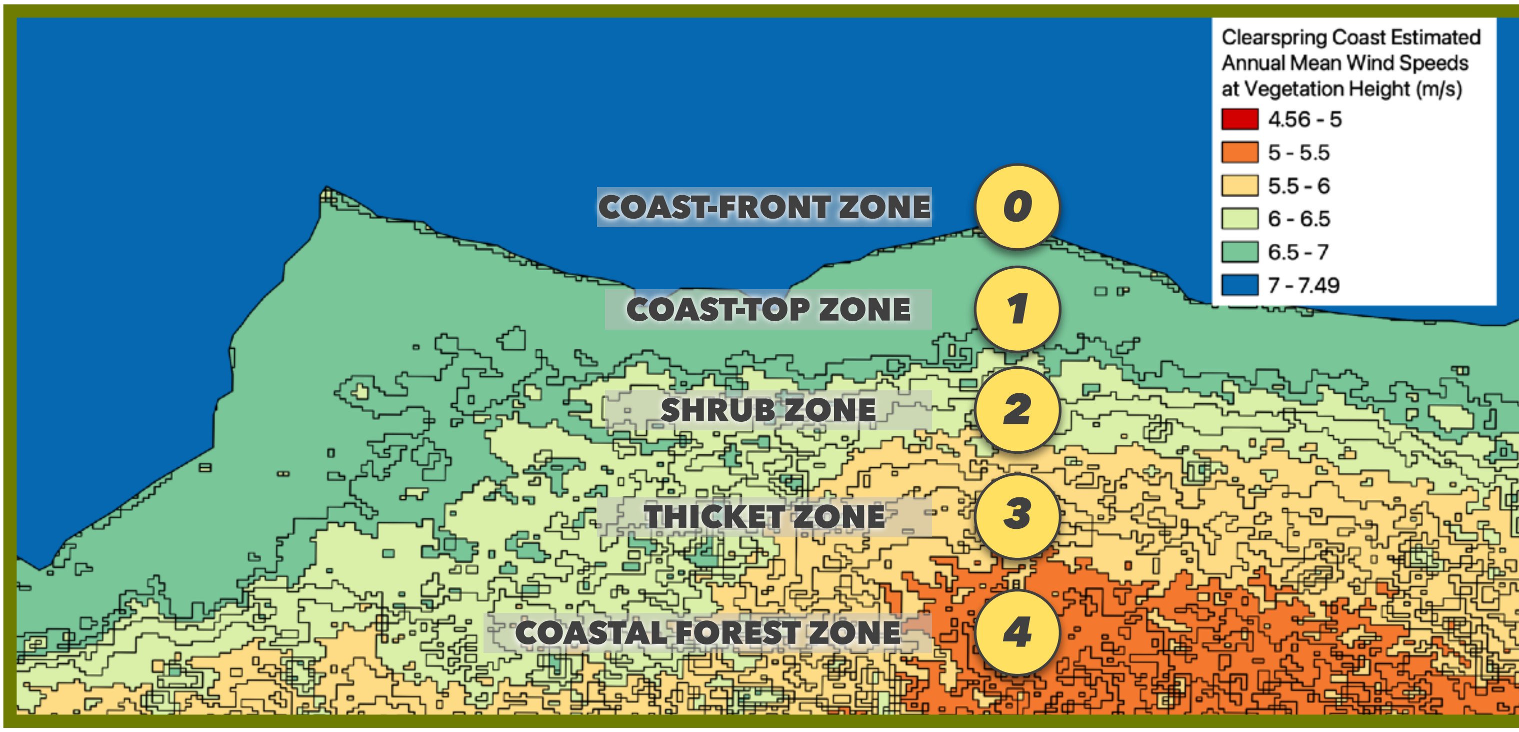
Although a 1 m resolution seems accurate, it is too large a scale to detect the minute variations along our krummholzing coasts. Despite these challenges and limitations to measuring wind as well as mapping small-scale topographical and vegetative data, a number of standard GIS processes can create maps which illuminate various aspects of coastal krummholzing ecology. While not precise enough for detailed study, these data-derived maps showcase some general patterns and trends of our coasts which can inform future restoration work and guide future studies. Island-wide processing of this data could yield a relatively accurate provincial distribution map of krummholzing coastal ecosystems, crucial in understanding, protecting and restoring these vulnerable locations.

The map above shows the vegetation height of the Clearspring 1 site, visually categorized by meter. It highlights horizontal bands of vegetative height which have been often observed during fieldwork. These zones run approximately parallel with our windy coastlines, generally perpendicular to the average direction of krummholzing winds. Each coloured category of vegetative height, on the map above, tells the story of the intensity of the krummholzing winds and its effects on floral development. The thickness, severity of deformity as well as flora species found across each of these **ecological wind zones** are all influenced by the area's mean annual wind speed, rates of erosion, local seed-sources, past land-use and drainage properties. For instance, dune sites often lacked the continuous horizontal vegetation patterning common on cliff sites, most likely due to the volatile dynamics of sandy coastal systems.

Similarly to marine shorelines and their ecological tidal zones, each with their own associated flora and fauna. Many of these ecological wind zones were observed to have associated groups of flora species as well as common patterns of specimen distribution. Distinct botanical species groupings seemed to be relatively consistent when categorized by coastal types in conjunction with specific ecological wind zones.

Through data analysis and fieldwork observations, five ecological wind zones were categorized. These can then be further classified by coastal-type and soil drainage. While there is surely more natural variation than this simple categorization system, this approach helps to build a transferable restoration framework.

ECOLOGICAL WIND ZONATION



Each of the five ecological wind zones have transitory edges, shifting over time with patterns of ecological succession. Propagation and growth of flora species in each zone is heavily influenced by local wind patterns. As vegetative cover develops and matures, it changes these wind patterns, shifting zonal boundaries and reducing krummholzing effects for more inland areas. This results in a relatively ordered pattern of ecological wind zonation, whether continuously along our cliffs or in scattered areas throughout our dune systems.

The five ecological wind zones that follow are numbered from zero to four, from coast adjacent to inland, with a colloquial zone name given to each.

ZONE ZERO: The *COAST-FRONT ZONE* is closest to the oncoming coastal winds. This zone is located where land and sea meet, whether vertically along a cliff-face or lying low among the tides in a salt marsh. It often provides the greatest challenges for many flora species. The windy coast-front zone often has other harsh conditions depending on coastal type such shifting sands, erosion, and salt-intrusion. This zone is generally colonized by native specialist species, although some more common species from further inland zones can end up growing here due to erosional forces.

ZONE ONE: The *COAST-TOP ZONE* is located directly interior to zone zero. Still exposed to very strong winds, but often with lessening marine effects. These forces limit the height and propagation of native flora, limiting the species that can growing in this zone. On dryer sites, this area is often dominated with grasses, goldenrods, yarrow as well as scattered and stunted bayberry, currants and wild rose. As drainage lessens, dense areas crowberries, three-tooth cinquefoil and cranberries can develop. There are other less-common specialists of this zone such our native junipers as well as lingonberry. Spruce can be found in this zone, generally carpeting or throwing in shape, often scattered singly or in small clumps. Dune systems have their own unique flora in the coast-top zone due to their drastically different soil and disturbance rate. Coast-top zones along our cliffs can be very similar to the *coastal barrens* of Nova Scotia, such as those surveyed in Cape Breton.

Cranberries, cinquefoils & junipers

ZONE TWO: *The SHRUB ZONE* occurs once frictional forces along the preceding coast-top zone, primarily due to vegetative development, allow for substantially increased survival rates for woody flora, particularly shrubs. Bayberry, wild rose, aronia, winterberry holly are often found growing in stunted forms with much evidence of die-back. Spruce can also be found growing, larch on wetter sites, although generally less numerous. These specimen trees tend to vary in deformity depending on coastal wind intensity and position amongst the shrubbery. Near the back of this zone, or inland side, shrubs continue to gain height, forming dense brambly thick-growing hedges Wasp nests were often found amongst the densest areas of shrubbery. Again, dune systems have their own unique shrub zone specialists but share many common maritime species with other coastal-types.

ZONE THREE: *The THICKET ZONE* is named after the historic nomenclature used to describe our coastal krummholzing habitats. The area is partially-sheltered from coastal winds by the preceding shrub zone. This protection increases the survival-rate of young conifer trees, often white spruce, resulting in dense and tightly-packed thickets. Whenever seed sources are present, other tree species, such as white birch and red maple, can grow throughout this zone, although rarely in high proportions compared to the conifers. Depending on the protection provided by the shrub zone, trees in this zone can grow quite straight in their early years, only to be exposed to the full-force of the wind once they reach over the tops of the preceding shrub zone. Again, dune systems have their own unique thicket zone specialists but share many common maritime species with other coastal-types.

ZONE FOUR: *The COASTAL FOREST ZONE* is an area that bears much more study. It is located at the far reaches of krummholzing coastal forces, which be as close as 20m from the shore. Across many other locations such as Greenwich, East Point, Basin Head and the Clearspring coast sites, this area can be found 100 - 400 m inland. Hog Island showcases the potential for restoration work within this zone, with healthy white ash, red oak and sugar maple found growing near the coast on George's Island, sheltered by krummholzing habitats of Hog Island towards the Gulf. This zone begins as local tree-form becomes more more typical, often with reduced canopy height but mild deformity. These canopy specimens can be well-spaced and this coastal forest system is clearly capable of growing native trees that are typically considered to be upland forest species. Both Hog Island and East Point, two sites with no evidence of recent farming, support a number of interesting wildflower, ferns, non-vascular and fungal species when compared to more ecologically disturbed study sites. Again, dune systems have their own unique coastal forest zone specialists but share many common maritime species with other coastal-types.

Although it is the strong and constant coastal winds which strongly dictate the patterns the ecological wind zones, local soil structure plays an important role in each zone's botanical nuances. These soil-based sub-classifications can be simplified through three divisions with each approximating levels of water-availability in the soil. While not always applicable in across all zones and coastal types, these simple soil sub-categories are particularly apparent along our coastal cliffs. While certainly informed by provincial soil drainage information, this data-set was not always precise enough to describe local coastal soils. Coastal soils are another area that would benefit from more direct research.

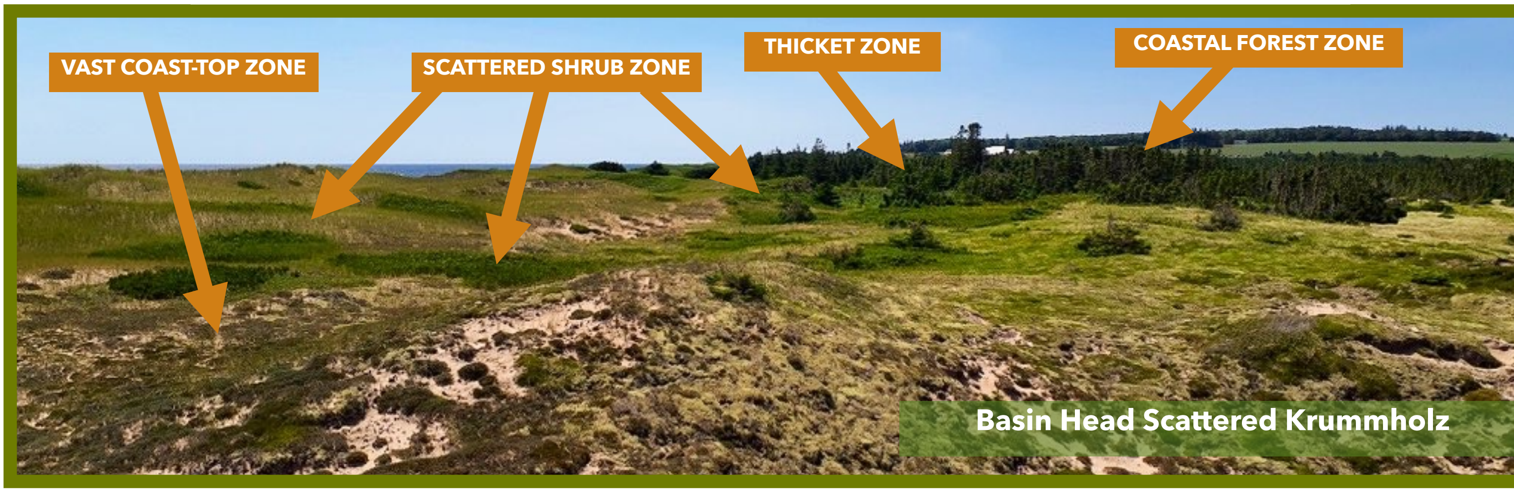

Enmore: a wet soil site

Dryer Soil Sites: Many cliff sites, often with higher levels of ecological disturbance, were dominated by typical full-sun agricultural species as well as native grasses, yarrow, blue-eyed grass, starry-false Solomon's seal and asters. It is difficult to know if this species grouping formed naturally, possibly an example of the "coastal meadows" reported by early Island explorers. It may also be the product of ecological disturbed sites, indicating the need for restoration work. Dry dune sites have unique drought-tolerant species, such as marram grass, not found commonly across all cliff sites.

Medium Soil Sites: When present along our cliffs, this soil type results in the most similar krummholzing coastal ecology to sites visited in Cape Breton. These are typically dominated by species of the heath family such as the crowberries, cranberries, but also three-toothed cinquefoil. Small remnant pocket-populations of this botanical grouping were often found at sites with heavy agricultural histories, which displayed dryer soil *site* species predominantly. Developed secondary dunes share many species in common with medium cliff *sites,* however still retain their high rate of endemic sand specializing species.

Wet Soil Sites: Only one study site with ample wind could be truly classified as a wet site, located along the perched peat bogs of North Cape. This site had its own unique array of flora, as well as many species found in the medium soil grouping. Without additional wet soil study sites, it is hard to ascertain the typical species and native diversity of this grouping. That being said, localized wetter habitats on study sites, such as the Basin Head dune swales or clearspring cliff-top seeps, supported a number of similar species to North Cape, including a variety of sphagnums as well as round-leaved sundew.

KRUMMHOLZ DISTRIBUTION PATTERNS



Patterns of krummholzing distribution were also apparent during fieldwork and GIS mapping. Six relatively distinct patterns of krummholz distribution were identified. By qualifying each study site by its dominant krummholzing distribution pattern, post-fieldwork analysis could be used to compare these observed categories to other site variables.

All of these differing patterns of specimen distribution and development tell a story of ecological succession and recovery from past disturbances. Studying these patterns has been very beneficial towards informing restoration planning.

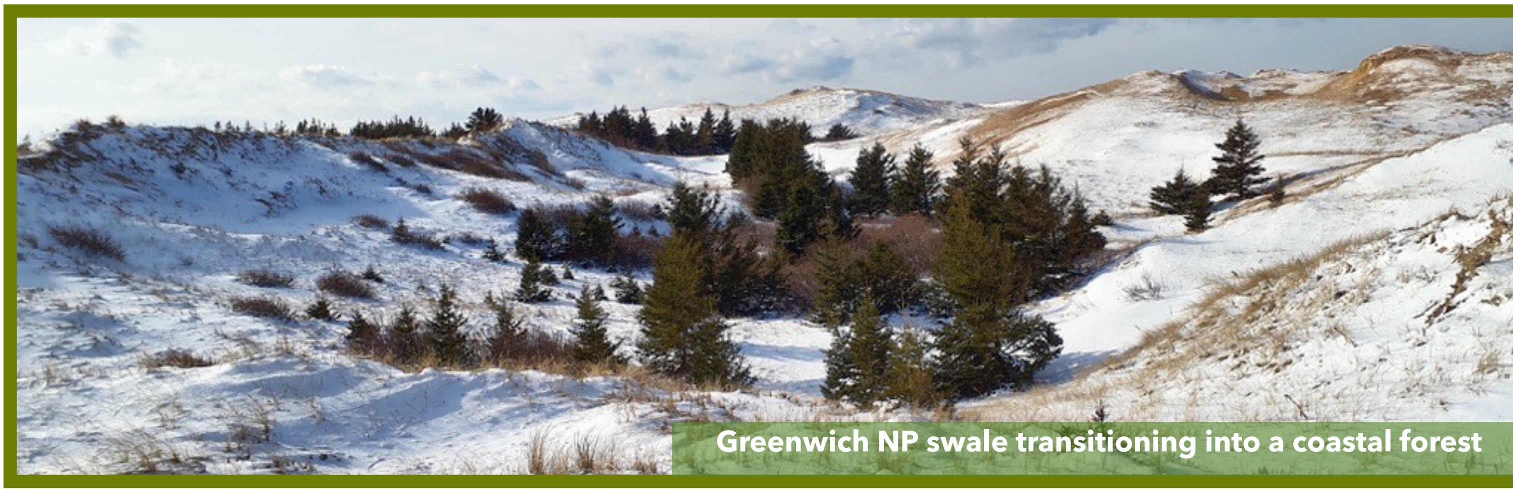
For instance, sites with straight coastal fronts of krummholzing trees growing up to the cliff's edge often had high-levels of coastal tree fall after Fiona, suggesting that this distribution pattern is associated with high-levels of erosion.

The table below shows the different categories of krummholz distribution patterns seen across study sites by their coastal types. Scattered krummholz patterns are most often found on dune systems, while both types of frontal patterns (undulating and coastal) were more often found amongst cliffs and bluffs. Dense areas were locations where krummholz vegetation was broken up, generally due to some kind of infrastructure or human-use such as mowing. Sparse krummholz patterns were seen at one PEI National Park site that had been often disturbed until recently, and was in the very early stages of regeneration. The sites with minimal krummholz effect were both low-plain coast types, located in more sheltered and lower-wind areas.

KRUMMHOLZ DISTRIBUTION PATTERNS BY COASTAL TYPE

KRUMMHOLZ DISTRIBUTION PATTERN	TOTAL #	DUNES	CLIFF	BLUFF	LOW	DUNES/CLIFF
Scattered Krummholz	10	8	1	0	0	1
Undulating Front	6	1	5	0	0	0
Coastal Front	5	1	0	1	0	3
Dense Areas	4	0	2	2	0	0
Minimal Krummholz Effect	2	0	0	0	2	0
Sparse Krummholz	1	0	1	0	0	0

KRUMMHOLZ DISTRIBUTION PATTERNS



Greenwich NP swale transitioning into a coastal forest

The following table shows the same distribution patterns by biodiversity and other indicators. The preliminary findings below suggest a number of interesting conclusions.

The *scattered, undulating front and minimal effect* categories, are hypothesized to be more natural examples of krummholzing coasts. They have the highest average number of rare native species as well as tree age. They also have the lowest average ED index rating. The *coastal front* type had the highest average number of species, although this is predominantly the result of the uniquely diverse Cow River site skewing a low study size. These areas also scored the highest average F index rating, most likely due to their increased exposure to erosion. *Dense and sparse* categories had the highest levels of ecological disturbance on average, although sparse krummholz fared better during Fiona. This suggests newly developing krummholz might be more resistant to storms then highly disturbed semi-mature krummholz. Cutting into what krummholz habitats we have, whether for cottage or other development, might leave them particularly vulnerable to future cyclonic events.

More study sites with a diversity of these patterns would help to understand the processes of ecological succession across our krummholzing coasts, informing and improving future restoration efforts.

KRUMMHOLZ DISTRIBUTION PATTERNS BY OTHER INDICATORS

KRUMMHOLZ DISTRIBUTION PATTERN	TOTAL #	AVG ED index	Avg F index	Avg Nspp	Avg Rspp	Avg Spp rich	Avg Age
Scattered Krummholz	10	4.60	10.29	66.56	7.67	70.11	70.00
Undulating Front	6	4.17	9.17	58.75	5.00	71.40	73.75
Coastal Front	5	5.00	15.50	94.67	1.67	114.50	55.00
Dense Areas	4	6.00	11.00	46.33	2.00	55.00	61.67
Minimal Krummholz Effect	2	3.50	14.00	79.00	3.00	87.00	82.50
Sparse Krummholz	1	6.00	6.00	N/A	N/A	N/A	N/A

East Point krummholzing spruce & fir

The coasts of Prince Edward Island share a similar history to more inland areas of our province. Our shores have a long history of harvesting, farming as well as private cottage and tourism development. These reoccurring disturbances have left lasting across our krummholzing coasts.

