Quantifying shoreline modifications adjacent to eelgrass meadows in the Strait of Georgia Bioregion

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QUANTIFYING SHORELINE MODIFICATIONS ADJACENT TO EELGRASS MEADOWS IN THE STRAIT OF GEORGIA BIOREGION

by

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Cristiani, J.M., Bannar-Martin, K.H, and Rubidge, E.M. 2023. Quantifying shoreline modifications adjacent to eelgrass meadows in the Strait of Georgia Bioregion. Can. Tech. Rep. Fish. Aquat. Sci. 3574: vi + 18 p.

Coastal marine ecosystems face threats from various marine and terrestrial human activities. Shoreline modifications that result from these activities can significantly impact the health and functioning of coastal biogenic habitats, including seagrass meadows. Quantifying the extent of shoreline modifications adjacent to seagrass meadows is therefore crucial for assessing potential human impacts to seagrass ecosystems. Here, we map, characterize, and quantify shoreline modifications adjacent to eelgrass (*Zostera marina*) meadows in the Strait of Georgia Bioregion. Using aerial imagery and a spatial dataset of seagrass distribution, we digitized shoreline modifications within 100 meters inland of each seagrass meadow. We focused on areas that have been de-vegetated and altered from their natural state. We characterized modifications into six categories (road, residential, industrial, agriculture, greenspace, unclear). The median percent of modified shoreline area was 9%. Of the 685 meadows analyzed 19% had no modifications, and 9% were more than 50% modified. The dominant modification type was residential development. The resulting dataset provides valuable information for assessing land-use patterns and predicting impacts to nearshore ecosystems. This study highlights the importance of managing seagrass within its broader landscape context, and it emphasizes the need for ongoing data collection and analysis to inform effective seagrass management strategies.

RÉSUMÉ

Cristiani, J.M., Bannar-Martin, K.H, and Rubidge, E.M. 2023. Quantifying shoreline modifications adjacent to eelgrass meadows in the Strait of Georgia Bioregion. Can. Tech. Rep. Fish. Aquat. Sci. 3574: vi + 18 p.

Les écosystèmes marins côtiers sont menacés par diverses activités humaines marines et terrestres. Les modifications du littoral résultant de ces activités peuvent avoir une incidence significative sur la santé et le fonctionnement des habitats biogéniques côtiers, y compris les herbiers marins. Il est donc essentiel de quantifier l'étendue des modifications du littoral à proximité des herbiers marins pour évaluer les répercussions potentielles de l'humain sur les écosystèmes d'herbiers marins. Ici, nous cartographions, caractérisons et quantifions les modifications du littoral à proximité d'herbiers de zostère (*Zostera marina*) dans la biorégion du détroit de Georgia. À l'aide d'images aériennes et d'un ensemble de données spatiales sur la répartition des herbiers marins, nous avons numérisé les modifications du littoral dans un rayon de 100 mètres de la côte adjacente à chaque herbier marin. Nous nous sommes concentrés sur les zones qui ont été dévégétalisées et modifiées par rapport à leur état naturel. Nous avons classé les modifications en six catégories (route, milieu résidentiel, milieu industriel, milieu agricole, espace vert, non défini). Le pourcentage médian de la superficie modifiée du littoral était de 9 %. Sur les 685 herbiers analysés, 19 % n'ont subi aucune modification et 9 % ont été modifiés à plus de 50 %. Le type de modification dominant est le développement résidentiel. L'ensemble de données qui en a résulté fournit de l'information précieuse pour l'évaluation des schémas d'utilisation des sols et la prévision des répercussions sur les écosystèmes littoraux. Cette étude met en évidence l'importance de la gestion des herbiers marins dans le contexte plus large du paysage terrestre, et souligne la nécessité d'une collecte et d'une analyse continues des données afin d'élaborer des stratégies efficaces pour la gestion des herbiers marins.

1 Introduction

The health and functioning of coastal marine ecosystems are under threat from a variety of human activities (Halpern et al. 2019). Coastal activities such as agriculture, residential development, and logging can create pressures on the marine environment. A modified shoreline may exacerbate the impacts of these broad scale activities by altering levels of sedimentation, nutrient runoff, and pollution in the nearshore environment (Dethier et al. 2016; Todd et al. 2019). For coastal biogenic habitat in British Columbia such as seagrass, modifications that harden the shoreline may decrease the ecosystem services that these habitats provide, e.g., buffering from wave energy and sea level rise (Shaughnessy et al. 2012; Robb 2014; Gittman et al. 2016). Furthermore, these pressures can impact seagrass productivity and survival, and thus impact the community of species that rely on seagrass (Iacarella et al. 2018; Nahirnick et al. 2019; Murphy et al. 2021). Therefore, knowing the presence of shoreline modifications adjacent to seagrass meadows would allow us to better characterize potential ecological impacts to individual seagrass meadows and to understand seagrass ecosystem dynamics in a broader landscape context.