Prior to European arrival, the Island was estimated to be 98% forested, made up of a mosaic of forest types, often predominantly deciduous. By the 1720's, the first significant European settlements were established by the French, and the process of harvesting and land clearing began.

The French Period (1534-1758)

The French period was predominantly focused on establishing several colonies across the province, clearing land primarily for agricultural purposes. Coastal areas were often the first settled, with dune meadows and salt marshes used for grazing livestock. When it came to clearing heavily forested areas, controlled burns were a commonly-used part of the process. There are multiple historic accounts of fires that got out of hand and spread through large areas. Two particularly large fires occurred along the northeast coast in 1751 and 1752, resulting in a barren, burnt-out landscape from St. Peter's all the way to East Point. Joseph de la Roque described the East Point area after the fire in 1752 as a "desert" or wasteland. The after-effects of these events were still recorded by the British surveyor, Samuel Holland, in 1765.

Coastal Forests in the French Period

There are records of our coastal krummholzing coniferous areas from the French Period, although these are sparse. Six different "coastal spruce" sites are mentioned in historic French records, two in the Cavendish area, two along the southern coast, one near Basin Head Provincial Park, as well as a recording from the Cascumpec Sandhill Islands (near Oulton's Island). It is worth noting, that some areas which are now known for growing coastal spruce, were predominantly hardwood forests of good spacing and size during this period, this is supported by various historic accounts as well as archaeological findings of Ponomarenko in both New London Bay and St. Peter's Bay.

"Tracadie Island" Dune System

The British Period (1758-1900)

The British period of settlement saw intensified harvesting for ship-building, increased emigration, further agricultural development as well as a number of large-scale land-use policies which have influenced Island ecology ever since (ex: Absentee Landlords). By 1900, only approximately 30% of the province was under forest cover, much of that was second-generation growth after heavy harvests or past fires. Land clearing during this period was highly-motivated by the ship-building industry which was at its peak in the mid-19th century. After land was cleared for ships masts and other materials, it was put under agricultural production. As the ship-building industry declined, select areas were abandoned, allowing their return to forest.

Coastal Forests in the British Period

Thickets of coastal spruce were reported throughout this period. Lord Selkirk astutely observed in 1803, "the spruce prevails only because of the exposed situation killing the other woods". Johnstone remarked, in 1822, about the transition from "this stipe of softwood" into a forest-type of larger, well-spaced deciduous trees, similar to present day George's Island. A report in 1875 by the Land Commission mentioned scrubby spruce along the coastal front near Orby Head, one of the planned restoration sites. It states that the coastal spruce extends about three-quarters of a mile from the shore, or 1.2 km. While it is thought that this figure is likely exaggerated, present-day study sites such as the Clearspring coasts had krummholzing spruce present for more than 300m inland.

ECOLOGICAL DISTURBANCES

Cottage building along the Clearspring cliffs

As our provincial history shows, few areas of the Island, even our coastal dunes, were untouched by European settlers. Many of the indicators of these past land-use practices are still evident: old paster fencing in salt marshes, low-diversity reforested farmlands, remnant charcoals and stumps from past fires as well as more recent developments such as beach-front parking. These changes to our coastal habitats are particularly apparent when comparing the 1935 Provincial aerial photos to our modern satellite imagery. More than half of this project's study sites were under agricultural production in 1935, farming almost into the dunes or up to cliff edges, with little to no tree cover to be found at that time. The first half of the **modern period** (1900-Present day) was heavily agricultural. Forest cover slowly returned with the abandonment of many family farms during the second half of the modern period.

The varying ecological disturbances, in both type and timing, across our krummholzing coasts are critically important to consider when looking at natural succession and current habitat health. Both of which greatly inform restoration planning and work. Without coupling the comprehensive field assessments with archival historic research, it is very difficult to ascertain exact timings, extents, and varieties of disturbances across each site. That being said, using the provincial database of historical aerial photos, as well as ecological indicators on-site, some broad conclusions can be made about past ecological disturbances.

A methodology of ecological disturbance assessment was developed by creating three broad disturbance categories with a variety of sub-categories. As mentioned above, quantification of disturbance data is difficult without extensive archival research as well as a value system to weight various disturbances and their effects. Such as value system would require creating a complex index to compare the diverse ecological disturbances which can be found across our Province. For instance, farming tends to have a much greater effect to habitats then small-scale fuelwood harvests. A value-weighed index would allow for more nuanced comparison between study sites as well as more precise indication of the intensity of past disturbances.

A simplified ecological disturbance index (ED Index) was developed to allow for comparative site analysis. The disturbance index is simply a count of how many of the twelve sub-categories of disturbances occurred on-site, fully, partially, or in very close proximity. This resulted in a score for each site between zero and twelve, with lower scores indicating fewer historic disturbances. This allowed various study sites to be compared by their level of disturbances through the ED index in reference to other site variables.

ECOLOGICAL DISTURBANCES CATEGORIES


Post-Fiona erosion and damage in Dalvay NP

The assessment rubric used the following ecological categories, which are by no means comprehensive. These disturbances were selected as they could be efficiently confirmed during fieldwork or through archival review of provincial aerial photos and/or any additional resources, such as land steward reports and the analytical historic forest research by Doug Sobey and others.

AGRICULTURAL

Farming: refers to evidence of farming since 1900. Primarily based on historic aerial photo evidence coupled with field clues

Grazing: much harder to ascertain from aerial photos, evidence for a history of grazing was based on lands steward accounts (Ex: Greenwich sites) or from field evidence, such as old fence posts in salt marshes.

PRESENT USE

Mowing: refers to on-going mowing of coastal site which was witnessed during fieldwork.

Coast Access: refers to coastal access by foot, with or without infrastructure. For example, certain cliff sites make coastal beach assess dangerous to impossible.

Popular Spot: refers to the study site being in an area of high-use, such as areas of the National Parks or Basin Head Provincial Park.

Cottages: refers to the on-site or close-proximity of cottages or other recreational private properties.

INFRASTRUCTURE

Tourism Development: refers to coastal infrastructure such as playground equipment, boardwalks, bathrooms and other recreation-based development, either on-site or adjacent.

Road Construction: refers to historic or field-based evidence of road construction since 1935. Roads such as the East Point road, which predate 1935, were not included in this category.

Parking: refers to sites with a parking area, paved or unpaved, which is located on-site or directly adjacent.

Small-Scale Harvesting: refers to sites which have evidence of wood harvesting but also had constant forest cover since 1900.

Industry: refers to any medium to large scale industrial infrastructure or action, such as the wind turbines at North Cape, old or new wharfs and/or related activities such as dredging.

Waterway Infrastructure: refers to culverts, dams and other water infrastructure on-site or adjacent.

ECOLOGICAL DISTURBANCE BY COAST TYPE

Long Pond Dune to Cliff Post-Fiona Erosion (red arrow at area of densest krummholz)

While hardly conclusive, the ED index does suggest some trends that may be indicative of broader patterns. More study sites would be beneficial in filling in knowledge gaps and compensating for categories with small sample sizes. The analyses that follow compare sites by their ED index and a variety of biodiversity indicators as well as their coastal types. The Biodiversity indicators include the estimated age of the stand as well as the number of native, rare and total flora and fungi species found during site visits. It also includes the average Fiona index by category, another index developed during this study to quantify the effects of hurricane Fiona. It will be explained in more detail later in this report. The higher the Fiona index, the greater the damage done by the storm.

ECOLOGICAL DISTURBANCE INDEX BY COASTAL TYPE

DISTURBANCE INDEX	Total Surveyed	Dunes	Cliff	Bluff	Low	Dunes/Cliff
TOTALS	**28**	**10**	**9**	**3**	**2**	**4.0**
1	**0**	0	0	0	0	0
2	**1**	0	1	0	0	0
3	**5**	3	1	0	1	0
4	**9**	3	2	1	1	2
5	**4**	2	0	1	0	1
6	**5**	0	5	0	0	0
7	**3**	2	0	0	0	1
8	**1**	0	0	1	0	0
9	**0**	0	0	0	0	0

ECOLOGICAL DISTURBANCE ANALYSIS

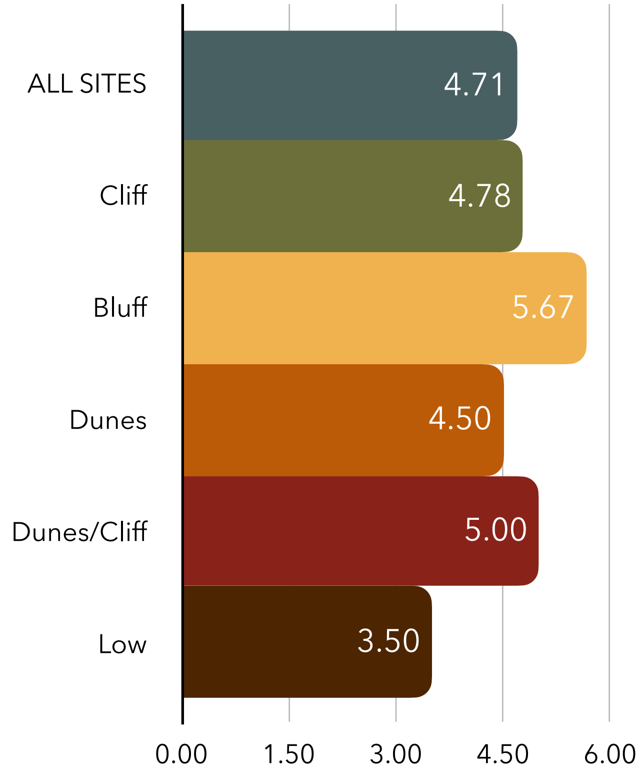
The table on the previous page is primarily useful in determining gaps in survey coverage across coastal types. Low plain and bluff coasts are still the least represented as they are less common across our windiest shores.

The chart to the right shows the averaged value of ED index across all sites as well as by coastal type.

The table below compares sites grouped by their determined ED index to the previously mentioned biodiversity indicators. Sites with lower ED indices tended to have more rare and native species diversity as well as older trees. These sites also tended to have lower Fiona indices, which suggests that they fared the historic storm better.

Developing a more comprehensive and value-weighted ED index culd yield better analysis, especially when comparing sites of equal ED index but with difference types of historic disturbances.

COASTAL TYPE BY AVERAGE ED INDEX



ECOLOGICAL DISTURBANCE INDEX BY BIODIVERSITY INDICATORS

ED INDEX	Total Surveyed	Avg Fiona Index	Avg Age	Avg Rare Spp	Avg NSpp Rich	Avg Spp Rich
ALL SITES	**28**	**10.5**	**63.6**	**3.7**	**67.4**	**74.1**
1	**0**					
2	**1**	8.0	120	6.0	80.0	87.0
3	**5**	8.7	82	9.0	90.8	94.8
4	**9**	11.7	64	3.0	57.6	64.4
5	**4**	11.7	50	0.3	68.7	73.0
6	**5**	9.8	55	0.0	34.0	39.0
7	**3**	10.0	47	1.3	55.0	65.7
8	**1**		60	1.0	73.0	89.0
9	**0**					

AGRICULTURAL DISTURBANCES

Historic agricultural disturbances have far ranging effects on site ecology, biodiversity and general health. This category, in particular, would benefit from a more in-depth ecological disturbance index which could take into account the timing of farming and extent. Due to the current simple count-based ED index, evidence of farming has the same value as any other category, which does not accurately reflect the true scope of ecological disturbance when compared to other smaller scale activities.

AGRICULTURAL DISTURBANCES BY COASTAL TYPE

DISTURBANCE TYPE	Total Sites	Dunes	Cliff	Bluff	Low	Dunes/Cliff
ALL SITES	**28**	**10**	**9**	**3**	**2**	**4**
AGRICULTURE	**17**	**4**	**7**	**3**	**0**	**3**
Farming	15	2	7	3	0	3
Grazing	2	2	0	0	0	0
No Evidence	**11**	**6**	**2**	**0**	**2**	**1**

The table above shows agricultural disturbance occurence by coastal type. Dune coasts were the least affected by agricultural disturbances, while most cliffs and bluffs had been farmed after 1900.

The table below yields some more interesting conclusions. Although limited in quantity, sites with no evidence of farming tended to be older with higher average numbers of native and rare species. Grazed sites were both located along dune type coasts, a harsh habitat with fewer species capable of surviving the conditions.

AGRICULTURAL DISTURBANCES BY BIODIVERSITY INDICATORS

DISTURBANCE TYPE	Total Surveyed	AVG Fiona Index	Avg Age	Avg Nspp	Avg Rarespp	Avg Spp Rich
ALL SITES	**28**	**10.5**	**63.6**	**67.4**	**4.9**	**74.1**
AGRICULTURE	**17**	**10.4**	**51.5**	**50.6**	**1.7**	**55.5**
Farming	15	8.9	53.0	60.2	2.3	68.9
Grazing	2	12.0	50.0	41.0	1.0	42.0
No Evidence	**11**	**12.0**	**80.5**	**81.2**	**5.9**	**87.0**

PRESENT-USE DISTURBANCES

The present-use category covers activities which are constant or occurring every summer season. The table below shows each sub-category by coastal type, with only two of the surveyed sites with no evidence of present-use (Sites: East Point and Hog Island). While cottages and mowing both occur at low frequencies, this is partially due to the lack of private study sites as well as windy sites which are lacking krummholzing specimens.

PRESENT-USE DISTURBANCES BY COASTAL TYPE

DISTURBANCE TYPE	TOTAL SURVEYED	DUNES	CLIFF	BLUFF	LOW	DUNES/CLIFF
ALL SITES	**28**	**10**	**9**	**3**	**2**	**4**
PRESENT USE	**26**	**9**	**8**	**3**	**2**	**4**
Mowing	7	0	5	2	0	0
Coast Access	17	7	1	3	2	4
Popular Spot	17	7	6	1	0	3
Cottage	9	2	2	3	1	1
No Evidence	**2**	**1**	**1**	**0**	**0**	**0**

The table below showcases the biodiversity indicator analysis by present-use sub-category. Again, both sites that had no evidence of present-use had lower-average Fiona index ratings as well as higher-average varieties of species, both native and non-native. Both of these sites also had no recent evidence of farming. Mowing seemed to cause the greatest drop in species richness as well as the average number of rare species at those sites. However, these sites also had relatively low average Fiona index ratings, most likely due to their lack of vegetative cover, excluding effects such as windfall and breakages.

PRESENT-USE DISTURBANCES BY BIODIVERSITY INDICATORS

DISTURBANCE TYPE	Total Surveyed	AVG Fiona Index	Avg Age	Avg Nspp	Avg Rarespp	Avg Spp Rich
ALL SITES	**28**	**10.5**	**63.6**	**67.4**	**4.9**	**74.1**
PRESENT USE	**26**	**10.9**	**57.6**	**58.1**	**2.2**	**65.7**
Mowing	7	9.6	55.0	46.3	1.3	55.0
Coast Access	17	11.8	60.3	64.6	2.5	72.1
Popular Spot	17	10.4	57.9	59.7	2.7	66.9
Cottage	9	11.8	57.2	61.8	2.4	68.6
No Evidence	**2**	**8.0**	**105.0**	**111.0**	**10.5**	**115.5**

INFRASTRUCTURE DISTURBANCES

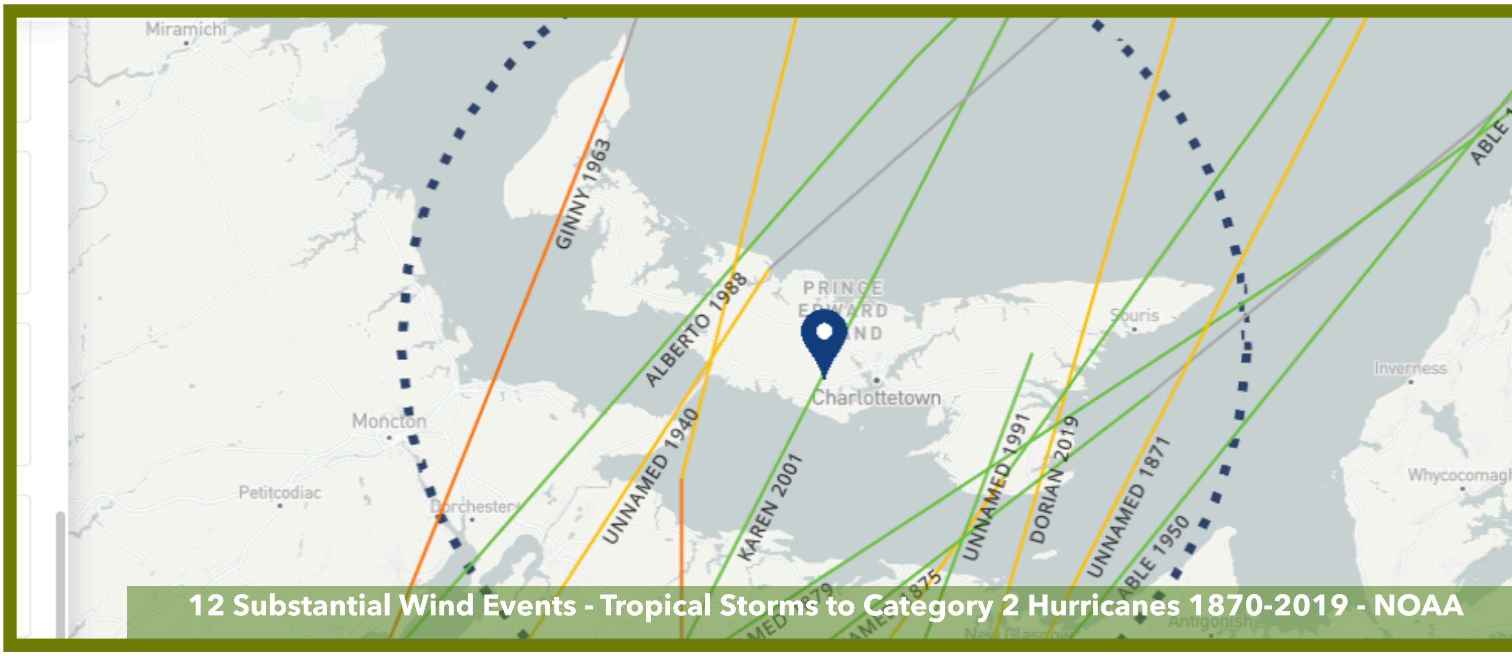
INFRASTRUCTURE DISTURBANCES BY COASTAL TYPE

DISTURBANCE TYPE	Total Surveyed	Dunes	Cliff	Bluff	Low	Dunes/Cliff
TOTALS	**28**	**10**	**9**	**3**	**2**	**4**
INFRASTRUCTURE	**23**	**8**	**8**	**2**	**2**	**3**
Tourism Development	11	3	5	1	0	2
Road Building	13	5	4	1	1	2
Parking	10	3	5	1	0	1
Small Scale Harvesting	4	1	3	0	0	0
Industry	4	2	1	0	1	0
Waterway Infrastructure	2	1	0	1	0	0
None	**5**	**2**	**1**	**1**	**0**	**1**

INFRASTRUCTURE DISTURBANCES BY BIODIVERSITY INDICATORS

DISTURBANCE TYPE	Total Surveyed	AVG Fiona Index	Avg Age	Avg Nspp	Avg Rarespp	Avg Spp Rich
TOTALS	**28**	**10.5**	**63.6**	**67.4**	**4.9**	**74.1**
INFRASTRUCTURE	**23**	**11.0**	**67.6**	**73.6**	**3.3**	**82.0**
Tourism Development	11	9.3	51.4	50.7	1.2	59.7
Road Building	13	11.1	55.8	65.0	2.8	73.3
Parking	10	10.0	52.5	51.0	0.8	60.2
Small Scale Harvesting	4	7.5	98.8	92.3	8.3	97.8
Industry	4	15.0	87.5	89.0	5.0	97.7
Waterway Infrastructure	2	13.0	60.0	93.5	1.5	103.5
None	**5**	**9.75**	**59**	**63**	**5.2**	**67.8**

MARITIME WIND EVENTS



12 Substantial Wind Events - Tropical Storms to Category 2 Hurricanes 1870-2019 - NOAA

Hurricane Fiona arrived September 22nd, 2022 and was a storm of historic proportions, with max winds of 149 km/h recorded at East Point. It left a wake of destruction across most of the Province, including large areas of wind-fall and coastal flooding. Despite this magnitude of power, many of the coastal krummholzing study sites fared through the storm with less damage than sites located further inland.

Atlantic Canada is no stranger to large-scale storms, such as our famous winter Nor'easters and autumnal tropical cyclones. A report from Nova Scotia, published in 2020, concludes that hurricanes make landfall in that province once every seven years on average. The intensity of these storms varies, with most causing low-severity wind-throw. High-severity storms are estimated to have a mean annual disturbance rate of 0.08%*$year^{-1}$ (or a 1250 year return interval). This rate is province-wide, which means certain areas of NS, particularly along the south-eastern coasts, would have severe storms more often. While these statistics are not specific to PEI, and are even reported by the paper's researchers to be skewed-high compared to probable averages, this general trend of strong storm events is an on-going and integral part of our regional ecology & climate.

For instance, the establishment of the older eastern hemlock groves in Nova Scotia have been attributed to past storm events. These storms caused windfall, creating gaps in the canopy of the forest, allowing well-established areas of shade-tolerant hemlock saplings to thrive.

Many native species of trees rely, at least partially, on wind for their seed dispersal strategies. These include species from families such as the ashes, maples, birches, aspen, and most of our conifers including hemlock. These fluffy or winged seeds are generally ready to fly by late summer or fall, the time of year which coincides with our autumnal cyclone season. Periodic cyclonic events may be an important part of our native tree species' dispersal strategies.

PEI is a little over one-tenth the size of Nova Scotia, and lacks the latter's geological diversity. Its small size, coastal location and sandstone structure, leave more of the province exposed to coastal winds. While PEI lacks the extra windy crags of Nova Scotia due to its flatter topography, it also does not have its sheltered inland areas. Our more northern geographic position and lack of exposure to the true Atlantic Ocean coast, most likely means that PEI has severe hurricanes slightly less-often then NS.

HISTORIC ISLAND STORMS

Greenwich beach in 1935 still showing damage from "Hurricane Five" of 1923

There have been a number of historic storm events documented in PEI's history which caused large-scale damage. While not as commonly hit as Nova Scotia, our province's unique geography, topography, soil structure and agricultural history have often made us more vulnerable when strong storms occur. There was no official provincial summary of historic storms obtained for reference, although local, regional and international reports, data and papers were found. Ascertaining the true scope and power of large-scale storms, prior to the 1950's, is difficult. Without extensive research into the provincial archives and historic newspapers, many local accounts have been overlooked. The historic ecology and economy at the time of each reported event is worth noting when looking at historical accounts. Many of these historic storms occurred when forest cover across the province was very low, resulting in low reports of blow-down limiting inland destruction. These same reports often mention extreme coastal flooding, sometimes moving kilometres up river systems, coupled with large numbers of shipwrecks.

The map on the previous page, using NOAA's online historical hurricane tracker, shows 13 cyclonic events between 1870 and 2019. The same source lists an additional 56 extratropical cyclone events, which represent weakened tropical storms as well as Nor'easters. Mention of six more historic storms were found prior to 1925, five of which are referenced in Douglas Sobey's work on Island forests. Including Hurricane Fiona, there has been at least 20 high-wind events since 1811. Eleven of these events were intense enough to be written about in journals, newspapers and/or history books, many citing shipwrecks, major flooding and wind fall as well as structural damage across PEI. Only two particular storms mention wide-spread provincial damage beyond sailors at sea, the unnamed "Hurricane Five" of 1923, and Hurricane Fiona of 2022.

Alan MacEachern, from Western University, wrote a recent article about the forgotten "Hurricane Five", which has many comparisons to Hurricane Fiona. Over 50 bridges, dams, wharves and roads were destroyed or damaged, including Crooked Creek bridge in Oyster Bed, five kilometres inland. After the storm, the Charlottetown Guardian reported, " … many barns and farm buildings destroyed… Charlottetown suffered most destruction of its beautiful trees". A house in Rustico floated away, Charlottetown streets were blocked by broken trees, telephone posts and wires. Even L.M. Montgomery reported many trees felled along "Lover's Lane" in Cavendish. A paper looking at the after effects of "Hurricane Five" on Greenwich National Park was published in 2005. It details the complete destruction of the foredunes reaching 300 to 600 m inland as well as a 70 year ecological recovery.


THE CHARLOTTETOWN GUARDIAN
The People's Paper Read by Everybody
Covers Prince Edward Island Like the Dew
CHARLOTTETOWN, CANADA WEDNESDAY, OCT. 3, 1923

All Maritimes Hit by Monday's Storm

FURTHER PARTICULARS OF THE HAVOC WROUGHT BY MONDAY'S TERRIFIC GALE

More Than Twenty Bridges Throughout the Province Washed Away or Rendered Impassable.— Large Quantity of Grain Crop May Yet be Saved.— Seed Potato Crop not Endangered — Many Barns and Farm Buildings Destroyed and Some Horses Killed.— Charlottetown Suffered Most in Destruction of Beautiful Trees.

THE STATEMENT OF SIR HENRY THORNTON IS NOT ACCEPTED

STORM SPREADS HAVOC IN OTHER PARTS OF MARITIMES

The Wind Blew 45 Miles an Hour Accompanied by a Heavy Downpour of Rain—Sydney Express Held up, Crops Damaged, and Wires Down in Moncton, Two Landslides on C. N. R.

BERLIN REPORT REVOLUTION AT KUESTRIN TO BE NOW ENDED

Charlottetown Guardian Front Page, Oct 3 1923

By averaging the intervals of years between high-wind events, we can come up with a broad frequency of occurence historically. While these derived averages are hardly precise, they help demonstrate the frequency of wind storms and their obvious effect across our province as well as their role in our local ecology.

Only twenty wind events were included in the frequency analysis, these were either notable historic events, or storms which NOAA still categorized as a *tropical storm* or *hurricane* when it was passing PEI. None of this research or processing included powerful historic blizzards, although these can have great effects upon our coasts as well. Records of these storms spanned from 1811 to present day, they were averaged over the total span of time as well as between 1811-1923 and 1923-2023. The events were also broken into several categories: historically-reported storms, historically destructive storms, and extreme storms. With only two extreme storms and limited quantifiable data on storm metrics such as wind speeds, this category was excluded from the averaging process.

AVERAGE WIND EVENT HISTORICAL OCCURENCE

Date Range	# Wind Events	Avg Wind Event Interval (years)	# Historically-Reported Wind Events	Avg Historically-Reported Event Interval (years)	# Historically-Destructive Wind Events	Avg Historically-Destructive Event Interval (years)	# Extreme Wind Events	Avg Extreme Event Interval (years)
1811-Present	**20**	**14.3**	**10**	**22.9**	**5**	**36.6**	**2**	**N/A**
1811-1923	9	15.5	5	26.0	2	42.0	1	**N/A**
1923-2023	11	13.4	5	19.8	3	33.0	1	**N/A**

HURRICANE FIONA

Blooming Point primary dune loss

As mentioned, Hurricane Fiona hit in September, 2022 during the course of this study. While impeding and delaying the previously-planned restoration plantings, it offered a unique opportunity to assess the resiliency of our diverse krummholzing habitats to these high-wind events. Site visits started by October 3rd, 2022, only 10 days after the storm. The Clearspring study sites were fortuitously visited just days prior to the storm, creating a short interval for comparison. Other sites, such as those in the PEI National Parks took longer to gain safe access.

An additional assessment rubric was developed to account for Fiona specific effects upon coastal krummholzing habitats. The quick pivot of project focus combined with the historic intensity of Fiona made it was difficult to develop a comprehensive protocol and dataset prior to starting post-storm fieldwork.

Through visiting previous study sites, as well as new additions, a simple post-Fiona assessment rubric was created. The effects of Fiona on krummholzing ecologies were broken down in to nine categories, each ranked qualitatively: none, low, medium, high. By assigning a value system to these rankings, a Fiona index for each site could be created, based on the number and qualitative intensity of each effect at each site. Most of the sites under-study lacked substantial present-day infrastructure and buildings which is why that kind of damage is omitted, although it was often seen while commuting to field sites.

Deciduous Defoliation:
The extent and intensity at which deciduous shrubs and trees loss their leaves.
Coniferous Foliage Browning:
The extent and intensity at which coniferous needles browned.
Windfall:
The approximated proportion of blowdown witnessed.
Coast-Fall:
The extent of tree fall due to coastal erosion.

Dune Erosion:
The extent and intensity of primary dune loss.
Cliff Erosion:
The extent and intensity of cliff loss.
Coastal Flooding
The extent and intensity of coastal flooding.
Tree-Trop Break:
The extent and intensity of partial tree truck break.
Tree-Limb Break:
The extent and intensity of tree-limb break rather than blowdown.

POST-FIONA ANALYSIS

Clearspring Coast Pre-Fiona

Clearspring Coat Post-Fiona

The derived Fiona index can theoretically scale between zero and twenty-seven, with higher-values indicating a greater extent and/or intensity of damage. Even with this capacity for rating damage, none of the study sites rated above twenty, with Savage Harbour the highest at eighteen. The general trend seen across many krummholzing sites is their relative lack of storm damage compared to non-krummholzing shorelines and even more inland sites. Some krummholz, such as those found along the Clearspring cliffs, showed very little damage of any kind, save for some erosion and browning of coniferous needles. Even dune sites like Basin Head and Greenwich had low levels of wind-fall in the sandy-soiled back dunes, surprising, considering they are predominantly colonized by white and/or black spruce, typically shallow-rooted species. Sites in the PEI National Parks were more resilient to erosion where substantial krummholzing spruce had been growing, other areas, such as parking lots, lost significantly more coastline.

This scale allows other assessment variables to be easily analyzed in comparison to the effects of Fiona, such as looking at the number of sites by their Fiona index across different coastal types in the table below.

SITE FIONA INDEX BY COASTAL TYPE

FIONA INDEX	Total Surveyed	Dunes	Cliff	Bluff	Low	Dunes/Cliff
TOTALS	**19**	**8**	**7**	**1**	**1**	**2**
0	0					
1-3	0	0	0	0	0	0
4-6	1	0	1	0	0	0
7-9	7	2	3	1	0	1
9-12	5	3	2	0	0	0
13-15	4	1	1	0	1	1
16-18	2	2	0	0	0	0

POST-FIONA ANALYSIS

The Fiona index can also be compared with a number of other useful variables to better understand high-wind event resiliency along our coasts. For instance, the table below shows various levels of Fiona index by number of corresponding sites, biodiversity indicators and average ED index. Again, this data is limited by the small number of study sites as well as qualitative assessment methodology. For example he lone site in the 4-6 F-index category, showed little damage as much of it had been mowed up until recently, resulting in little vegetative cover beyond grasses.

FIONA INDEX BY # OF SITES AND BIODIVERSITY INDICATORS

FIONA INDEX	Total Surveyed	Avg ED index	Avg Age	Avg Rare Spp	Avg NSpp Rich	Avg Spp Rich
TOTALS	**19**	**4.5**	**60**	**4**	**49**	**52**
0	0					
1-3	0					
4-6	1	6.0	50.0			
7-9	7	3.6	66.4	6.3	56.0	59.0
9-12	5	5.4	58.0	2.0	33.0	34.7
13-15	4	4.5	58.8	1.0	58.8	60.0
16-18	2	4.5	50.0	0.0	50.0	51.0

RESTORING KRUMMHOLZ HABITATS

Regenerating white spruce growing amongst thick herbaceous ground cover at East Point

Although the planned restoration trials were delayed by Hurricane Fiona, fieldwork observations, data collected and restoration planning efforts have coalesced into a variety of methodologies which will be enacted and tested during the 2023-24 season of the krummholz project.

As previously mentioned, our coastlines have seen drastic changes in their ecology over the last 250 years. Whole stretches of well-developed coastal forests with reports of oak, maple and other well-spaced hardwood trees, were harvested for ship-building and land-clearing. After clearing, many of these coasts were put into agricultural production, cliffs were often farmed almost until the edge, or up until rum-running roads. Farm fields abutted the inland edges of our sandy shores, with livestock sent to graze amongst the back dunes and salt marshes. Changes in land-use over the latter-half of the 20th century, saw agricultural production slow, with many coastlines returning to heavy vegetative cover. Over the last 40 years, cottage construction along our coasts has increased, leading to a myriad of ecological disturbances and damage to our krummholzing coastal habitats. Many of the study sites have been affected by actions further along the coast, due to the inter-connected nature of coastal littoral processes, inland riparian health, and adequate vegetative cover.

Our coastal habitats provide innumerable community benefits through their provision of diverse ecological services. From protecting our shores against constant erosion, to sheltering our inland communities and habitats from powerful winds, to providing crucial habitat for migrating species, our krummholzing coastal habitats are an integral part of our Island ecology. With a long history of degradation and many on-going threats, these habitats need both protection and restoration, especially when faced with increasingly common and severe storms such as Hurricane Fiona.

Coastal hedgerow planting ~2019

Coastal hedgerow planting 2022 Post-Fiona

Although not necessarily concurrent with this study, the Macphail Woods Ecological Forest Project has lead many windy shoreline plantings using native species since 1991. As part of our restoration work and native plant landscaping efforts, we have worked with a variety of community groups and private land owners to afforest and/or enhance coastal habitats across PEI. A variety of lessons were learned over the years through trial and error, which can inform future restoration work in coastal krummholzing habitats. Two particular case-studies help illustrate some of the lessons learned in coastal restoration.

CASE STUDY# 1: south shore windy cliff landscaping

The photos above come from a private cottage cliff site along a windy coast on the south shore. The Macphail Woods team was tasked with planting a multi-functional coastal hedge for privacy, shoreline protection, biodiversity, and food for wildlife. The landowners were keen to try some species that typically aren't found growing along our coasts, such as hemlock and white ash, as well as various ferns and wildflowers.

This multi-year project has resulted in a dense and diverse hedgerow with a variety of native trees and shrubs including American elm, white ash, white birch, red maple, red oak, striped maple, eastern white cedar, common elder, aronia, serviceberry, witch hazel, male fern, and many more. The more sensitive species such as hemlock, striped maple as well as ferns, were planted in sheltered locations within 100 meters from the shore. Not all specimens were successful, which were always excellent learning opportunities. Specimens which were identified to be struggling were often transplanted to new, more sheltered locations across the site, often with improved results. Despite the learning curves and challenges, most of the specimens planted over the years are still thriving, even after the damage from Hurricane Fiona. The estimated survival-rate for plantings over the course of this multi-year landscaping project is estimated to be more than 90%.

Coastal white spruce protected by old log

CASE STUDY# 2: north shore low exposed plain

Another interesting private site was planted in the spring of 2022, near Rustico along the northern shore. This area was located along the exposed coast of a bay, with a low-plain type coast and a history of agriculture. Much of the area had the tendency to flood during storm surges, inundating soils with brackish bay waters.

The goal of this private coastal project was to restore this highly disturbed area to a native diversity of flora, while protecting the shore and enhancing wildlife habitat.

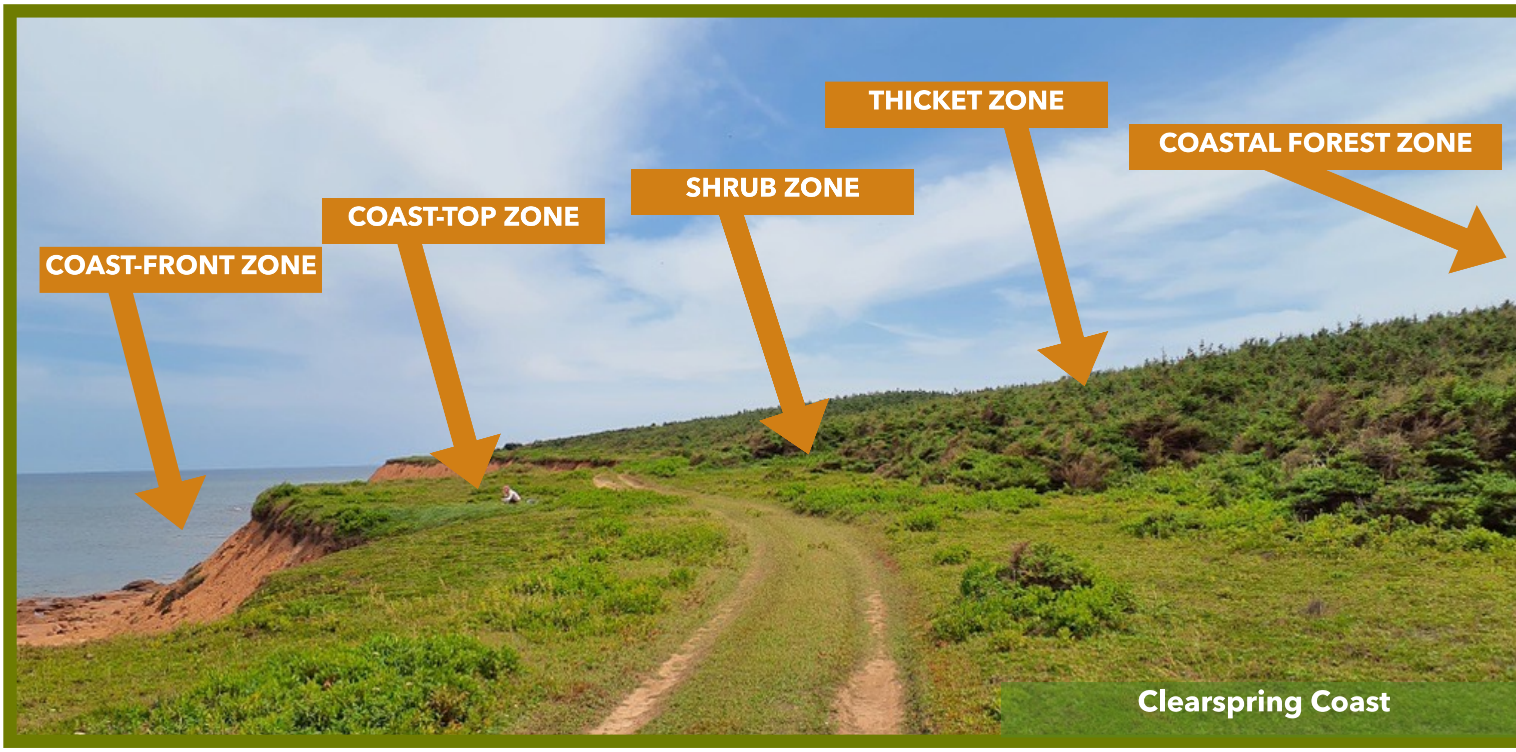
Based on observations during krummholz fieldwork as well as other sources, the restoration strategy used for this involved creating a series of chevron-shaped mounds out of large logs and soil with high organic content which were then planted with a variety of shrubs & wildflowers. The large logs would act has sponges and protection for the young plantings, increasing available moisture and buffering the winds, they would also slow coastal waters during storm surges. Plantings were mulched with coarse wood chips to protect freshly dug soils and tender roots from desiccation. The results of these techniques over the course of the growing season were excellent, all specimens were reported to be thriving. Hurricane Fiona caused ample coastal flooding, which deeply inundated the area, swept away the chevron logs, and caused much damage in the local area. Despite this, most of the planted chevron specimens are still in place as of early April 2023, with some buds started to swell with the coming spring. This site will be revisited for additional restoration plantings and maintenance during the 2023 season, which will also yield more insight into how the plants recuperate this growing season from the harsh conditions and historic storm.