Assessing human activities for an entire coastal region is generally done at broad spatial scales. For example, impact mapping and assessments for all of BC have been done with a 2 km+ spatial resolution (Clarke Murray et al. 2015), which exceeds the size of many seagrass meadows as well as the size of the shoreline region which could be locally impacting a meadow. In addition, many spatially distinct meadows may exist close together, where only a high resolution assessment of shoreline modifications could distinguish the potential impacts between them. Fine-scale assessments of impacts to seagrass exist for the BC coast, but these are typically done in detail for only a few meadows due to logistical constraints (Iacarella et al. 2018; Nagel et al. 2020). Ideally, impacts are quantified at broad and fine scales for entire regions. For example, along the Atlantic coast of Canada, Murphy et al. (2019) quantified activities at the Bay scale (i.e., activities occurring in the watershed or ocean but not overlapping with the meadow) and the local scale (occurring in or in close proximity to the meadow) for 180 seagrass meadows across two bioregions. Together, these analyses allow us to better understand the variation in anthropogenic influences on seagrass meadows and the seagrass-associated biological communities across bioregions and at multiple scales relevant to management efforts.

The objective of this project is to map and quantify the inland shoreline modifications adjacent to all known seagrass meadows in the Strait of Georgia Bioregion of British Columbia - a subset of the Salish Sea (DFO 2009a). Eelgrass (*Zostera marina*, the dominant habitat-forming seagrass species) has been identified as an Ecologically Significant Species (DFO 2009b), and eelgrass meadows have been designated as Ecologically and Biologically Significant Areas (EBSA) due to their productivity, sensitivity, and support for biological diversity (Rubidge et al. 2020). Therefore, it is important to acquire information on human activities to predict impacts and categorize meadows by their degree of naturalness, as areas of high or low naturalness may be a priority for additional management and conservation efforts (UN CBD 2008). While shoreline modifications do not represent all of the human activities potentially threatening seagrass, a high resolution dataset is currently needed and can complement other existing human impact data.

2 Methods

2.1 Seagrass spatial data

Eelgrass (*Z. marina*) is the primary subtidal and intertidal meadow-forming seagrass in British Columbia. Meadows may also consist of the non-native seagrass, *Zostera japonica*, in the intertidal zone. Seagrass occurs to depths of up to 10 meters and can form meadows many km^2 in size (Murphy et al. 2021). We used a spatial dataset of seagrass in the Salish Sea compiled in 2018 for Cristiani et al. (2021). This dataset consists of surveyed and modeled data from a variety of government and non-governmental sources - primarily polygon data representing eelgrass meadows compiled by the British Columbia Marine Conservation Atlas (BCMCA 2011) and the ShoreZone coastal mapping inventory (Coastal and Ocean Resources 2017) (Table 1). Shoreline data are linear features generated from aerial imagery that classify the ecological features of the BC coast including eelgrass. In the dataset from Reshitnyk (2016), these linear features were combined with bathymetric data following the methodology in Gregr et al. (2013) to generate predictions of eelgrass extent. The dataset includes 685 spatially distinct meadows across the Strait of Georgia Bioregion as well as in the southern portions of the Northern Shelf Bioregion and Southern Shelf Bioregion (Figure 1).

Table 1. Eelgrass spatial data sources

Eelgrass dataset source	Coverage	Dates	Access
British Columbia Marine Conservation Atlas	coastwide	1890-2010	bcmca.ca/data/eco_vascplants_eelgrass_polygons
Hakai Institute (modified Shorezone data)	coastwide (with gaps in the Strait of Georgia)	1992-2017	catalogue.hakai.org
Islands Trust	Gulf Islands and Howe Sound	2012-2014	islandstrust.bc.ca (restricted)
Community Mapping Network	coastwide (but used just Tsawwassen and Boundary Bay polygons to fill gaps in other datasets)	unknown	cmnbc.ca/atlasgallery/eelgrass-bed-mapping
Personal observations	West and North Vancouver	2016	request from author

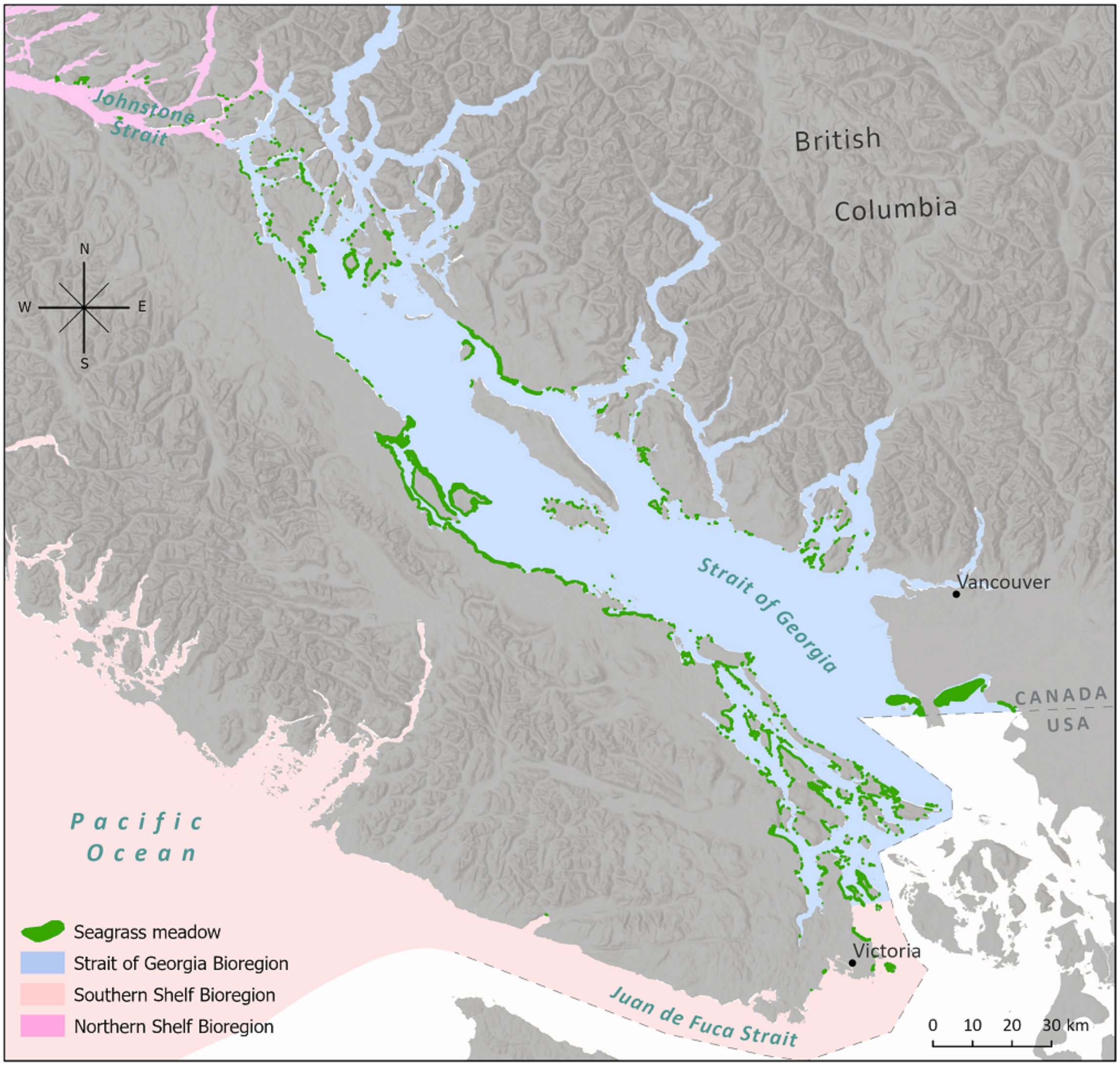

Figure 1. Seagrass meadows in the Strait of Georgia Bioregion and southern portions of the Northern Shelf Bioregion and Southern Shelf Bioregion. The outlines of the meadow polygons are exaggerated for visualization purposes.

2.2 Shoreline area adjacent to seagrass meadows

Previous guidelines on the width of marine riparian buffer zones for protecting sensitive habitat typically range from 50-150 meters (Levings and Jamieson 2001; Lemieux et al. 2004). We followed the methodology in a similar study of anthropogenic impacts (Iacarella et al. 2018) and examined shoreline modifications within 100 m inland of the coastline adjacent to each seagrass meadow. For our analysis we used the high water coastline from the 1:20,000 scale Freshwater Atlas provincial dataset (GeoBC 2010) and buffered inland from this line. Quantifying modifications within a buffer zone required generating consistent width buffers from all meadows onto land. The perimeters of meadows, however, do not always exactly border the shoreline due to variable mapping accuracies and errors, as well as some meadows only existing in the subtidal zone. This would result in slightly different buffer extents on to land. Aside from a few exceptions, the majority of meadows are in close proximity to a coastline, and therefore, to create consistent width buffers on land we first adjusted the perimeter of meadows to match the coastline using digitization tools in ArcGIS.

2.3 Quantifying shoreline modifications

To quantify shoreline modification adjacent to seagrass, we identified any structures (e.g. buildings, houses) and areas de-vegetated from their natural state (e.g. lawns, logged areas, agriculture, armoured shoreline) within the 100 meter buffer from the high water line towards land. De-vegetated areas can increase nutrient run-off from agricultural areas and sewage outfalls, potentially resulting in eutrophication (Hauxwell et al. 2003; Vandermeulen 2005; Quiros et al. 2017). Hardened and de-vegated areas may also increase the outflow of sedimentation resulting in decreased light levels in seagrass meadows (Vandermeulen et al. 2012; Dethier et al. 2016; Todd et al. 2019).