COASTAL RESTORATION GUIDELINES

BASIC GUIDELINES OF COASTAL RESTORATION:

1) **Plant at springtime whenever possible.**
   Past coastal plantings seem to adjust to harsh coastal conditions much quicker when planted in Spring. These will often outgrow plants planted in the previous fall over the next growing season.
2) **Use or create natural buffers.**
   Logs, brush piles and other organic-based buffers can help young plants get established and mature enough to provide buffers for other specimens and species.
3) **Enhance soils and mulch plantings.**
   Our constant coastal winds combined with salty soils can limit both the availability to and conservation of water for shoreline plantings. Through the addition of ample amounts of organic matter to planting site soils, new and old flora on-site will have increased access to water as well as important minerals and nutrients. Mulching with coarse wood chips helps to reduce moisture loss by drying winds and moderate soil temperatures in these full-sun sites.
4) **Diversity of form and native species**
   Like all restoration plantings, adding biodiversity through planting native species is integral to habitat enhancement and resilience. As demonstrated by many of the study sites, our Island shores are capable of growing a variety of coastal specialist species as well as many species not often thought to belong in these habitats. Our cliffs and dunes showcase a variety of vegetative zones with diverse mixes of trees, shrubs, wildflowers, ferns, and more, each with their own environment functions, contributing to the health of the whole. Restoration plantings should mimic these natural groupings and zonations, creating diverse and structurally complex shoreline habitats.
5) **Micro-manage species placement.**
   Coastlines are subjected to constant and strong forces such as salt, winds and waves. These extremes can be quickly moderated by vegetative growth, increased soil moisture or other structural barriers to these forces. When planting coastal sites, take note of micro-habitat sites which can drastically differ in conditions within a few meters. Dune swales offer a natural example. After a section of sandy soil in blown-out, creating a low-elevation depression amongst the dunes, uncommon flora will begin to colonize the wetter soils. Overtime, as more substantial woody plants find enough moisture and protection in the small swale, they can begin to develop into a coastal dune forest. This late-successional dune habitat, such as those seen at Basin Head or Greenwich, are relatively stable and resilient to the challenges of coastal life, including strong storms. Mimicking this natural process during restoration plantings
6) **Mimicking ecological patterns.**
   As previously mentioned, krummholzing coastlines grow in a variety of patterns of distribution and vegetative zonations. Planting rows of spruce up to the cliff's edge will yield more loss of life than success. Targeting key areas and following nearby vegetative patterns can provide ample insight into planting distance from the shore for a variety of common native species. Other patterns are typical to specific coastal types, such as scattered clumps of krummholzing trees in dune systems rather than some kind of coastal front. Copying these natural and ecological patterns will help advance natural succession, increase biodiversity and improve resiliency in our coastal habitats.
7) **Plant Small Specimens.**
   Generally, save for specific micro-sites, smaller specimens tends to settle into the conditions quicker than shocking a taller, more resource-hungry specimen. The quicker a plant adjusts to these harsh conditions the higher the survival rate for future seasons.

RESTORATION BY ZONE



Patterns of ecological wind zonation are influenced by many local variables at each site, from average winds speeds to soil drainage to elevation to available seed sources. Ever changing and dynamic systems, our Island shores follow harsh rules of ecological succession which are often disrupted due to natural and unnatural disturbances. Well-developed dune experience localized blow-outs from high-wind events, dropping the elevation of dry dune areas, transforming them into a water-logged dune swale. Fast-eroding bluffs make life for vertical-growers like seaside plantain even more precarious.

Despite these processes, constantly caused by marine forces, our patterns of distribution and species diversity across our krummholzing coasts follow identifiable patterns. The previously described ecological wind zones are apparent across our coasts, although the sizing, shape and extent can vary greatly across our Province. That being said, each of the zones can be found along all of our windy shorelines, making it a useful pattern for mimicking when planning restoration work.

The four sections that follow are divided by each of our coastal types. Each coastal type is then categorized by each of its ecological wind zones, including descriptions of ecological functions and processes, variants of these areas across our province, primary and secondary native species as well as patterns of krummholz distribution. While not comprehensive, these restoration sheets provide quick and accessible knowledge which will improve ecological research, planning and restoration.

These can be used on-site by identifying the area's coastal type and any particular qualities or habitats, such as dune swales, areas of cliff with wetter soils. Combined with the previous guidelines, the restoration by ecological wind zone description that follow, are prototype templates for sound restoration planning. They provide basic explanations of common krummholzing distribution patterns, ecological succession and functions as well as lists of the primary native species that found across this diverse and important Island habitats.

COASTAL CLIFFS

The coastal cliff type is the most represented provincially making up almost 50% of our shorelines. These can range in height, with higher elevation cliffs often exposed to higher mean annual winds. Our coastal cliffs are areas where erosional processes are in action, with some areas losing meters every year. Cliff soils can vary across the province, although many are relatively thin before hitting sandstone below. These differing soil properties coupled with wind power and exposure, result in several distinct cliff-type communities of ecological wind zonation.

Island cliffs often demonstrate the effects of ecological wind zonation most clearly. These zones are often continuous and undulating with our coasts, compared the scattered zonation found in dunes. High-wind cliff areas display long and wide ecological wind zones as cascading vegetative heights gradually slow the wind. Close-cropped low-growing species give way slowly to increasingly tall shrubs and eventually a thicket of gnarled conifers.

Cliff sites, of either dryer soils or with more ecological disturbances, tend to have less continuous horizontal zonation with more breaks or scattered pioneers. Some of these sites, such as Cameron Island, support small meadows of grasses with scattered asters and blue-eyed grasses which might be natural formations, although more research would be needed to make such a conclusion.

Wet cliffs are more often a small seep or another localized area of poor drainage. North Cape is the only study site in which this soil condition was present across a wider area. Despite their small size, wet cliffs can either mitigate or enhance the krummholzing effects of the wind, allowing a greater diversity of native species to grow while also distorting typical continuous horizontal ecological wind zonation seen at dryer cliffs.

CLIFF: ZONE ZERO - COAST-FRONT ZONE

An extremely difficult area to grow in due to constant winds and erosion as well as little actual soil. This generally vertical surface is not uniform due to the cleavage patterns of our sandstone rocks, creating various and precarious growing surfaces for the few native species who can tolerate such difficult locations. Depending on erosional forces, this area can become too difficult for even our vertical specialists to grow in. Coast-top zone species can sometimes creep over the cliff's edge and continue growing more or less vertically. This can include species which grow in this pattern as well as others, which end up in these positions due to erosional forces.

This zone tends to have little difference amongst varying soil-types. Our exposed sandstone cliffs are constantly desiccated by coastal winds despite varying soil conditions. Seeps with almost constant water-flow might prove the exception, although studying these is dangerous and difficult.

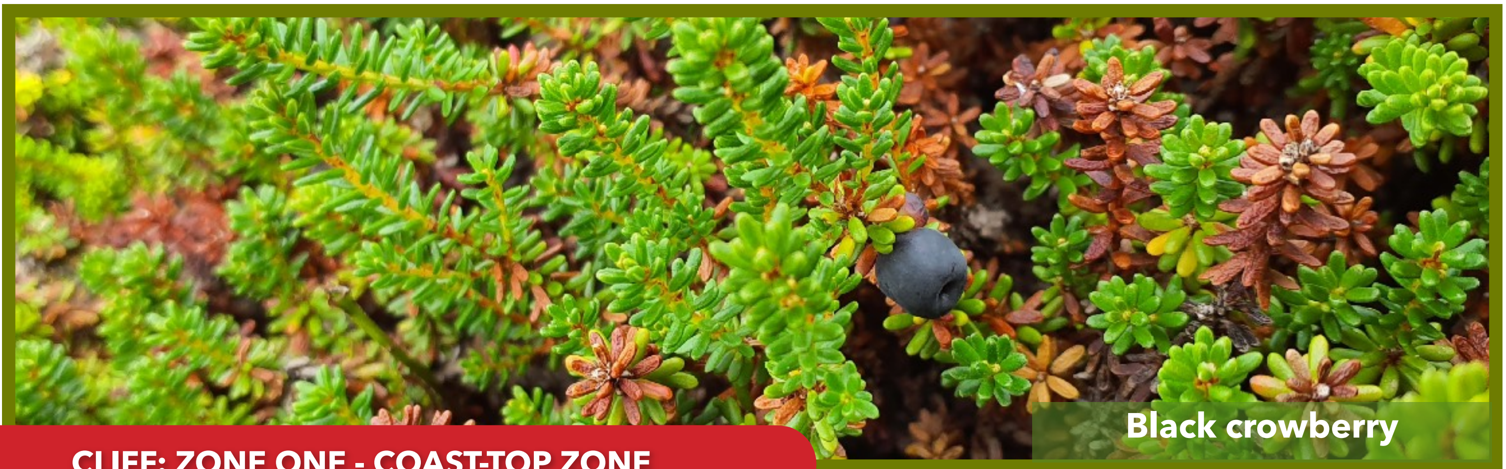
This zone presents unique and dangerous challenges for restoration work depending on cliff height and stability which would require specialist skills, tools and equipment to plant. One strategy is to plant appropriate species along the the coastal edge of the coast-front zone, letting them colonize the slopes if and where they are able.

Ecological Function: The health of this zone is critical in moderating the effects of erosion along our coastal cliffs. Slowing these erosional processes, while important to human society, also plays an important role in providing and preserving habitat for cliff-dwelling species such as the at-risk native bank swallow.

Krummholzing Distribution Pattern: Some individual shrub and tree species end up perched or hanging along the cliff edges. It is suspected they most often germinate in the coast-top zone, with erosional forces eventually bringing the cliff's edge to them. Other woody species can creep down the cliff using adventitious roots. Other herbaceous species, which cannot technically be considered krummholzing have adapted to the wind and vertical surface, often growing denser as they slow erosional rates.

Primary Native Species: *Plantago maritima, Spergularia canadensis*
Secondary Native Species: *Juniperus horizontalis, Empetrum nigrum*

CLIFF COAST-TOP ZONE



CLIFF: ZONE ONE - COAST-TOP ZONE

While still exposed to the most powerful winds, the horizontal growing surface of this zone allows for a much greater diversity of flora to be found. These areas are much more affected by soil properties as well as past ecological disturbances, which in turn affect the array of species found. This zone of high-wind prevents many species from propagating while limiting the height of those that can. Many of the species found in this zone are low or horizontal growing species.

They also vary in width depending on local winds and erosional rates as well as successional state. East Point, an older, windier, and faster eroding cliff site, generally has a narrow band of this zone compared to younger sites along the Clearspring coast despite a similar array of species.

Ecological Function: While protecting against erosion and providing ample food for wild life, these often coarsely-foliated species help to slow winds at ground level creating the conditions needed for the development of a shrub zone.

Krummholzing Distribution Pattern: Woody shrubs and trees can develop in the inward areas of this zone, usually singly or in scattered clumps with high rates of deformity. This zone often displayed conifer carpeting and other forms of primarily horizontal growth even in our tree species.

Dry Cliff Coast-Tops

Primary Species: *Grasses, Achillea millefolium, Symphyotrichum novi-belgii, Solidago sempervirens*
Secondary Species: *Lathyrus japonicus, Sisyrinchium montanum, Maianthemum stellatum, Juniperus communis*

Medium Cliff Coast-Tops

Primary Species: *Empetrum nigrum, Sibbaldia tridentata, Vaccinium macrocarpon, Juniperus horizontalis*
Secondary Species: *Solidago puberula, Empetrum eamesii, Vaccinium vitis-idaea*

Wet Cliff Coast-Tops

Primary Species: *sphagnum spp., Empetrum nigrum, Eriophorum spp. Rubus chamaemorus, Iridaceae spp*
Secondary Species: *Drosera rotundifolia, Sarracenia purpurea, Orchidaceae, Osmundastrum cinnamomeum*

CLIFF SHRUB ZONE

Common juniper

CLIFF ZONE TWO: SHRUB ZONE

This zone often displays an undulating front of dense wind-clipped shrubbery, mimicking the same patterns shown by more interior krummholzing trees. As lucky specimens germinate and survive, they disturb and slow surrounding ground-level wind patterns, improving subsequent survival-rates for nearby flora. This small-scale effects cascades over time and area as vegetation matures and spreads. As cliff shrub zones mature, they mimic the patterns of bay and headland seen along our coast. This process creates alcoves of swirling winds which are gathering places for various local seeds.

This area both shields and inhibits developing coastal trees. In densest areas, thick shrub-canopies create dense shade. Localized strong wind events and generally harsh conditions eventually cause small-scale areas of shrub death which release any pioneering tree species.

Ecological Function: The cliff shrub zone provides a strong buffer against winds for young tree species while providing ample food and shelter for wildlife. Many of the shrubs growing along our coast can fix nitrogen into the soil through processes involve soil bacteria. The roots of this zone are often dense, anchoring soils against erosion.

Krummholzing Distribution Pattern: Woody shrubs and trees can develop in the inward areas of this zone, usually singly or in scattered clumps with high rates of deformity. This zone often displayed carpeting and in other forms of primarily horizontal growth amongst the scattered conifers.

<u>Dry Cliff Shrub Zone</u>
Primary Species: *Morella pensylvanica, Rosa virginiana, Spiraea alba,*
Secondary Species: *Rubus idaeus, Prunus virginiana, Ribes glandulosum*

<u>Medium Cliff Shrub Zone</u>
Primary Species: *Morella pensylvanica, Rosa virginiana, Juniperus communis*
Secondary Species: *Aronia melanocarpa, Ilex verticillata, Kalmia angustifolia*

<u>Wet Cliff Shrub Zone</u>
Primary Species: *Myrica gale, Gaylussacia baccata, Ilex spp., Kalmia angustifolia*
Secondary Species: *Rhododendron canadense, Kalmia polifolia, Ericaceae spp*

CLIFF THICKET ZONE

Thicket zone at East Point

Similarly to thicket zones along other coastal types, this area is dominated by wind-deformed conifer trees, often creating densely-shaded crawl spaces populated by a variety of mosses and lichens. This area often grows in an undulating front mimicking patterns seen in the shrub zone, especially in medium soil sites. On sites with less ecological disturbances, other species than spruce were found growing in this zone such as balsam fir, red maple and white birch. Sporadic tree death creates small patches in this zone which are densely populated with shrubs, wildflowers and occasional wasp nests, like small areas of the shrub zone.

When ample water is available, even under high winds, the dense wind-shaped conifers are sometimes found as a wall against oncoming winds. When it is not, they form as densely clumped islands circled by a thin shrub zone amongst a vast coast-top zone, often of grasses. The conifer species found in wet areas can differ greatly from dryer sites.

The dryer soils seems to slow the even-spread of this zone resulting in more patchy development. Dryer areas often have more sudden tree death present than other types of thicket zones.

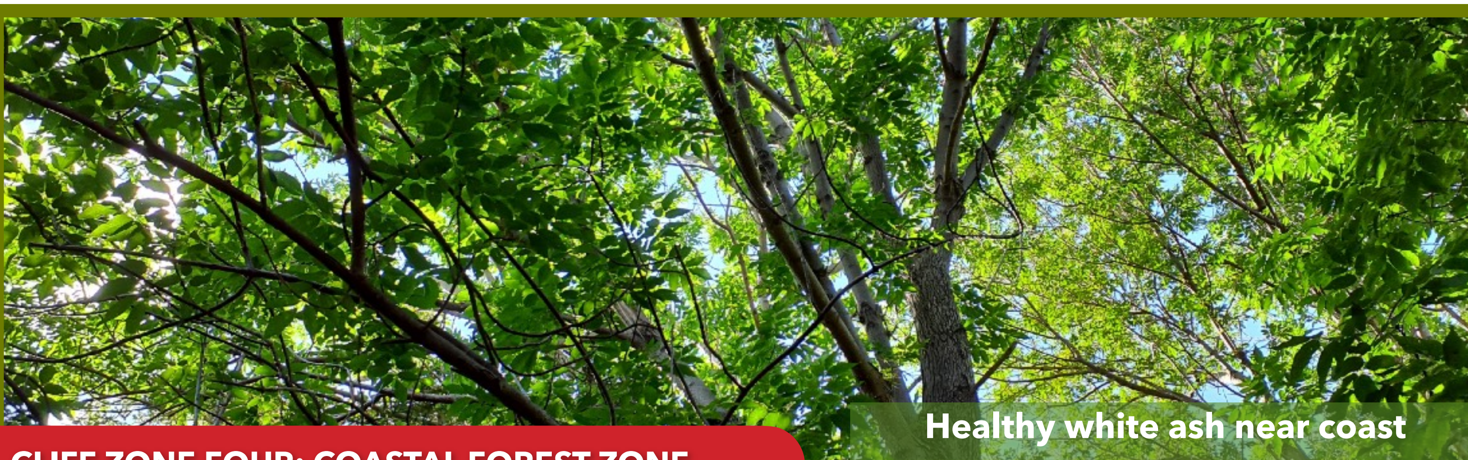
Ecological Function: This zone is crucial in slowing winds for the more inland areas, all the while providing excellent habitat with both protection and ample wild food. The root systems of this zone help to strengthen our cliffs against erosional forces.

Krummholzing Distribution Pattern: This zone typically displays an undulating coastal front, following shoreline as well as soil drainage patterns. High-rates of erosion can sometimes result in this area bordering the cliff's edge.

<u>Dry Cliff Thicket Zone</u>
Primary Species: *Picea glauca*
Secondary Species: *Betula populifolia, Acer rubrum*

<u>Medium Cliff Thicket Zone</u>
Primary Species: *Picea glauca*
Secondary Species: *Abies balsamea, Betula papyrifera, Betula populifolia, Acer rubrum, Sorbus americana*

<u>Wet Cliff Thicket Zone</u>
Primary Species: *Picea mariana, Larix laricina*
Secondary Species: *Abies balsamea, Thuja occidentalis,*



Healthy white ash near coast

CLIFF ZONE FOUR: COASTAL FOREST ZONE

Many of the ecological potentials of this zone are unknown, although sites such as East Point and George's Island would suggest that this area can grow a diverse array of non-coastal specific species culminating in relatively stable forested habitats. Coastal forests, visited in Cape Breton, with no history of plowing but with higher winds, hosted a variety of typically deep forest species such as Christmas fern, herb Robert, beaked hazelnut, sugar maple, white ash and red oak. Male fern and bush honeysuckle could be found spreading into the coastal barrens.

Our typical cliff coastal forests are often young, coupled with agricultural histories, limiting their natural species diversity. Rare coastal forest sites, such as the Tracadie Oaks stewarded by the INT, showcase mature red oaks growing near the shore in old dune soils. These fared through even hurricane Fiona with little wind-fall, although with lots of limb breakage.

This zone will be targeted during restoration trials with a variety of native species of trees, shrubs, wildflowers and ferns.