Shoreline modifications were digitized from satellite and aerial imagery in Google Earth Pro (see Appendix B for detailed workflow). We used the imagery on Google Earth that was available during December 2020 – January 2021. The majority of roads were included using an existing provincial dataset (Province of British Columbia - Digital Road Atlas). This dataset consists of linear features which were buffered using the number of lanes and standard lane widths. Modifications were classified into six categories: road, residential, agriculture, industrial, greenspace, and unclear. Within each category, an additional descriptor was also listed if relevant (Table 2). Overwater structures (e.g. floathomes, docks, aquaculture) were not considered to be shoreline modifications as these are associated with a different suite of impacts (e.g. shading, boat traffic), and these features were captured in separate studies (Iacarella et al. 2019; Cristiani 2022).

To quantify the overall level of shoreline modification we totaled the area of all modification types per buffered area and calculated the percent of the buffered area that is modified. The percent modified was then associated back with the adjacent seagrass meadow.

Table 2. Shoreline modification primary classifications and additional subcategory descriptors.

Modification	Subcategory descriptors
Road	paved; dirt; rail
Residential	house; RV; lighthouse
Industrial	logging; airport; general development; parking; storage; onland marina infrastructure; church; electrical; ferry; hospital; train yard; shipping
Agriculture	crop; cleared agricultural land; onland aquaculture
Greenspace	cleared greenspace; campground; golf; park; recreation
Unclear	unclear modification

3 Results

The spatial distribution of shoreline modifications varied across the region. Examples of the extent and diversity of modifications are shown in Figure 2, and the full dataset is accessible online (see Data availability section). As expected, the seagrass meadows with the highest total levels of adjacent shoreline modification occurred near population centers. The lowest levels of modification occurred near smaller islands and in the northern part of the study area (i.e. Johnstone Strait). The median amount of modified shoreline was 9%. Of the 685 meadows, 19% had no modifications, 9% were more than 50% modified, and 1% were more than 80% modified (Figure 3). The dominant modification type across the study area was residential development (Figure 4a). All other modification types had relatively low values, except at two meadows (Crofton, Duncan Bay) where the shoreline was more than 75% modified by industrial development (Figure 4c). Agriculture varied by latitude with most coastal agriculture occurring in the southern portion of the study area, where for example, the shoreline of the Roberts Bank meadow was 24% modified by agricultural uses (Figure 4b).

Figure 2. Shoreline modifications within buffered areas adjacent to seagrass meadows. All buffers are 100 meters wide, as measured from the coastline. The six selected areas are shown for example and do not imply any significance over other areas.

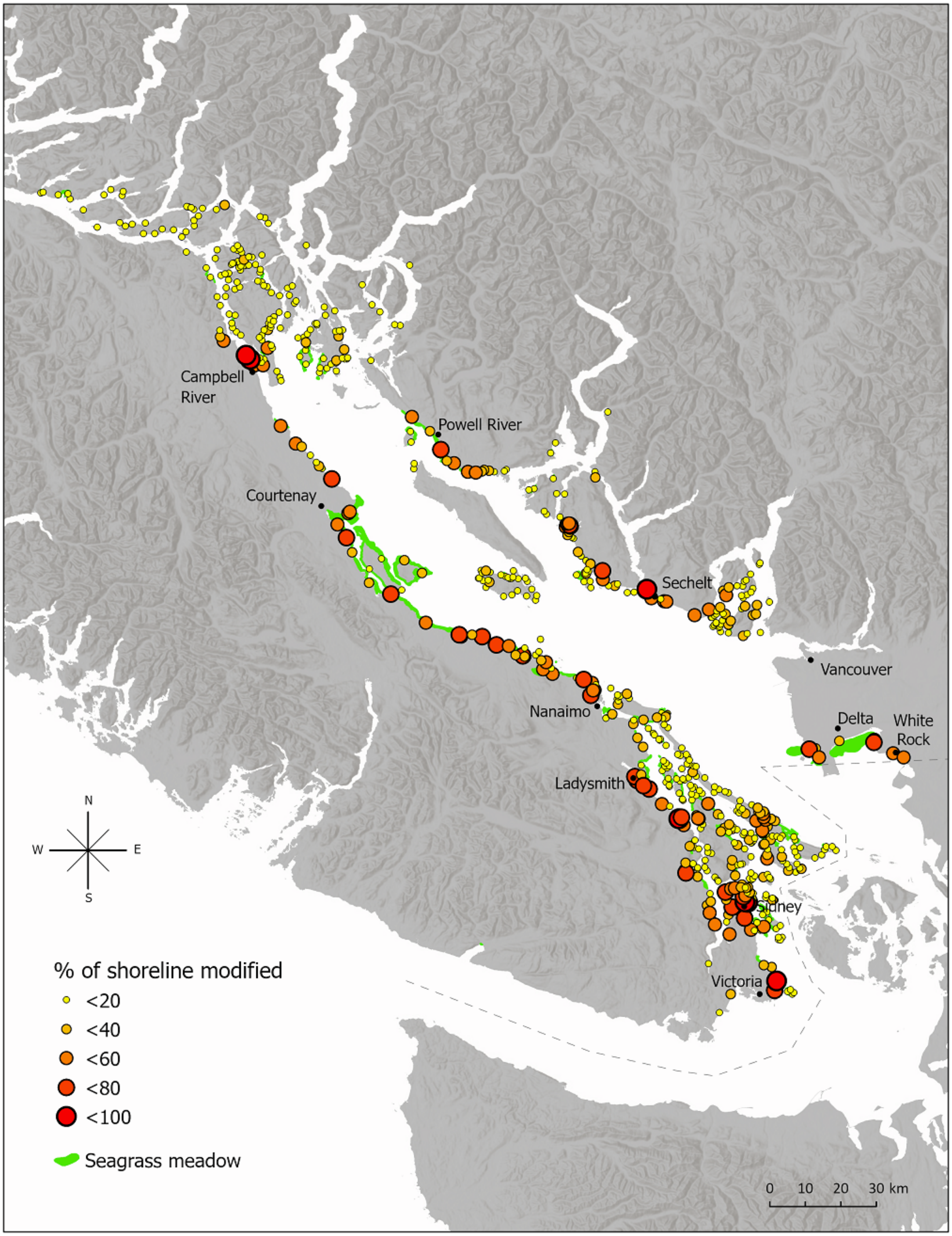

Figure 3. The percent of shoreline modified within the buffered area adjacent to each seagrass meadow.