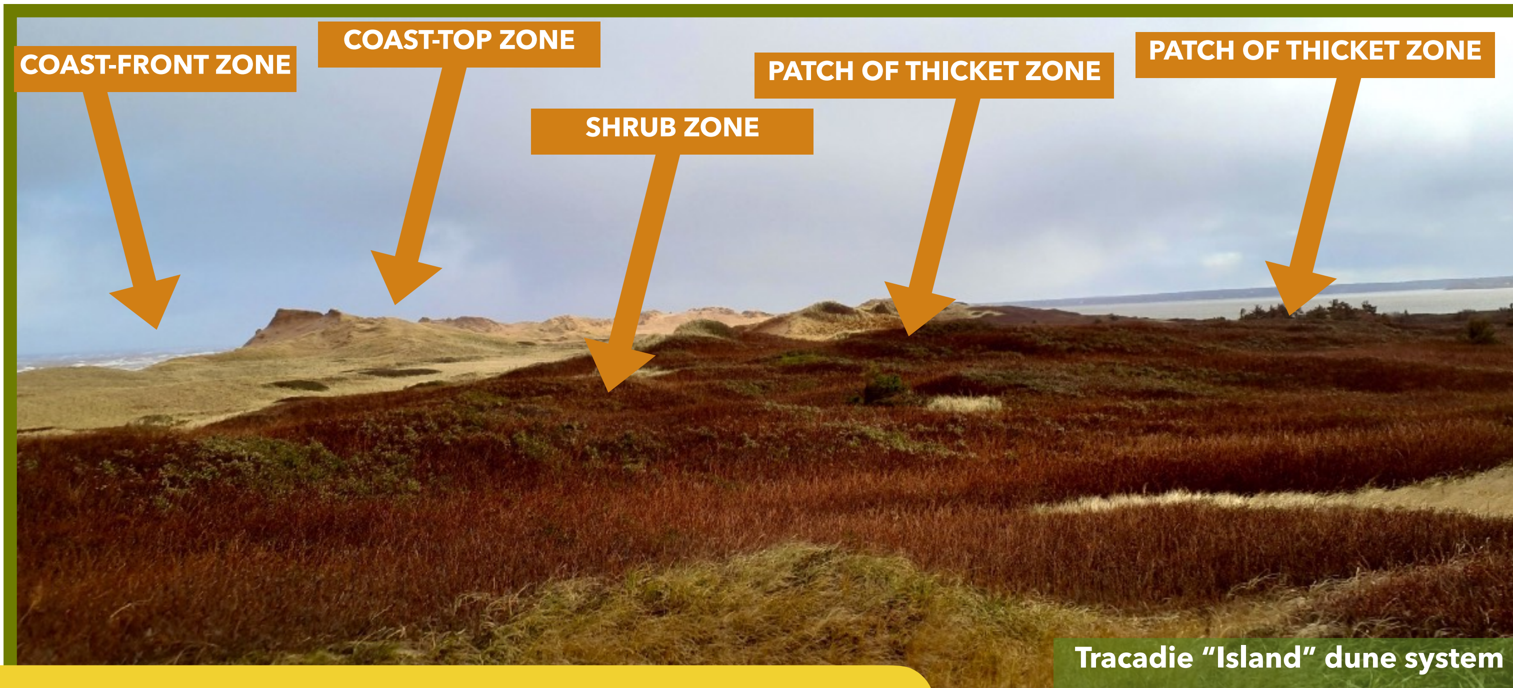
Ecological Function: These forests were once a hotspot of diversity, capable of growing a wide-variety of native species. This areas provide a bevy of ecological services while connecting our shores to our more inland habitats.

Krummholzing Distribution Pattern: This zone typically displays an undulating coastal front, following shoreline as well as soil drainage patterns. It most likely maintains a lower average canopy-closure percentage due a higher average rate of wind disturbance.

<u>Younger Cliff Coastal Forest Zone</u>
Primary Species: *Abies balsamea, Acer rubrum, Betula papyrifera,*
Secondary Species: *Quercus rubra, Sorbus americana, Lonicera canadensis, Cornus canadensis*

<u>Older Age Cliff Coastal Forest Zone</u>
Primary Species: *Quercus rubra, Acer rubrum, Betula papyrifera, Linnaea borealis, galium spp*
Secondary Species: *Acer saccharum, Fraxinus americana, Dryopteris filix-mas, Polystichum acrostichoides, many others.*

RESTORING COASTAL DUNES



Tracadie "Island" dune system

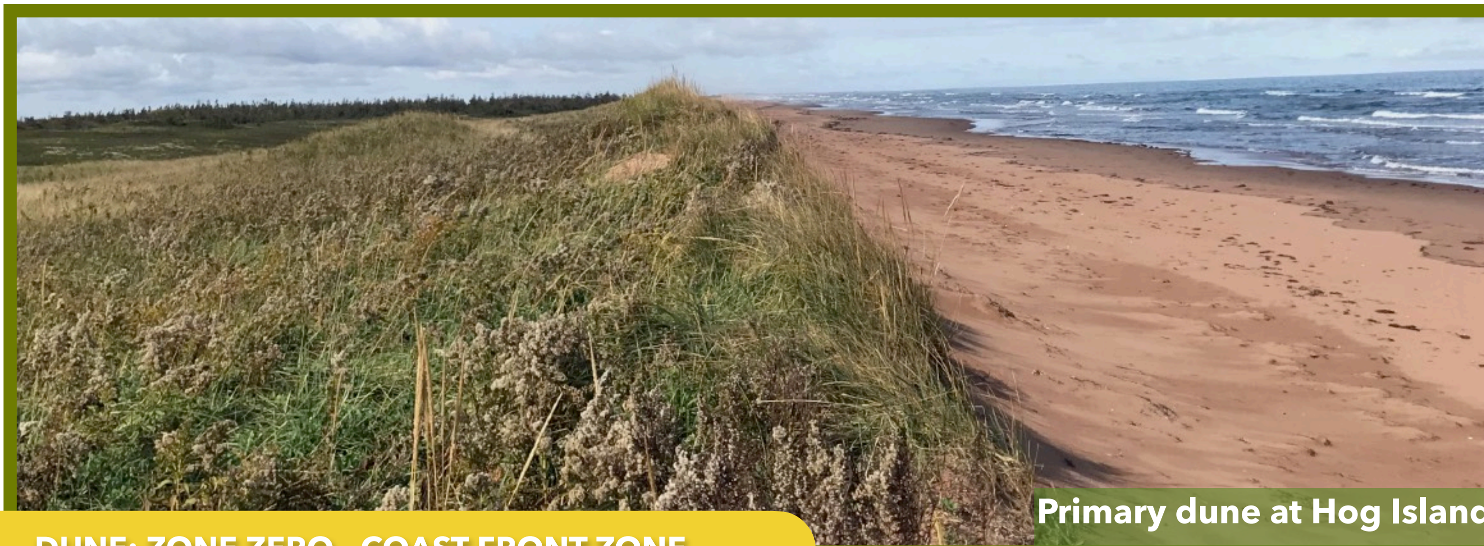
COASTAL DUNES

Coastal dunes account for just over 30% of our coastlines, generally concentrated along our northern shores. While all of our dune systems are found in relatively high-wind areas, displaying krummholzing patterns in species of woody growth, they differ in many ways from krummholzing cliff habitats.

Dune sands are an interesting growing medium. While sandy soils are known for their high-drainage, they also hold less salts then more clay-based mediums. High-wind dunes experience shifting sands constantly with periodic large wind disturbances resulting in drastic but local topographical changes, such as blow-outs. These can create low-elevation depressions in dune systems, allowing increased access to the groundwater, creating sphagnum covered dune swales.

Dunes systems are already noted to follow a topographical system of succession, with the largest primary dunes adjacent to the windy coast. Similarly to cliffs, the primary dunes can be a relatively vertical obstruction to high-coastal winds, absorbing the brunt of the wind's power as well as salt/sand-spray and ice damage. With their protection, the inland secondary dunes can be a much calmer habitat, with less frequent disturbances, allowing a greater variety of flora to flourish. Along protected swales, or wind-sheltered back-dunes, a succession of species, from lichen to moss to marram, create conditions in which shrubs, and then trees, may grow. Given time and periodic disturbance, the back dunes can develop into a mosaic of micro-habits in various levels of succession.

Due to the volatile topography and difficult growing medium coupled with krummholzing conditions, dune system vegetation develops in scattered clumps, often in wetter or more protected areas. With a clear coast-front zone and an almost all encompassing coast-top zone, small islands of krummholz show their own compressed tight version of the ecological wind zones. With time and luck, these scattered patches grow in size, eventually connecting into undulating coastal fronts of krummholz zones, more similar to those seen along our cliffs



Primary dune at Hog Island

DUNE: ZONE ZERO - COAST-FRONT ZONE

The coastal front of our dune systems is exposed to consistently strong winds which constantly shift the loose, dry sands. This area is generally colonized by our native dune-specializing flora as well as some common introduced species. This area is subject to high disturbance rates, sometimes severe enough to clear the area of vegetation, but usually only for a time. Many of this zone's specialist species have unique and diverse dispersal strategy to cope with such a volatile habitat.s Other sites, located along particularly windy stretches of coast and can have large areas with little to no vegetation.

Primary dunes in areas of high-wind can grow to large heights, while sandy areas along lower-wind shores will form lower dune-like berms. Taller, steeper dunes tend to lack any vegetation along the exposed slope, the sandy medium shifts too often for any plants to grow. Dune Coast-front vegetation tends to gather along the bottom of the primary dune when slumping sands level-out. In younger and less-steep dunes, marram grasses and other species can successfully colonize the gradually sloping sands. Areas that area colonized can be quickly destroyed during high-wind events, either through high-tides reclaiming the sands, or blowing winds burying the colonizing flora. Many of our specialize species have adaptations for these kinds of events.

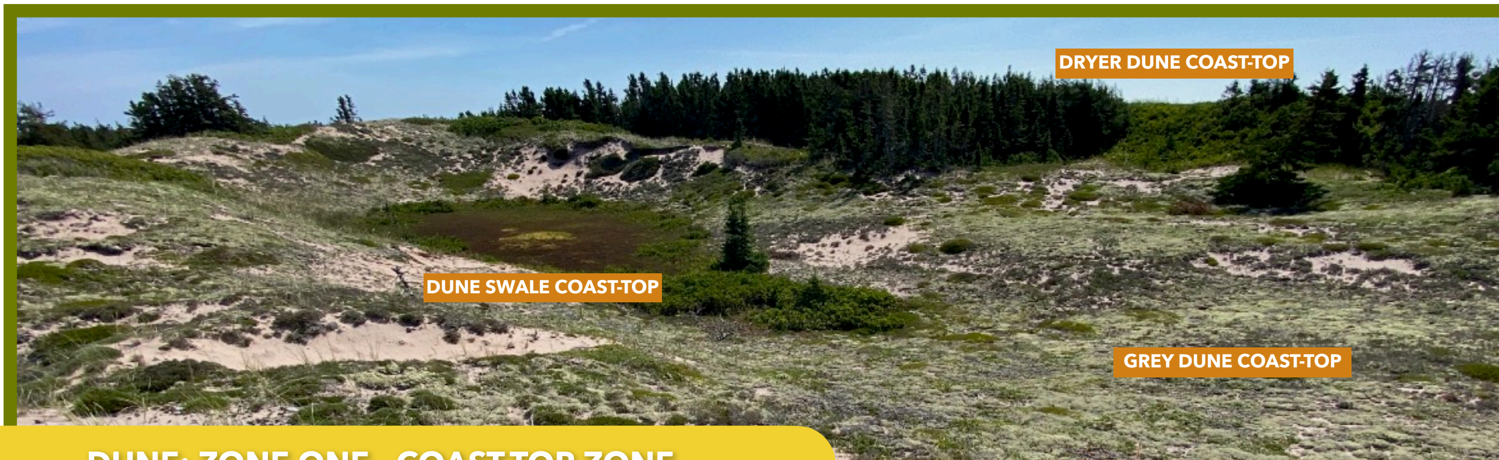
Ecological Function: The health of these battered primary dune fronts is critical in moderating conditions inland, protecting our estuaries, forests, and communities from high-wind events.

Krummholzing Distribution Pattern: This area rarely has krummholz woody plant growth due to its extreme conditions

Dune Coast-Front Zone

Primary Species: *Cakile edentula, Amaranthaceae spp, Calamagrostis breviligulata*
Secondary Species: *Leymus mollis, Solidago sempervirens,*

DUNE COAST-TOP ZONE



DUNE: ZONE ONE - COAST-TOP ZONE

The front of this zone is usually found perched at a relatively high elevation along the primary dune's ridge. High-drainage, shifting sandy soils as well as high wind exposure allow few plants to grow along this ridge but marram grass. Given enough time and luck with no large ecological disturbances, woody shrubbery can creep up the backside of the primary dune and reach the peak.

The rest of the dune system, although shielded by the primary dune from the worst winds, is still exposed to full-sun, sandy-soils, and generally a lot of wind. This creates a very different pattern of ecological wind zonation then seen on cliff sites. After the clear horizontal coast-front zone of the primary dune, the rest of the dune system is a vast area of the coast-top zone with islands of the successive zones of krummholzing woody vegetation.

On dryer or more elevated areas, marram grass and seaside goldenrod are the dominant species, although there are a number of other species which can be found scattered throughout. Areas of lower elevation or stabler sands, "grey dunes" often develop a unique mixture of other species including reindeer lichens, bearberry, heathers, and crowberries.

Ecological Function: The small group of specialist species which grow in this zone, are integral in the processes of dune creation as well as resilience and stability. Without the binding roots of marram grass and others species, our primary dunes lose their structural integrity, weakening the protection they offer for more inland habitats.

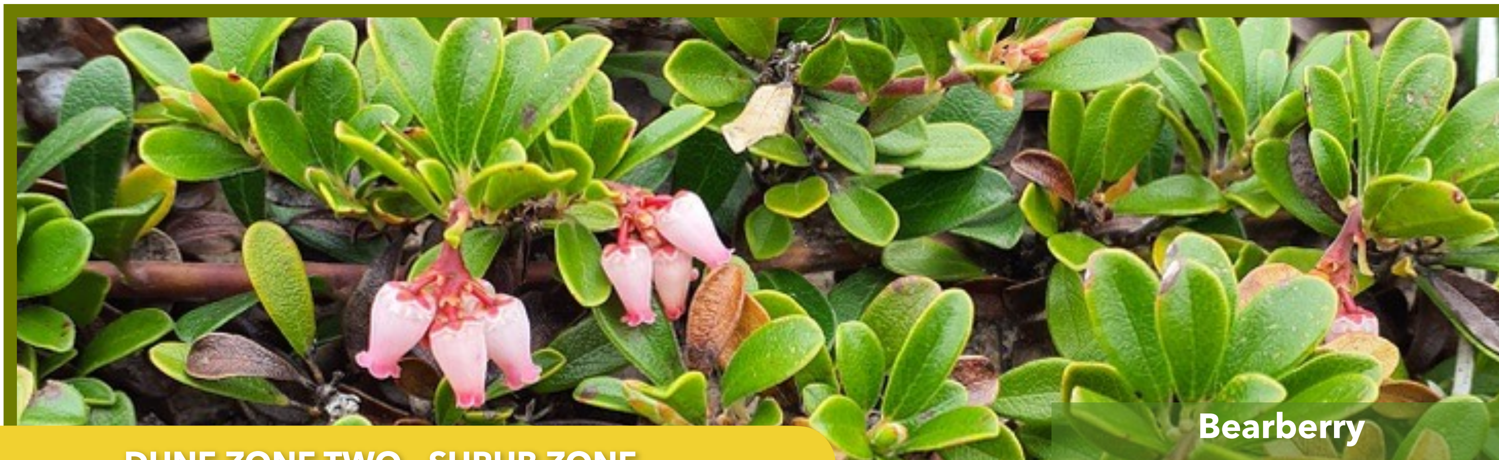
Krummholzing Distribution Pattern: This zone has a clear coastal front along the primary dune. The rest of the zone can range across many areas of exposed secondary dunes across these coastlines. More disturbed dunes tend to have larger surface areas of this zone of the dryer variety. Areas with more stable sands, tend to grow a greater diversity of native flora found in grey dunes and swales.

<u>Dryer Dune Coast-Tops</u>
Primary Species: *Calamagrostis breviligulata, Solidago sempervirens,*
Secondary Species: *Moehringia lateriflora, Leymus mollis, Calystegia sepium*

<u>Grey Dune Coast-Tops</u>
Primary Species: *reindeer lichens, Empetrum nigrum, Hudsonia tomentosa, Arctostaphylos uva-ursi*
Secondary Species: *Corema conradii, Empetrum eamesii, Hudsonia ericoides*

<u>Dune Swale Coast-Tops</u>
Primary Species: *sphagnum spp, Polytrichum strictum, Drosera rotundifolia, Vaccinium oxycoccos*
Secondary Species: *Dendrolycopodium hickeyi, Chamaedaphne calyculata, sedges*

DUNE SHRUB ZONE



DUNE ZONE TWO - SHRUB ZONE

As previously mentioned, the following woody vegetative zones of Island dune systems do not always show the long continuous patterns seen in cliff krummholz. Instead, they begin in small clusters, where small numbers of specimens successfully germinate in the harsh conditions, often with the protection of flora from the coast-top zone. As the small shrubs and trees develop, they shift local wind conditions, allowing their seed to germinate tightly around the initial clump. This process can continue, if not disturbed, creating oblong wind-shaped islands displaying condensed ecological wind zonation. As these scattered krummholz islands grow in area, nearing one another, the shrub zones of each will link. Along calmer areas of dunes, the shrub zone can extend into much vaster areas, displaying the undulating front seen along our krummholz cliffs .

Dune swales support additional varieties of native shrubs along their edges. These areas can support many bog species that can be found along the zones of wet cliffs. These species can spread away from these swales when growing in calmer, late-successional secondary dunes, such as those found at Basin Head.

Ecological Function: The dune shrub zone can have a surprising collection of native species, many of which provide ample wild-food at various times of year. This zone is often dense enough to create protection for small fauna as well as nesting sites for coastal birds.

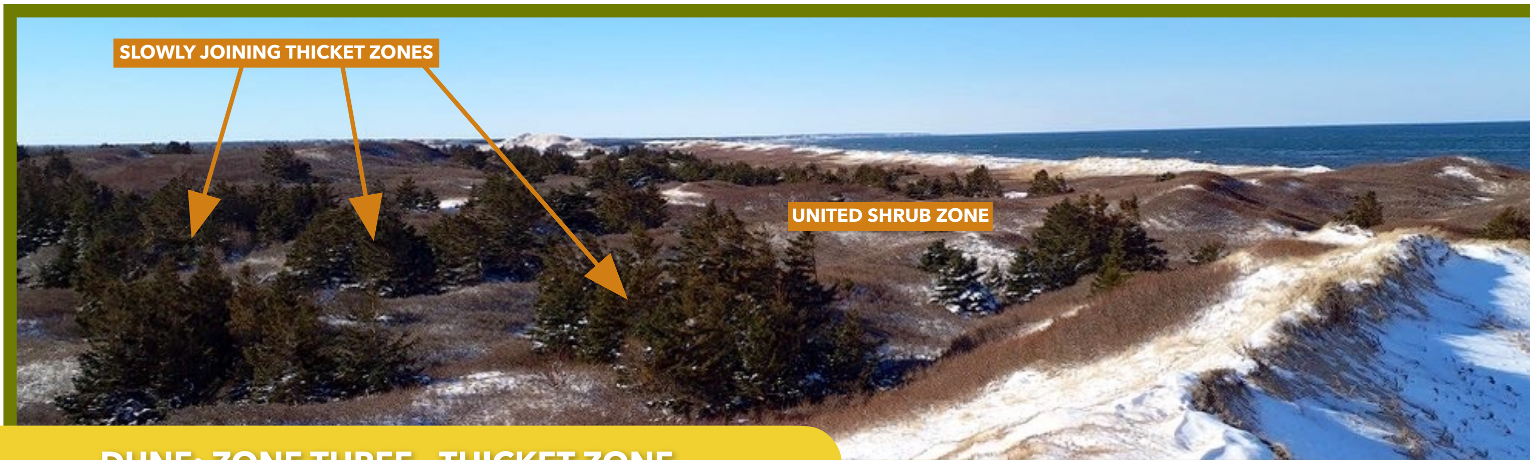
Krummholzing Distribution Pattern: Scattered throughout the dunes, this zone grows along the out-edge of the krummholzing clumps. On more stable dunes, these scattered areas can join, eventually shifting into an undulating coastal front.

<u>Dryer Dune Shrub Zone</u>
Primary Species: *Morella pensylvanica, Rosa virginiana, Spiraea alba, Calamagrostis breviligulata*
Secondary Species: *Moehringia lateriflora, Leymus mollis, Calystegia sepium, Rubus idaeus, Ilex verticillata*

<u>Grey Dune Shrub Zone</u>
Primary Species: *Arctostaphylos uva-ursi, Gaylussacia baccata, Morella pensylvanica*
Secondary Species:*, Comandra umbellata, Vaccinium angustifolium, Juniperus communis, Ilex verticillata, Ilex mucronata*

<u>Dune Swale Shrub Zone</u>
Primary Species: *Kalmia angustifolia, Myrica gale, Chamaedaphne calyculata*
Secondary Species: *Rhododendron canadense, Rhododendron groenlandicum, Ilex verticillata*

DUNE THICKET ZONE



DUNE: ZONE THREE - THICKET ZONE

Developing from scattered clusters, the dune thicket zone is not always as dense as those found growing along our cliffs. While still a gnarled and tangled obstacle, harsh dune sands often result in many dead standing specimens and dead branches.

The scattered development of dune krummholz result in various locations where thicket zones can be found, ranging from the slightly-sheltered back of the primary dune to the calmer secondary dunes bordering our inland estuaries. Scattered patterns of distribution can join overtime, creating large areas of this zone. Generally, the typical scattered pattern of distribution lessens further from the coast, with back dunes sometimes covered in undulating lines of shrub and thicket zone.

Other species of deciduous trees and shrubs were found growing amongst these patches, often in close proximity to the shore. Well-developed secondary dunes, like Basin Head had a greater variety of shrubs growing in the thicket zone such as black huckleberry.

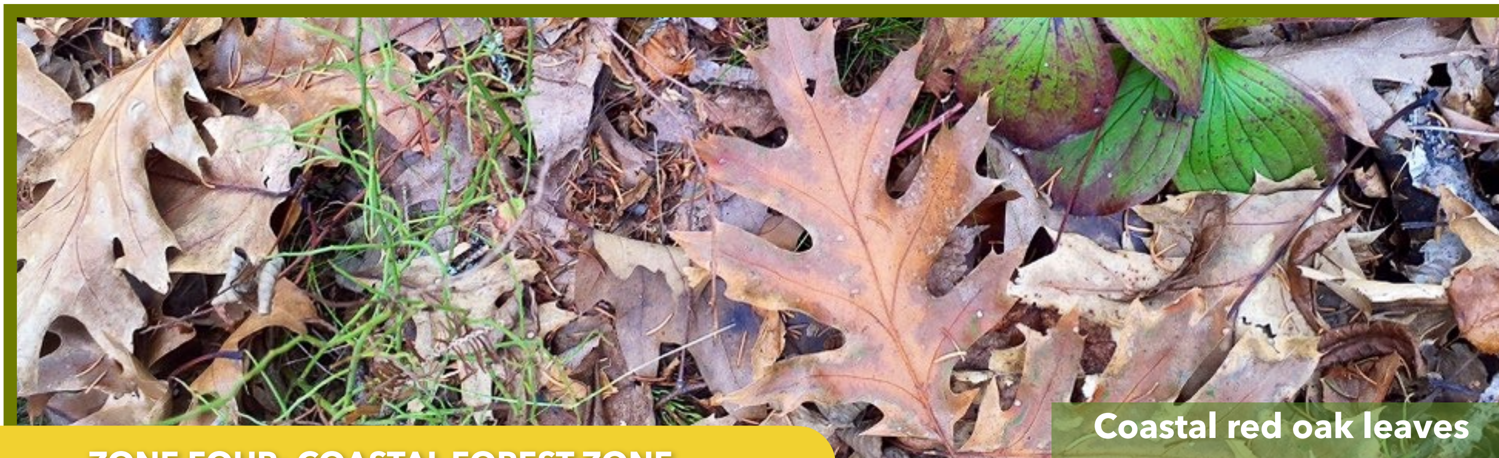
Ecological Function: The scattered clumps of this zone slow wind-speeds across the dune system. It also creates sheltered alcoves or "krummholz caves", short and small gaps under the low-canopy of the thicketing spruce. These "krummholz caves" are home to variety of lichens and mosses as well as lots of wildlife signs and activity.

Krummholzing Distribution Pattern: Like other dune zones with woody plants, this area initially develops as scattered clumps throughout the dune system. Given time and lack of disturbances, these clumps will slowly join, eventually creating an undulating front.

<u>Dryer Dune Thicket Zone</u>
Primary Species: *Picea glauca*
Secondary Species: *Betula populifolia, Sorbus americana, Acer rubrum, Amelanchier spp,*

<u>Grey Dune Thicket Zone</u>
Primary Species: *Picea mariana*
Secondary Species: *Abies balsamea, Acer rubrum, Amelanchier spp*

DUNE COASTAL FOREST ZONE



Coastal red oak leaves

ZONE FOUR: COASTAL FOREST ZONE

Similarly to the rest of the dune zones, the coastal forest adheres to a similar scattered pattern of ecological succession resulting in two identified forms of coastal forest found across study sites. Many of our dune systems currently support small scattered patches of coastal forest such as those found at Basin Head, Tracadie Island and Hog Island. Other sites have larger areas of forested land across old dune systems, however most of these sites are located in the National Park with a history of farming as well as many other ecological disturbances. Greenwich displays a unique coastal forest growing on the relatively undisturbed dunes.

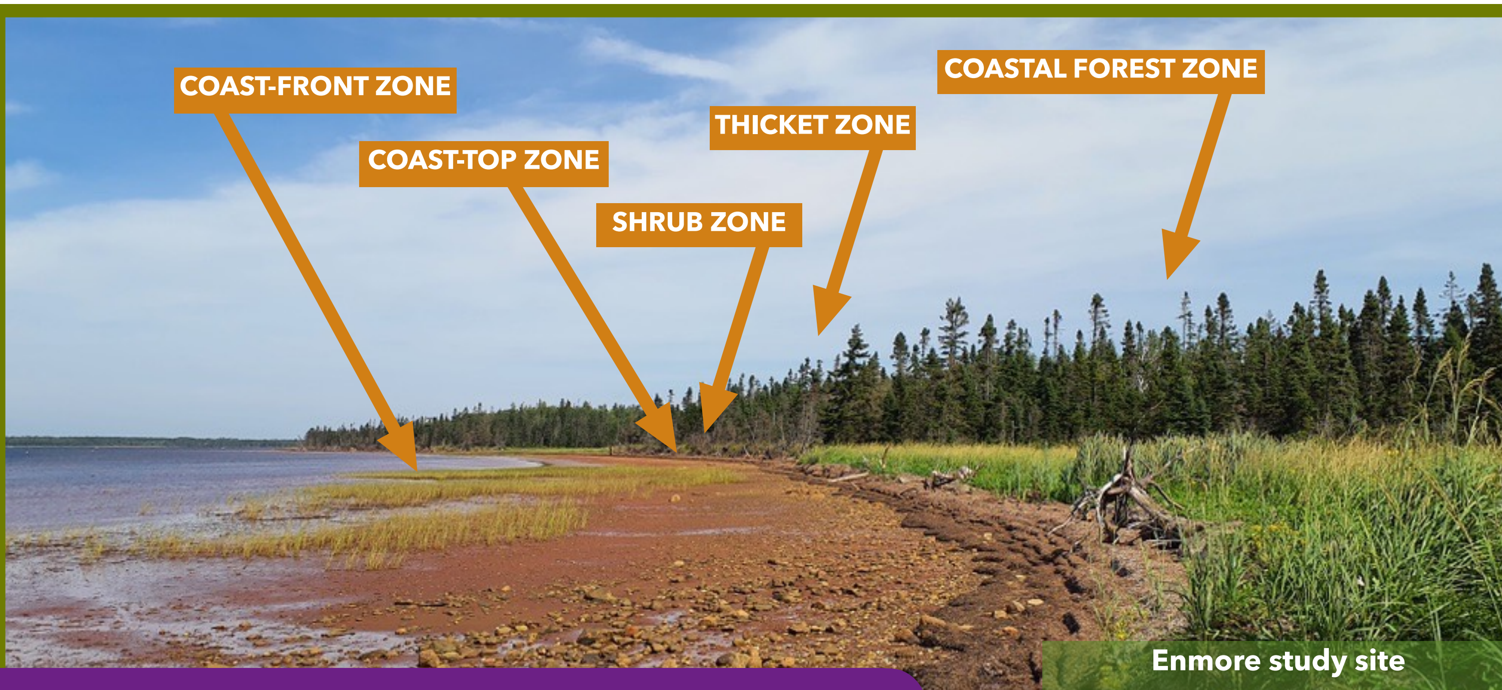
Despite their differences in size and distributions, these forests are home a surprising variety of flora. Many common native woodland species were found growing in sandy forests such as bunchberry, twinflower, starflower, false-lily-of-the-valley, clintonia and lingonberry. Although a primarily coniferous canopy, these forest are often stunted in height but have ample vegetative ground cover.

Ecological Function: These forests were once a hotspot of diversity, capable of growing a wide-variety of native species. This areas provide a bevy of ecological services while connecting our shores to our more inland habitats.

Krummholzing Distribution Pattern: These areas are a rare late-successional part of our dune systems. Trees in this coastal forest tend to be reasonably well-spaced with ample sunny patches filled with remnant open dune species from the preceding ecological wind zones.

<u>Dryer Dune Coastal Forest Zone</u>
Primary Species: *Picea glauca*
Secondary Species: *Sorbus americana, Acer rubrum, Betula papyrifera, Comptonia peregrina, Quercus rubra*

<u>Grey Dune Coastal Forest Zone</u>
Primary Species: *Picea mariana, Abies balsamea*
Secondary Species: *Sorbus americana, Ilex mucronata, Linnaea borealis, Cornus canadensis, Vaccinium vitis-idaea*



COASTAL LOW-PLAINS

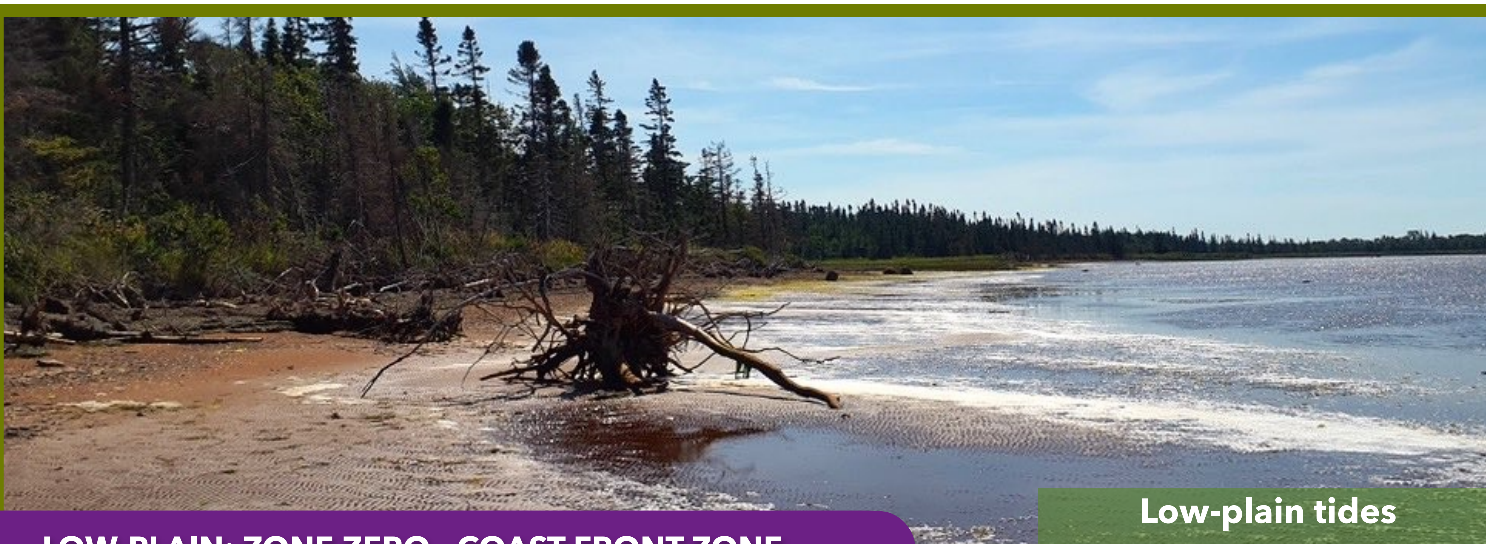
While many of our sheltered estuaries are low-elevation coasts, these are generally sheltered by other coastal krummholzing habitats. Exposed ocean-adjacent low-plains (non-estuarine) make up just over 15% of our shoreline. Many of these areas are located along our sheltered southern shores, generally locations with lower annual mean wind speeds. This coast-type tends to exhibit the weakest levels of krummholz deformation, due to their combination of weaker winds and wetter soils. Only a small number of study sites of this coastal type have been assessed. Adding more low-plain coast sites, particularly in Prince county, would greatly improve understanding of these areas.

Due to their low elevation, these are often areas of wetter soils, which helps to mitigate the desiccating condition of high-wind locations. This eases some of the growing challenges commonly found along other coastal types, generally resulting in habitats with above average biodiversity. That being said, local topography and hydrology dictate which soils receive salty waters and which receive fresh. Salt is often a powerful driving force behind many patterns of ecology along these shores, especially in areas of lower winds.

Salty areas often form salt marsh habitats, sometimes extensive in size. These are highly productive ecosystems, especially when mixed with freshwater sources. These habitats are home for many rare and native halophytic species which grow amongst the sea of cordgrasses. There are many excellent resources and guides to salt marsh ecology and restoration.

Low-plain coasts can also be dominated by fresh water, generally due to local riparian systems or poor soil drainage. Sites such as Enmore, have a silt-clay shore berm, which protects the coastal forest from salt-intrusion while preventing fresh inland soil-water from draining along the coast. Allowing larch, red maple, sphagnum mosses and ferns to grow in close proximity to the shore with little to no deformity.

LOW-PLAIN COAST-FRONT ZONE



Low-plain tides

LOW-PLAIN: ZONE ZERO - COAST-FRONT ZONE

These low-elevation shores are often dominated by tidal forces. Prone to salty soils with periodic inundation and often dominated by marine flora and fauna. Unlike cliff or dune coasts, the low-plain coast-front zone is a largely horizontal marine tidal ecology with only a small number of highly-halophytic species growing along the back shore.

While sometimes exposed to high annual mean winds, these areas more often too marine to allow krummholzing woody species to develop. This is largely the domain of sea weeds, molluscs and crustaceans. Despite this, it is still connected in the ecology of coastal low-plain krummholzing areas, such as providing food for forest-dwelling wildlife and slowing coastal flooding. Some studies suggest these coast-front areas benefit from the slow release of nutrients gathered by lichens in healthy coast-adjacent habitats through submarine seeps.

Other than eel grass, none of our other native plants flourish far from the backshore along our low-plains. As tidal effects lessen, our native cordgrasses, sea milkwort, common ragweed and other salt-tolerant native species begin to grow in greater and greater numbers.

Ecological Function: These productive areas support diverse marine populations of shellfish and seaweeds. The shallow waters help to slow coastal flooding and other strong wave action.

Krummholzing Distribution Pattern: The heavy salt-content of the soils as well as their periodic inundation makes this a difficult zone for woody plants to survive in.

<u>Low-Plain Coast-Front Zone</u>
Primary Species: *Marine species, eel grass*
Secondary Species: *cord grasses, sea milkwort*

LOW-PLAIN COAST-TOP ZONE

Sea milkwort

LOW-PLAIN: ZONE ONE - COAST-TOP ZONE

While not truly a "top" due to its low-elevation, coastal forces along low-plain coasts can create large areas of low-growing vegetation, similar to the coast-top zones of many cliffs and dunes. Other low-plain coasts, such as Enmore, have a solid shore berm created by constant tides and heavier soils. In these areas, the coast-top zone is a thin compressed band running parallel along the shore.

Despite the narrow nature of tidal-caused shore berms, they can be home to a surprising diversity of rare and native flora. Silverweed, common ragweed, rough cocklebur and Canada germander can be found growing amongst the piles of washed up eel grass.

Salt marshes develop in sheltered areas with calmer tides, limiting their number along our exposed northern coasts. Despite less wave action, many of these areas are still exposed to high-wind levels, which combined with salty-soils play a large role in this habitat's ecological processes. Where coastal flooding debris or muskrat habitation raise local topography above the most saline-levels, some native trees and shrubs can take root, growing in the strong winds. Similar to dune systems but even slower to develop, these areas create small krummholzing mounds, concentric islands with species featuring clear but compressed ecological wind zonation.

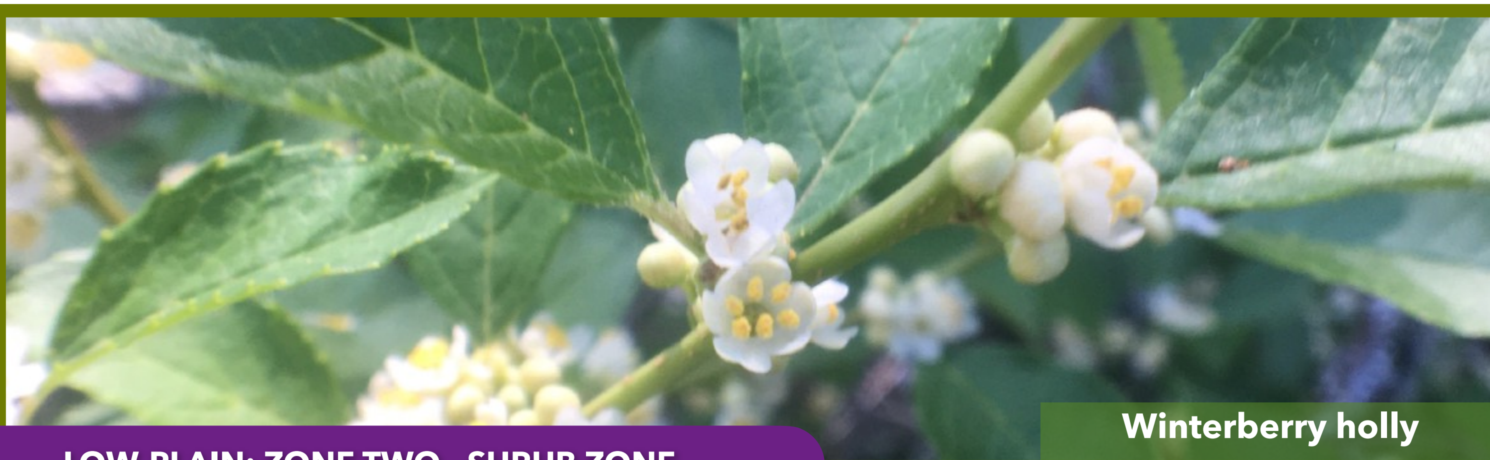
Ecological Function: This narrow zone is home to a number of rare and unique native species. These species help to secure our shores while decreasing salt-intrusion and winds for inland zones.

Krummholzing Distribution Pattern: This zone typically takes two different forms. In areas of salt marsh, this area is wide-spread, often following patterns of high soil salts. On shorelines with a heavy coastal berm, this zone is a thin horizontal band running along the berm.