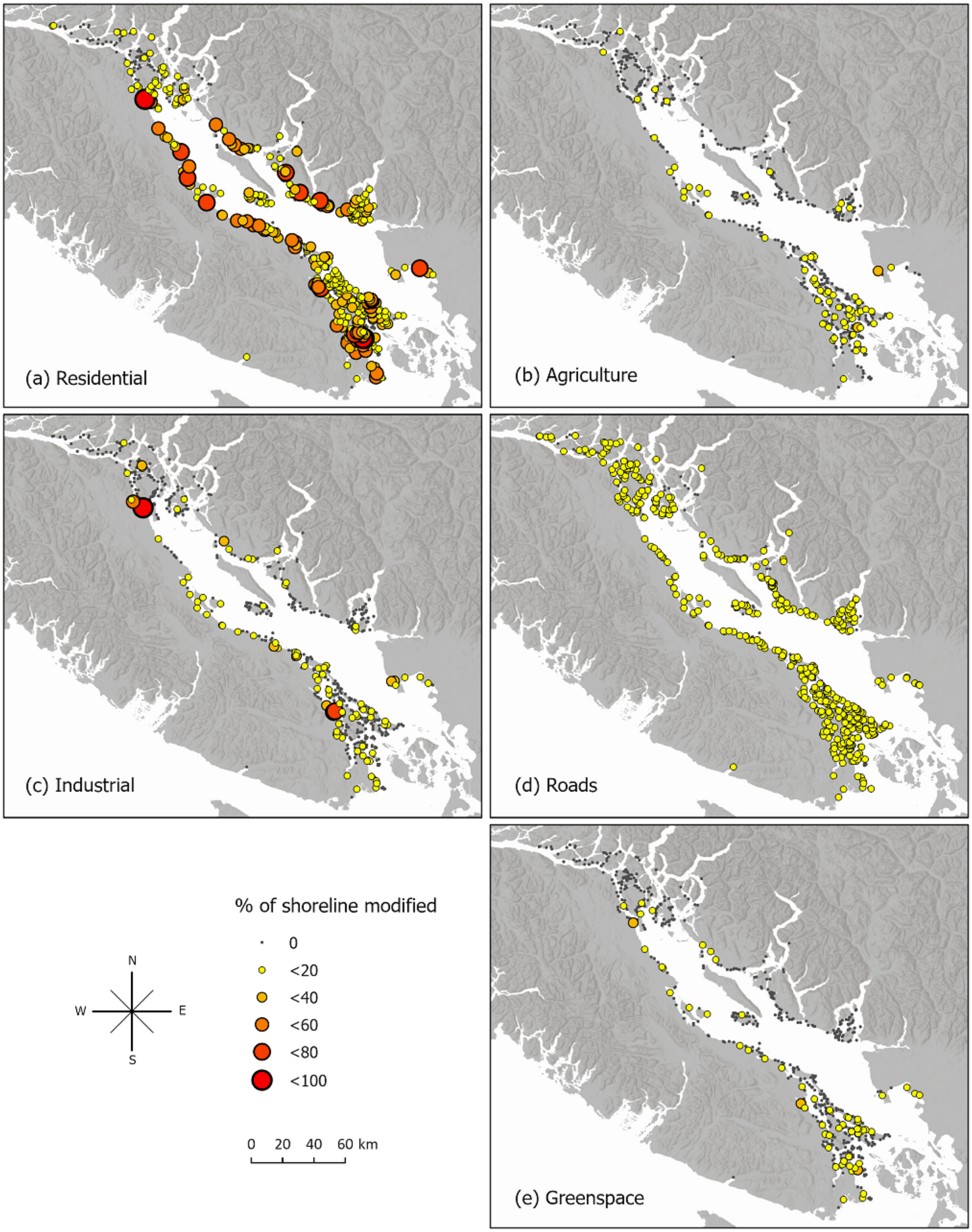

Figure 4. The percent of shoreline modified within the buffered area adjacent to each seagrass meadow by modification type: (a) residential, (b) agriculture, (c) industrial, (d) roads, (e) greenspace. Uncertain classification type is not shown.

4 Discussion

By quantifying shoreline modifications adjacent to seagrass meadows, we've provided a novel high resolution dataset for documenting land use over a large spatial extent and predicting potential impacts to nearshore ecosystems. The variation in the distribution and patterns of modifications across the region illustrate the different shoreline threats that seagrass meadows may face based on their location. While areas of high naturalness are generally targeted for conservation over degraded areas (UN CBD 2008; Rubidge et al. 2020), other criteria such as biological diversity, productivity and connectivity may result in targeting meadows that are threatened by shoreline activities (Rubidge et al. 2020; Cristiani 2022). If an area including a meadow is selected for management action and eelgrass is identified as a conservation objective, then it's likely the shoreline modifications will have to be considered for possible mitigation of impacts. It will then be important to know the spatial distribution of modifications because the management action will vary with the type of modification. The approach we demonstrate here could be also be applied to assess potential impacts to other nearshore habitat types that have been identified as ecologically significant.

This analysis could be strengthened by addressing some of its assumptions and limitations. We used a uniform buffer from the coast, but there is likely a distance-decay of the impacts from certain activities, such that subtidal meadows may experience impacts differently than intertidal meadows. In addition, a narrow buffer of vegetation on the edge of the coast could be enough to mitigate the effects of certain modifications behind this buffer. Most importantly, it will be necessary to quantify the relative severity of each modification and the vulnerability of seagrass to different pressures. For example, runoff from agricultural areas may be more damaging than runoff from residential areas (Teck et al. 2010). Shoreline modifications are representative of only one type of threat to seagrass, however, by quantifying severity and vulnerability scores, this data could be incorporated into larger cumulative effects analyses in which the overall impact of many stressors occurring in the larger watershed and surrounding marine environment is quantified (Clarke Murray et al. 2016, 2020; Murphy et al. 2022).

Due to the combination of seagrass meadow data with varying collection methodologies and error, there is uncertainty in the accuracy of our seagrass dataset, and it is best used for coarse estimates of presence and extent. Since the time of our analysis, there has been additional eelgrass mapping and refining of the existing datasets. A comparison to a new DFO dataset (Proudfoot et al. 2022) shows areas where our dataset may overpredict presence and where additional meadows have been added. In some cases, the polygons of the newer dataset are more precise (i.e., multiple small polygons that are represented as one large general polygon in the earlier dataset), however, these locations would not alter our analysis of shoreline modification. More important than discrepancies of overlap, are areas where the datasets do not overlap. Our dataset generally has more polygons in the Discovery Islands, Lasqueti Island, Howe Sound, and the Gulf Islands, as these meadows were retained as point and line features in the newer dataset and not extended as modeled polygons due to area uncertainty. The newer dataset fills data gaps in areas such as Sechelt Inlet and Saanich Inlet (Figure A.1). A recent ShoreZone dataset fills gaps along the Sunshine Coast, Texada Island, and near Vancouver (Figure A.2). Given these discrepancies, it will be important to view this shoreline modifications dataset as a starting point and to continue to develop it in conjunction with the most current eelgrass datasets.

Our analysis emphasizes the importance of managing seagrass and the biodiversity it supports in the spatial context of the larger landscape. While seagrass area is declining globally, it appears to be stable in the north Pacific (Dunic et al. 2021), and in the Washington state portion of the Salish Sea seagrass has been resilient despite an increase in human activities (Shelton et al. 2016). To further enhance successful seagrass management, understanding exactly which activities may be impacting seagrass locally will likely require a more precise analysis of human activities, the stressors they generate, and the vulnerability of seagrass to these stressors. Therefore, it will be important to continue to gather high resolution spatial data that informs the initial stage of these analyses.