<u>Low-Plain Salt Marsh Coast-Tops</u>
Primary Species: *Cordgrasses, Lysimachia maritima, Triglochin maritima, Solidago sempervirens, Salicornia maritima*
Secondary Species: *Spergularia salina, Teucrium canadense, Limonium carolinianum, Salicornia maritima*

<u>Low-Plain Shore Berm Coast-Tops</u>
Primary Species: *Ambrosia artemisiifolia, Calystegia sepium, Potentilla anserina*
Secondary Species: *Teucrium canadense, Xanthium strumarium*

LOW-PLAIN SHRUB ZONE



Winterberry holly

LOW-PLAIN: ZONE TWO - SHRUB ZONE

This often narrow zone follows the patterns of salt-content in coastal soils along low-plain coasts. These areas of woody-shrubs grow as soon as soil-conditions allow for both germination or survival. Variations in local-topography as well as freshwater sources, can decrease soil salt-levels and/or frequency of soil inundation.

Although often found along lower-wind shores, the shrub zone rarely develops into the dense wind-clipped examples found in other coastal types. These shrub thickets are generally only found along the edges of large salt marshes exposed to high-winds. In less windy areas, the shrub zone is still heavily-influenced by marine forces such as salt-spray and flooding during periodic high-wind events. This can lead to branch die-back and complete shrub death on occasion, which results in less-dense patches of partially dead shrub zone.

The on-average weaker winds do not exert enough force to create a wide shrub zone along these coasts, often only 5-10 m in depth. Despite this, these areas often protect inland coastal forests from the harshest weather, while providing ample food for wildlife.

Ecological Function: The shrub zone provides a strong buffer against winds for young tree species while providing ample food and shelter for wildlife. Many of the shrubs growing along our coast can fix nitrogen into the soil through processes involve soil bacteria.

Krummholzing Distribution Pattern: Often growing in lower-wind areas, our krummholz low-plain shrub zone tends to follow the patterns of soil salts along the inner-edges of our salt marshes, or horizontally along the back of coastal berms.

<u>Low-Plain Dryer Shrub Zone</u>

Primary Species: *Ilex verticillata, Morella pensylvanica,*
Secondary Species: *Spiraea alba, Aronia melanocarpa, Amelanchier spp*

<u>Low-Plain Wetter Shrub Zone</u>

Primary Species: *Ilex verticillata, Cornus sericea, Kalmia angustifolia, Vaccinium angustifolium, Myrica gale*
Secondary Species: *Alnus incana, Ilex mucronata, Morella pensylvanica, rosa spp, Spiraea alba, Viburnum cassinoides*

LOW-PLAIN: ZONE THREE - THICKET ZONE

Low-plain coast exhibit the mildest examples of the thicket zone when compared to other coastal types. The typically wet soils of these areas, mitigate much of the krummholzing influence of coastal winds. With lower average wind speeds common along our low-plains, these habitats often have a mild thicket zone largely following the inland reaches of salt.

Salt marsh display the best examples of what could be considered the thicket zone along these coasts. The previously mentioned, small krummholzing island, can display pronounced deformity in growth due to locally strong winds. These clumps of spruce and shrubs, are often gnarled and dense enough to form a roughly oblong krummholz. These are generally too small an area to ever develop a coastal forest zone, resulting in small clumps of salt-tolerant thicket zone vegetation amongst the salt marsh.

Mildly krummholzing spruce, often growing to near-average heights, grow densely along the back edges of salt-marshes and behind the protection of coastal berms. While not truly thickets, the species diversity of these areas in still primarily dominated by marine forces. There are specialist to these salty low-wind areas, especially amongst some of our non-vascular flora and lichens such *dicranum majus and parmelia sulcata*. Despite mild wind deformation, these areas still display the powers of salt-spray and sea-water and greatly contribute to the health of our coastal habitats.

Ecological Function: The thicket zone along our low-coasts, absorbs the typically weaker-winds of these areas. Our low-plain thicket zones often protect inland areas of poor drainage which support a variety of interest wetland species.

Krummholzing Distribution Pattern: Showing more deformity along windy salt marsh areas, the low-plain thicket zone can be found as scattered elevated islands amongst the salt marsh, undulating fronts at the inland edges of the salt marsh, or behind the shrub zone along coastal berms.

Low-Plain Thicket Zone

Primary Species: *Picea mariana, Larix laricina*

Secondary Species: *Picea glauca, Abies balsamea, Acer rubrum,*

Sphagnum mosses

LOW-PLAIN: ZONE FOUR - COASTAL FOREST ZONE

This zone is can vary depending on local geological, topographical and hydrological conditions. This is a zone of many habitats, which bears more research as well as zoning/habitat categorization of its own.

Despite the similarities amongst the preceding low-plain zones, their gradual shift onto land largely dictates where this zone will begin. Immediately following the thicket zone, coastal forests along wetter coasts can develop into typical coniferous bog or deciduous swamp forest relatively quickly . Although the province has low-plain coasts with better drainage, many of these flatter areas are still presently farmed, and have yet to be studied. The study sites with intact coastal forest zones were located along wetter soils, considered poor for farming.

Enmore, a wet coastal forest site, had a large diversity of species, particularly amongst the sedges, mosses and ferns as well as birds. The poor drainage as well as shore berm allow many salt-intolerant species to grow in close proximity of the shore. While these wet coastal forests show some mild krummholzing effect at the upper-levels of the canopy, most tree specimens were found growing at average heights for their age group but with a patchy canopy coverage, most likely from past wind-events but also senescence. The understory shrubs and ground cover seem to thrive both, under the shade as well as in the brighter forest patches. Historic accounts of similar areas suggest that species such as eastern hemlock use to grow in near these types of coasts.

The INT Blooming Point oaks site is another interesting location, although protected from the strongest northern winds by a dune system, the western side of this coastal forest zone is bordered by a wide salt marsh. This marsh and associated krummholz, slowed coastal flooding in the area during Fiona. The ecological potentials of our low-plain coastal forests, especially in areas with long continued traditions of farming, is truly unknown.

Ecological Function: Often a wet habitat, these areas are hotspots for biodiversity, connecting our coastal habitats to our more inland habitats.

Krummholzing Distribution Pattern: This zone tends to grow as a coastal front along the coastal berm or along the back-edges of the salt marsh, following patterns of soil salts.

RESTORING COASTAL BLUFFS

Cow River bluff

COASTAL BLUFFS

Coastal bluffs make up a small percentage of our provincial shorelines. They are also one of the least studied coastal types during the course of this project.

Despite their unconsolidated geology, coastal bluffs still share a number of similarities with cliff coasts. Usually located at higher elevations, plants growing along these slumping slopes are often exposed to high winds, while somewhat protected from waves and coastal flooding. The similar conditions often result in similar arrays of species across the ecological wind zones of cliffs and bluffs.

Unconsolidated materials along the coast erode much more readily, with the smaller grained materials swept out to sea first. This often leaves an assortment of larger sea-rounded rocks along the shore which some native species, like *Honckenya peploides* can take advantage of. The consistently high levels of erosion cause the bluff to slump, resulting in a less-vertical growing medium than cliff sites. These same processes can cause sods from the coast-top zone to partially slide down the bluff. These can root in temporarily and continue to grow in the coast-front zone. Eventually, they will end up on the backshore of the beach, where with luck, they can continue to grow. This causes a number of interesting species to be found growing in unlikely zones, rarely thriving but nonetheless contributing to the overall ecology.

The tops of coastal bluffs tend to be dryer sites, most likely related to the improved percolation of their unconsolidated geology. Ecological wind zonation patterns tend to be more broken and/or compressed, often due to erosion destroying areas of coast-top zone, bring the edge into the shrub or thicket zones.

Cow River, one of two bluffs sites, had a diverse riparian zone area greatly increasing biodiversity. While important to this study, this has skewed most results when analyzing these coastal types.

BLUFF COAST-FRONT ZONE

BLUFF: ZONE ZERO - COAST-FRONT ZONE

A poorly studied coastal type, these area lack the vertical sandstone structure of our cliffs. With varying degrees of slope, soil and rocky materials slump downwards, increasing coastal exposure for any plants growing there but adding nutrients to the backshore growing-medium.

The bluff coastal-front is an interesting place with a surprising variety of species, many interlopers from above. Clumps of slumping vegetation from the coast-top zone temporary take root along the bluffs, until a strong storm event or gravity pull them to the shore. There they can grow amongst the debris of the bluff, only to have their precious soil be carried-off after high-water events. Life on the bluff is always temporary.

Due to unconsolidated materials, increased porosity and lack of slabs of sandstone, coastal bluff coast-front zones are much easier growing mediums for our flora than our cliffs. Despite this, many species struggle propagating naturally along the cliffs, only to end up living there due to erosional forces. The looser growing medium is also more susceptible to erosion, making this a short-lived and precious zone to live in.

Ecological Function: The bluff coast-front zone is the first-line of defence against coastal erosion. This unconsolidated material slumps towards the backshore, adding nutrient and improving growing mediums for native plants.

Krummholzing Distribution Pattern: Although krummholzing woody plants can occasionally germinate along these slumping shores, more often they descent from a more inland zone due to erosional forces, often clumps of mixed species on sods of soil.

Bluff Coast-Front Zone

Primary Species: *Plantago maritima, Spergularia canadensis, grasses*

Secondary Species: *Morella pensylvanica, Spiraea alba, Moehringia lateriflora*

BLUFF: ZONE ONE - COAST-TOP ZONE

Bluff coast-tops often have similar assortments of species as cliffs. Located at elevation along the coast and exposed to local winds. These two coastal types are often reasonably alike in krummholzing patterns, distribution, and deformity, although unconsolidated geology causing some striking differences.

Coastal bluffs are generally less resilient to erosional forces due to its geological composition. Wave action can wear away the smaller-grained materials, causing the whole bluff to slump. This can gradually cause chunks of the coast-top zone above to break off, sliding towards the shore, sometimes taking root temporarily in the coast-front zone. If erosional processes are consistent enough, the coast-top zone will generally be missing, with only small patches remaining.

This constant loss of coast-top often results in different krummholz distribution patterns than seen along our cliffs. The constantly eroding bluff, breaks up the the clear horizontal patterns of ecological wind zonation. The coast-top zone along our bluffs is rarely as clearly defined as along our cliffs, it is a more transitory growing medium. As coast-top is lost, this can bring the cliff's edge into the shrub or even thicket zone, exposing previously protected specimens to higher-winds.

With only two study sites classified as bluffs, more sites of this type are needed to better understand the diversity and complexity of these coastlines.

Ecological Function: Bluffs support a diversity of flora along their short-lived coast-top zone. Many of these plants are berry-producers as well as many asters and other wildflowers for pollinators. Due to erosion, these plants often find themselves suddenly growing in the coast-front zone.

Krummholzing Distribution Pattern: This zone tends to form a coastal krummholzing front with various breaks in the patterns due to erosion.

<u>**Bluff Coast-Tops**</u>
Primary Species: *grasses, Fragaria virginiana, Symphyotrichum novi-belgii*
Secondary Species: *Rubus idaeus, Ribes hirtellum, Moehringia lateriflora*

BLUFF SHRUB ZONE

BLUFF ZONE TWO - SHRUB ZONE

This coastal type tends to have more porous soils in general, affecting this zone's diversity of native flora. This area tends to be densely covered in shrubs with various berry-producing plants intermingled. Depending on the rate of erosion, this zone can find itself periodically abutting the cliff's edge, effectively placing it in coast-top zone conditions. Again, more sites are needed to properly understand this coastal type.

Both bluffs studied were on dryer soils, which might be a common characteristic of these sites. Bayberry, wild rose and aronia were the dominant shrubs, although other species were present as well. Where these areas meet swales or riparian areas, sweet gale and winterberry holly could be found growing. The thickness of this zone is closely tied with average local wind speeds and rates of erosion. These forces affect the severity of the krummholzing effect and zonation, before they become coast-adjacent due to erosion.

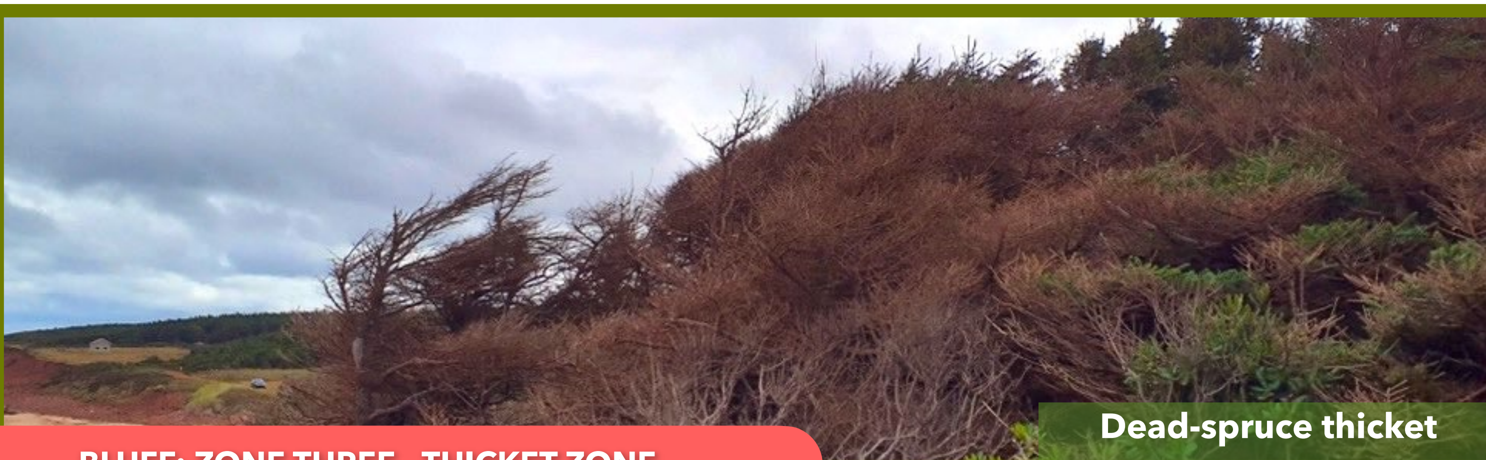
These areas are highly-productive for wildlife with many berry-producing species present. Many wildlife signs were found during fieldwork.

Ecological Function: Providing ample food for wildlife while slowing erosion and protecting our inland zones.

Krummholzing Distribution Pattern: This zone tends to form a coastal krummholzing front with various breaks in the patterns due to erosion.

Dryer Bluff Shrub Zone
Primary Species: *Morella pensylvanica, Rosa virginiana, Spiraea alba,*
Secondary Species: *Rubus idaeus, Prunus virginiana, Ribes glandulosum, Aronia melanocarpa*

Wetter Bluff Shrub Zone
Primary Species: *Myrica gale, Ilex verticillata., Kalmia angustifolia*
Secondary Species: *Spiraea alba, Alnus incana*



Dead-spruce thicket

BLUFF: ZONE THREE - THICKET ZONE

Similarly to the preceding shrub zone, the severity of krummholzing effect along bluff thickets is largely the result of the average local winds. The increased porosity of the soils and resulting levels of drainage do not help to mitigate the winds desiccating effects. This also seems to limit the more extreme levels of krummholzing forms seen along our cliffs, there may not be enough water availability to support extremely-stressed carpeting forms. More often, less deformed species have died standing, such as in the picture above. Partial to Complete throwing still occur often along our bluffs.

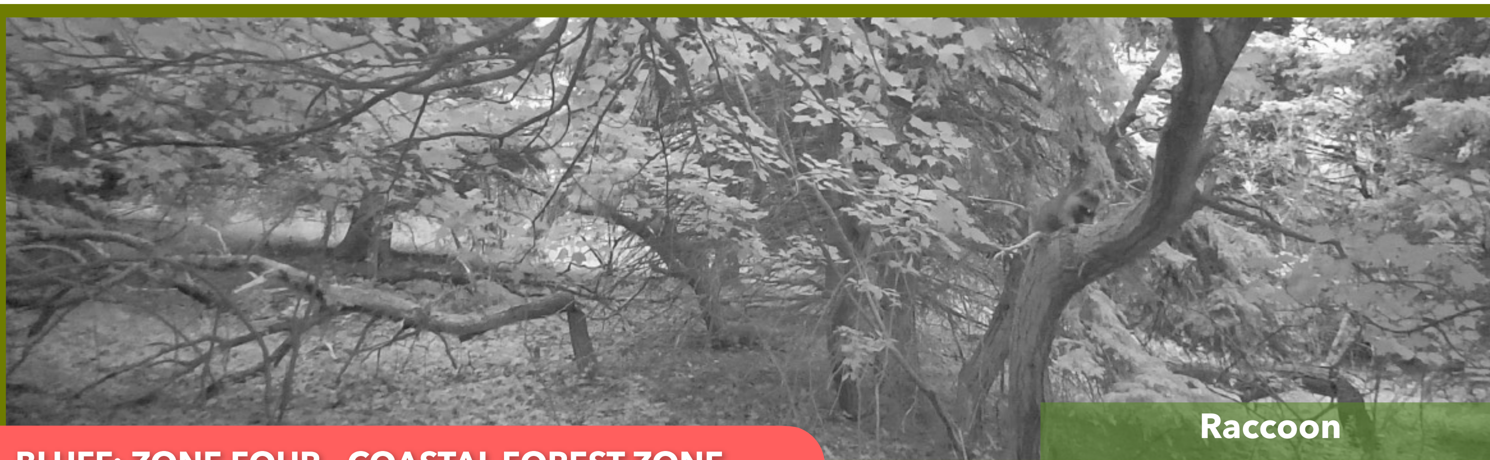
Much like cliffs, when undisturbed, bluffs tend to develop an undulating front of krummholzing zones along the shore, although erosion-prone soils tend to result in deformations to this process. This can result in the thicket zone straddling the edge of the bluff, with live-specimens sometimes slumping down into the coast-front zone.

Without more bluff sites, it is hard to determine the typical width of this zone across our krummholzing coasts. At Cow River, the thicket zone is under 30m deep, much less than at the Clearspring sites, despite relatively similar levels of winds. Whether this is due to increased drainage or site history is undetermined.

Ecological Function: This area is crucial in slowing winds for the more inland zones, all the while providing excellent habitat with both protection and ample wild food. The root systems of this zone help to strengthen our bluffs against erosional forces

Krummholzing Distribution Pattern: This zone tends to form an undulating coastal krummholzing front with various breaks, gaps and compressions in the patterns due to erosional forces.

<u>Bluff Thicket Zone</u>
Primary Species: *Picea glauca*
Secondary Species: *Abies balsamea, Betula populifolia, Prunus pensylvanica, Acer rubrum*



BLUFF: ZONE FOUR - COASTAL FOREST ZONE

With more sites, the ecological potential of this zone could be better understood. At Cow River, the coastal forest zone is an area of relatively tall and straight spruce trees of good girth at close-proximity to the shore. While many of these trees are reaching typical ages approaching increased senescence, there is a scattered second-generation understory of balsam fir, red maple, white birch and trembling aspen. Fieldwork observation would suggest this area capable of growing a variety of other native species of tree and shrub which could be planted with minimal forest intervention.

Study sites like Hog Island suggest that our coastal forest zone, across all coastal types, is an undervalued habitat in PEI, both in its protection and understanding. Historical records list a number of high-value late succession native species growing along coasts behind the thickets of shrubs and spruce.

Our shoreline bluffs often have increased rates of erosion due to their geological make-up. Coastal forests are valuable hotspots of biodiversity and habitat, buffering these vulnerable coasts from increased erosional and environmental pressures from land-use activities further inland.

Ecological Function: These forests were once a hotspot of diversity, capable of growing a wide-variety of native species. This areas provide a bevy of ecological services while connecting our shores to our more inland habitats.

Krummholzing Distribution Pattern: This zone typically displays an undulating coastal front, following shoreline as well as soil drainage patters.

<u>Bluff Coastal Forest Zone</u>
Primary Species: *Picea glauca, Abies balsamea, Populus tremuloides*
Secondary Species: *Acer rubrum, Betula papyrifera, Sorbus americana, many others*

ADDITIONAL INFORMATION

Meat Cove Krummholz, Cape Breton

Over the course of this project, much more data has been gathered on each site, including updated species list for all sites from the 2022-23 season. This project has included a number of other activities and endeavours, from propagating rare coastal species to public outreach and education. There was not sufficient time to include a comprehensive overview of everything within this report. The summary that follows addresses some of these other project actions, additional information can be provided upon request.

FIELDWORK DATA:
As previously mentioned, fieldwork continued throughout the past season, improving species lists at previously visited sites while adding over 15 new sites after Fiona. The relevant botanical data is being shared with the ACCDC and other groups such as local watershed groups. All sites have been as fully assessed as the season allowed. Photos and wind readings, as well as GPS locations for rare species, krummholzing specimens and other ecologically related data has been collected as well.

OUTREACH & EDUCATION:
This became a larger part of the project than initially imagined. Several levels of news media have covered krummholzing habitats and this research, including our local CBC and community organizations as well as the national CBC show, "What on Earth?" (This episode has yet to air). Starting in the winter of 2023, a public presentation was scheduled with Nature PEI and a guided tour with the INT. An additional public presentation was added with ECOPEI. After these initial presentations, a flurry of requests from local organizations have come in, requesting talks about our coastal habitats and their restoration. Three more presentations were added to this season of the krummholz project, one at a Post-Fiona Forest Conference and the others with the PEI Museums and Heritage Foundation and the Souris Area Wildlife Federation. Multiple walks and talks have already been scheduled for the 2023-24 seasons.

KRUMMHOLZ VIDEO:
Filmed and edited over the 2022-23 season, the video component of this project has joined with another PEI FLPP project for a larger release later in the year. This will be a beautiful and informative video showcasing these unique coastlines.

Collecting seed at North Cape

RESTORATION TRIALS:

As previously mentioned, restoration trials planned for the autumn of 2022 were cancelled due to hurricane Fiona. Although a setback, this allowed for longer planning and negotiation with restoration partners such as the PEI National Park. This has resulted in expanded restoration plantings across more sites in the National Parks. It also includes both financial and in-kind contributions from Parks Canada towards the krummholz project. The restoration planning and plantings will involve both organization working together, allowing each to learn from the expertise of the other. Their staff have extensive experience in dune restoration. In our Island province, the potential for these kinds of partnerships is just getting started with several other environmental groups interested in joining restoration efforts.

COASTAL SPECIES PROPAGATION:

Over the course of the krummholz project, a variety of seeds and cuttings have been collected from a variety of native coastal plants. This is a slow-process which doesn't always coincide with the timing of these reports. As this growing season continues, a better assessment of success-rates, species abundance and germination methods will be much more informative.

OFF-ISLAND STUDY

A part of these season's research, included a trip to northern Cape Breton, visiting three coastal krummholz sites. This was a very informative trip with large amount of species data and other assessment variables collected and observed. All three sites were interesting as none had an agricultural history, although two had been grazed. This made for biodiverse coastal krummholz, sometimes strikingly similar to George's Island, housing a number of species historically reported but not commonly seen along PEI's coasts. In particular, male fern, bush honeysuckle and herb robert were found spreading into the barrens or coast-top zone equivalent in Cape Breton, under higher average winds than most Island sites. Geological differences affecting soil qualities might be responsible for this but nonetheless, these sites gave ample inspiration for restoration potential on PEI.

STUDY SITES

Krummholz shores of Cape Breton

The initial 13 study-sites were chosen for their diversity of coastal types, habitats and locations along our Island Shore. The 2022-23 season saw an additional 15 sites added for study and seed collection, many of these were visited after Fiona or during the winter season. Although this increased the sample-size for many site categories, there are still knowledge-gaps to address concerning krummholzing coastal habitats which would require additional sites.

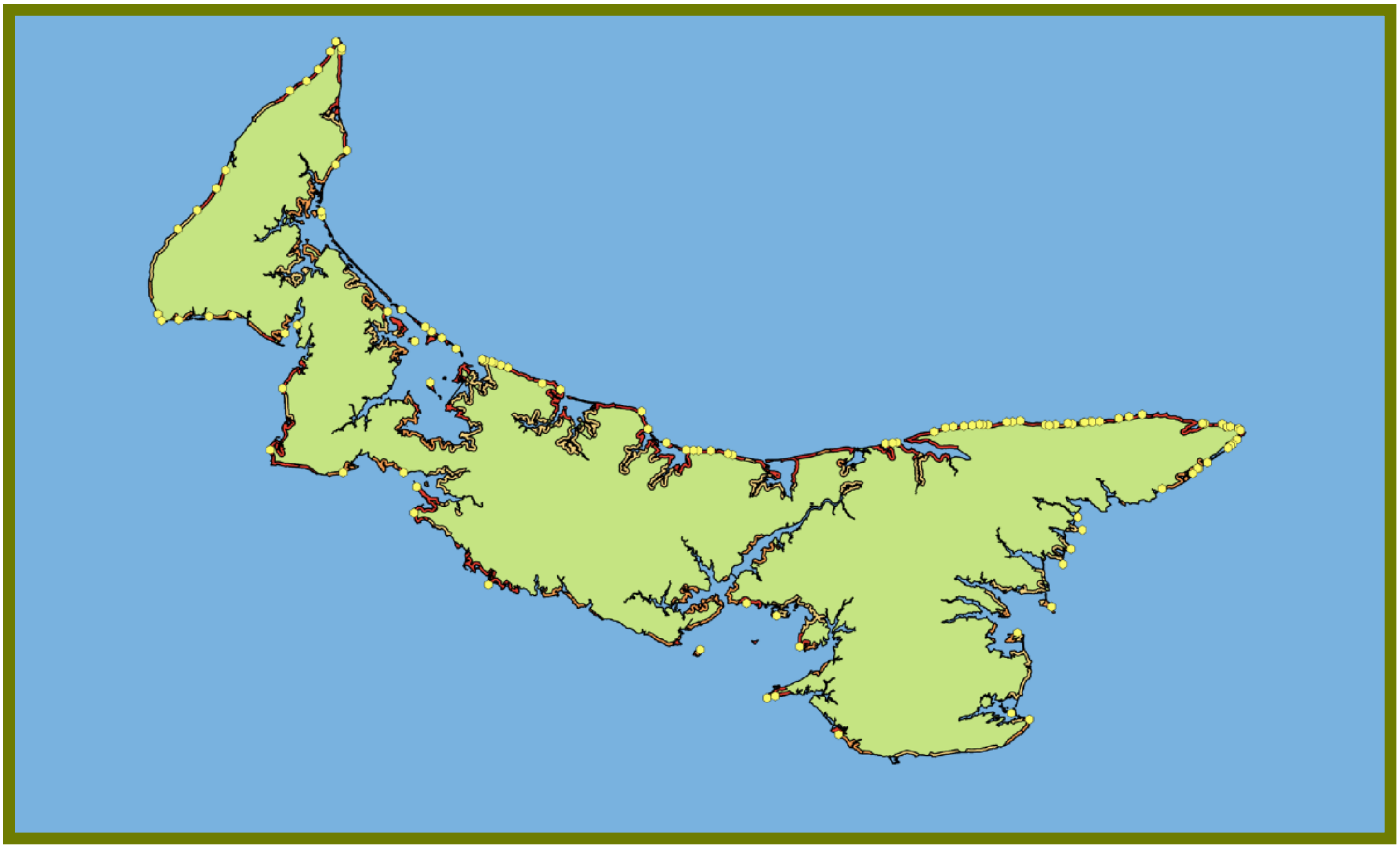
SITES BY COUNTY & COASTAL TYPE

COUNTY	Total Surveyed	Dunes	Cliff	Bluff	Low	Dunes/Cliff
TOTALS	**28**	**10**	**9**	**3**	**2**	**4**
KINGS	9	3	3	3	0	0
QUEENS	15	6	4	0	1	4
PRINCE	4	1	2	0	1	0

SITES BY COUNTY & OTHER INDICATORS

COUNTY	Total Surveyed	AVG D index	Avg F index	Avg Age	Avg Nspp	Avg Rarespp
TOTALS	**28**	**4.75**	**10.53**	**63.6**	**67.4**	**4.9**
KINGS	9	4.44	8.00	66.11	60.89	5.00
QUEENS	15	5.13	12.00	54.00	59.00	2.80
PRINCE	4	4.00	N/A	93.75	98.75	8.00

FUTURE SITES



As discussed previously, a number of different methods of processing field-data collected, governmental data and GIS mapping were used throughout the course of this project. A "krummholz zone" map was created which helps to highlight likely Island coastlines with strong annual average winds.

The above map is an updated version of that previously shown, overlain with 112 potential krummholz sites located across the province. While by no means exclusive, this methodology was used in choosing the 15 new sites added this year. Based on these results, more sites were chosen and marked for future research targeting previously mentioned knowledge gaps.

A number of data-sets are currently being gathered which will enhance this process, both in speed and quality. The shoreline type data-set, mentioned in previous krummholz reports, unploughed soils as well as geo-referenced historic aerial photos will all help target krummholz of particular interest.

Restoration trials in 2023 will be another crucial step towards improving restoration work across our coasts. With a better knowledge of the distribution, diversity and health of our coastal krummholzing habitats, we can better target and plan restoration as well as conservation work across the Province.

As this report shows, these priority places are the front-line protection for our inland habitats and communities, slowing erosion, lessening wind-events and housing diverse arrays of native flora and fauna, our coastal krummholz have a history of degradation which bears tending as climates change.

BIBLIOGRAPHY

ACCDC. [Website]. (2021). *Atlantic Canada Conservation Data Centre.* Retrieved from http://www.accdc.com/.

Adams, K., [Webpage]. (2009). *Rediscovering the Lowly Lichen across the National Park System*. Retrieved from https://www.nationalparkstraveler.org/2009/12/rediscovering-lowly-lichen-across-national-park-system5046.

Alden, J., Mastrantonia, J.L. (2013). *Forest Development in Cold Climates.* Springer Science & Business Media, 212.

Anjum, L. (2014). *Wind Resource Estimation Techniques: An Overview*. International Journal of wind and Renewable Energy, 3 (2), 26-38.

Archaux, F. [Webpage], (2011). *On Methods of Biodiversity Data Collection and Monitoring*. Retrieved from http://www.set-revue.fr/methods-biodiversity-data-collection-and-monitoring

Beusen, A.H.W., et al, (2013). *Global land–ocean linkage: direct inputs of nitrogen to coastal waters via submarine groundwater discharge.* Environ. Res. Lett. 8 034035, Retrieved from https://iopscience.iop.org/article/10.1088/1748-9326/8/3/034035

Brady, Nyle & Weil, Ray. (2010). Elements of the Nature and Properties of Soils. Pearson Education Inc.

Bowles, J.M., (2004). *Guide to Plant Collection and Identification*. UWO Herbarium workshop in Plant Collection and Identification.

Burzinski, M. (1999). Gros Morne National Park. Breakwater Books, 85-94.

Calder, John. (2018). Island at the Centre of the World: the geological heritage of PEI. Canadian Geological Foundation.

Cameron, R.P., Richardson, D.H.S., (2006). *Occurrence and Abundance of Epiphytic Cyanolichens in Protected Areas of Nova Scotia.* Canada. Opuscula Philolichenum, 3, 5-14.

Cornall, J., & Simard Geneviève. (2014). *Seashore life of eastern canada: A guide to identifying intertidal marine species.* Nimbus Publishing Limited.

Cox, D.D. (2002). *A Naturalist's Guide to Wetland Plants: An Ecology for Eastern North America*. Syracuse: Syracuse University Press.

Cox, D. (2003). *A Naturalist's Guide to Seashore Plants: An Ecology for Eastern North America.* Syracuse University Press.

Curley, R. & others. (2019). Mammals of Prince Edward Island and adjacent marine waters. Island Studies Press at UPEI.

Daley, S., (2009). *How Rocks Affect the Growth of Krummholz in the Mealy Mountains of Labrador*. [Honours Thesis]. Dalhousie University.

Daniels, L. [Webpage], (2015). *Wind Resource and Speeds*. Retrieved from https://www.windustry.org/wind_resource_and_speeds

BIBLIOGRAPHY

Davies, M. (2011). *Geomorphic Shoreline Classification of Prince Edward Island*. Atlantic Climate Adaptation Solutions Association.

Devilliers, P., Devilliers-Terschuren, J. (1996). *A Classification of Palaearctic Habitats: Issues 18-78*. Council of Europe. 29.

Finch, K. [Website]. (2017). *Magical Mushrooms, Mischievous Molds*. Retrieved from https://blogs.oregonstate.edu/inspiration/tag/krummholz/.

Gucker, Corey L. [Webpage] (2006). *Juniperus horizontalis. In: Fire Effects Information System*. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.fed.us/database/feis/plants/shrub/junhor/all.html [2022, April 10]

Henderson, D.C. (2009). *Occupancy Survey Guidelines for Prairie Plant Species at Risk*. Canadian Wildlife Service. Retrieved from https://www.npss.sk.ca/docs/2_pdf/Rare_Plant_Occupancy_Survey_Guidelines.pdf.

Hewson, E.W. et all. (1979). A Handbook on the use of Trees as an indicator of Wind Power Potential. National Technical Information Service.

Hewson, E.W. et all. (1979). Vegetation as an Indicator of High Wind Velocity. Department of Atmospheric Sciences, Oregon State Univeristy.

Hinds, James & Patricia. The Macrolichens of New England. The New York Botanical Press.

Jenkins, Jerry. (2020). Mosses of the Northern Forest: A photographic guide. Cornell University Press.

Jenkins, Jerry. (2019). Sedges of the Northern Forest: A photographic guide. Cornell University Press.

Jenkins, Jerry. (2022). Grasses of the Northern Forest: A photographic guide. Cornell University Press.

Johnston, H.D., (1967). *Marine Plants of the Atlantic Coast Provinces of Canada*. Industrial Development Service, Department of Fisheries of Canada.

Kim, N., Makar, M., Osleger, A., Shenouda, J. (2019). *The adaptive value of leaf quaking in Populus tremuloides.* California Ecology and Conservation Research. Retrieved from https://ucnrs.org/wp-content/uploads/2019/08/The-adaptive-value-of-leaf-quaking-in-Populus-tremuloides.pdf.

Kobylinski, A., Fredeen, A.L., (2015). *Importance of Arboreal Cyanolichen Abundance to Nitrogen Cycling in Sub-Boreal Spruce and Fir Forests of Central British Columbia, Canada*. *Forests* 2015, *6*(8), 2588-2607.

Kock, Henry. (2008). Growing Trees from Seed: A Practical Guide to Growing Native Trees, Vines and Shrubs. Firefly Books Ltd.

Larsen, J. A. (1982). *Ecology of the northern lowland bogs and conifer forests*. Acad. Pr.

Leslie, S. (2008). *Sea and Coastal Birds of North America: A guide to observing, understanding, and conservation*. Toronto: Key Porter Books Limited.

MacEachern, Alan. (2022). *Storms of a Century: Fiona (2022) & Five (1923)*. Retrieved from https://activehistory.ca/2022/10/32319/.

BIBLIOGRAPHY

Maine Natural Areas. [Webpage]. (2021). *Maine Natural Areas Program: Spruce - Fir Krummholz. Maine Department of Agriculture, Conservation and Forestry*. Retrieved from https://www.maine.gov/dacf/mnap/features/communities/sprucefirkrummholz.htm.

Mathew, S, Davidson-Arnott, R, & Ollerhead, J. (2010). *Evolution of a beach–dune system following a catastrophic storm overwash event: Greenwich Dunes, Prince Edward Island, 1936–2005*. Canadian Journal of Earth Sciences, volume 47, number 3.

McMullin, T., Anderson, F. (2014). *Common Lichens of Northeastern North America.* The New York Botanical Garden.

Malanson, G.P., et al. (2007). Alpine Treeline of Western North America: Linking Organism to Landscape Dynamics. Physical Geography, 28, (5), 378-396.

Novaczek, I., McLachlan, J. (1989). *Investigations of the marine algae of Nova Scotia XVII: Vertical and geographical distribution of marine algae on rocky shores of maritime provinces*. Proceedings of the Nova Scotian Institute of Science, 38, 91-143.

National Park System. [Website]. (2007). *Rocky Mountain National Park: The Subalpine Ecosystem*. Retrieved from https://web.archive.org/web/20070809001440/http://www.nps.gov/archive/romo/resources/plantsandanimals/ecosystem/subalpine.html.

New York Natural Heritage Program. (2022). *Online Conservation Guide for Alpine krummholz*. Available from: https://guides.nynhp.org/alpine-krummholz/.

Nimbus. (2001). *The last billion years: A geological history of the Maritime Provinces of Atlantic Canada*.

PEI GIS. [Website]. (2017). *GIS Data Catalog*. Retrieved from http://www.gov.pe.ca/gis/index.php3?number=77543.

Perzanowski, K., Jerzy. (2022). *Eastern Europe: Czech Republic, Poland, Romania, Slovakia, and Ukraine*. Retrieved from https://www.worldwildlife.org/ecoregions/pa0504.

Pope, R. (2016). *Mosses, Liverworts, and Hornworts: A Field Guide to Common Bryophytes of the Northeast.* Cornell University Press.

Powell, G. (2009). *Lives of Conifers: A Comparative Account of the Coniferous Trees*. The John Hopkins University Press.

Rankin, Joe. [Webpage] (2014). *Krummholz: The High Life of Crooked Wood*. Retrieved from https://northernwoodlands.org/outside_story/article/krummholz-wood

Read, J., Sanson, G.D. (2003). *Characterizing sclerophylly: the mechanical properties of a diverse range of leaf types*. New Phytologist, 160 (1), 81-99.

Research Branch Agriculture Canada / PEI Department of Agriculture. (1994). *Soil Survey of PEI*. Retrieved from www.gov.pe.ca/gis

Roland, A.E., Smith, E.C. (1969). *The Flora of Nova Scotia. Part I: The Pteridophytes, Gymnosperms and Monocotyledons*. Proceedings of the Nova Scotian Institute of Science, Halifax, NS: Nova Scotia Museum.

Roland, A.E., Smith, E.C. (1969). *The Flora of Nova Scotia. Part II: The Dicotyledons* . Proceedings of the Nova Scotian Institute of Science, Halifax, NS: Nova Scotia Museum.

BIBLIOGRAPHY

Rousk, Kathrin et al, (2013). *Moss-cyanobacteria associations as biogenic sources of nitrogen in boreal forest ecosystems*, Front. Microbiol., 17.

Sellmer, J., Bates, R., Hoover, G., [Article] (2013), *Ericacea (Heath) Family and their Culture*. Retrieved from https://extension.psu.edu/ericacea-heath-family-and-their-culture

Short, A.D., [Article], (2012). *Coastal Processes and Beaches*. Retrieved from https://www.nature.com/scitable/knowledge/library/coastal-processes-and-beaches-26276621/

Sobey, D. G., and W. M. Glen. 2004. *A mapping of the present and past forest-types of Prince Edward Island*. Canadian Field-Naturalist 118(4): 504-520.

Species richness. [Webpage]. (2015). *Tutorial 13.2 - Species richness and diversity*. Retrieved from https://www.flutterbys.com.au/stats/tut/tut13.2.html.

Webster, T. (2012). *Identification of Anomalous Coastline Change Areas and the Aggregation of Change Attributes for Littoral Cells*. Atlantic Climate Adaptation Solutions Association.

Webster, T. (2012). *Coastline Change in Prince Edward Island, 1968-2010 and 2000-2010*. Atlantic Climate Adaptation Solutions Association.

Weisberg, P.J., Baker, W.L. (1995). *Spatial Variation in Tree Seeding and Krummholz Growth in the Forest-Tundra Ecotone of Rocky Mountain National Park*, Colorado, USA.


Pink crowberry