5 Data availability

The shoreline modifications dataset is currently restricted to DFO Science and is available at: https://gis-hub.ca/dataset/shoreline-modifications-eelgrass, but can be made available to others upon a request to the lead author (john.cristiani@dfo-mpo.gc.ca). The seagrass dataset contains data with sharing restrictions, however, portions of the dataset can also be made available upon request.

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APPENDIX A SEAGRASS DATASET DIFFERENCES

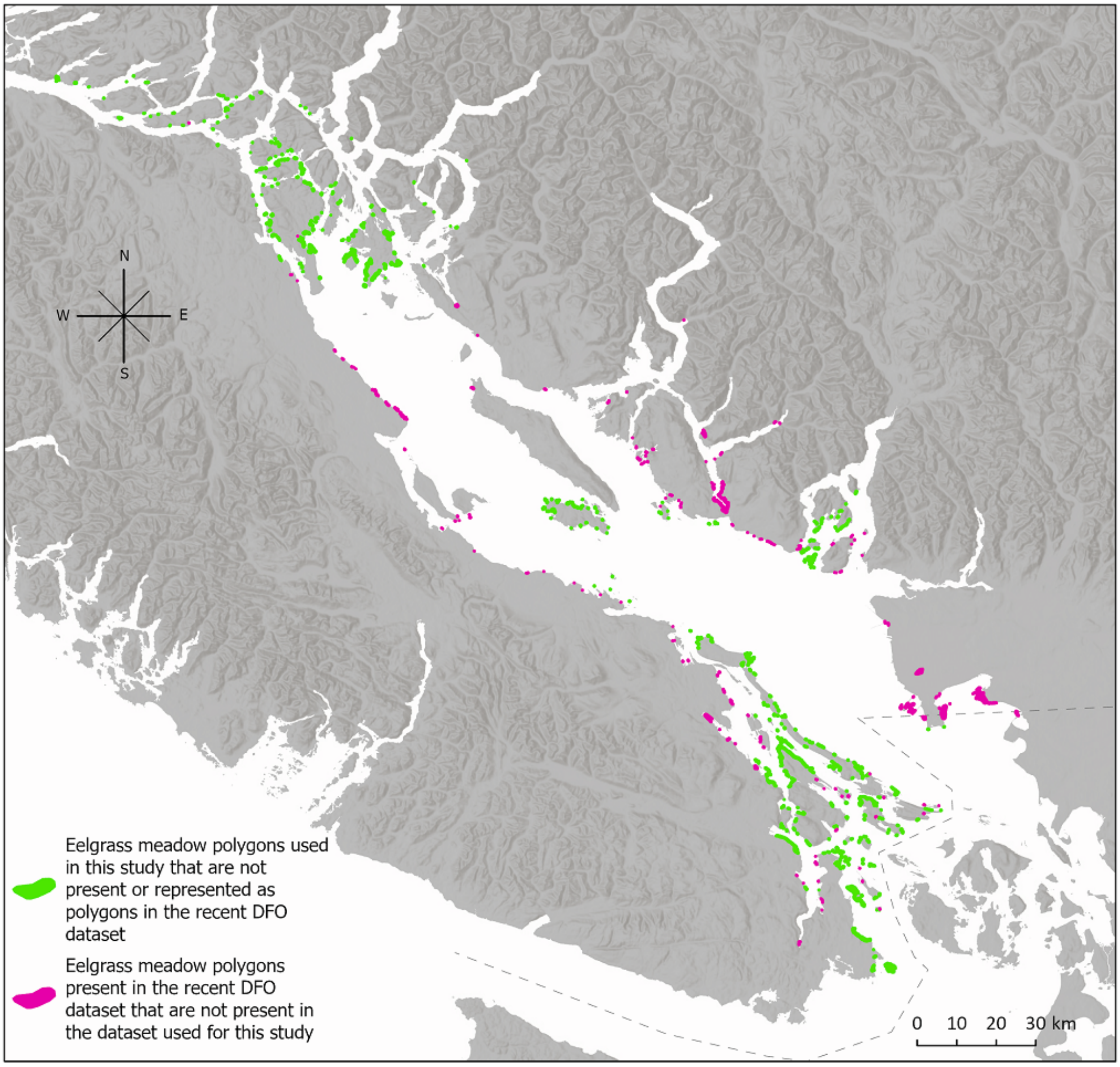

Figure A.1. The areas of difference between the dataset used in this analysis (created in 2018 for Cristiani et al. 2021) and the updated seagrass spatial dataset (Proudfoot 2022). Only areas where datasets do not overlap are shown. Our dataset generally shows more polygons in the Discovery Islands, Lasqueti Island, Howe Sound, and the Gulf Islands, as these meadows were retained as point and line features in the newer dataset and not extended as modeled polygons due to area uncertainty. The outlines of the meadow polygons are exaggerated for visualization purposes.

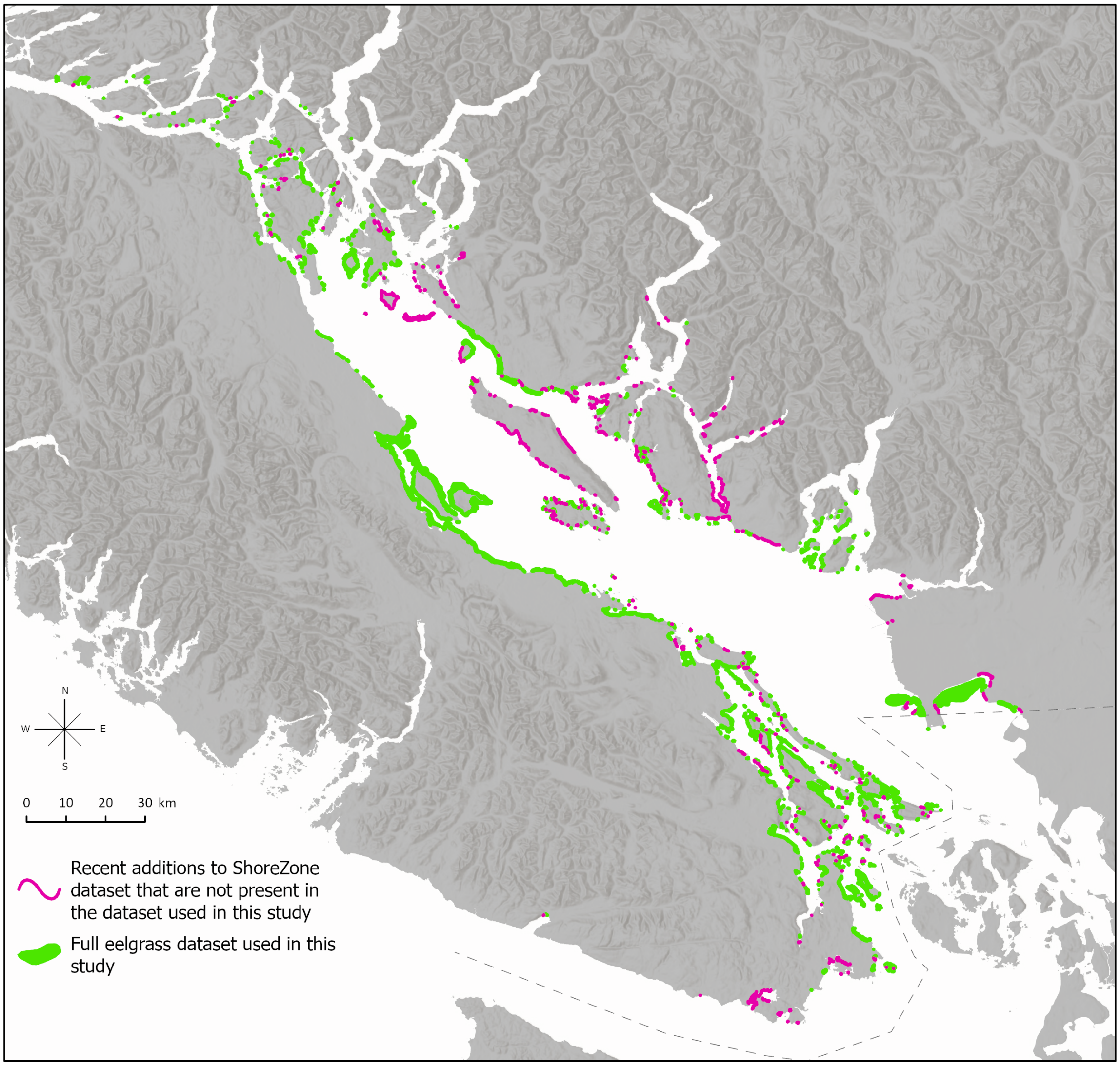

Figure A.2. The recent additions to the ShoreZone eelgrass dataset that are not present in the dataset used in this study. The outlines of the meadow polygons are exaggerated for visualization purposes.

APPENDIX B QUANTIFYING SHORELINE MODIFICATIONS WORKFLOW

Initial set up

1. Download Google Earth Pro (GE):
   - GE is being used because (1) it's free, and (2) it generally has better quality aerial imagery than what is available in ArcGIS.
   - There are some helpful keyboard shortcuts available here, particularly "reset to top-down tilt": https://support.google.com/earth/answer/148115?hl=en
2. Open the following KMZ reference files by double clicking on them. This will launch GE:
   - seagrass_buff_coast.kmz (the 100 meter inland buffers of the seagrass polygons)
   - seagrass_original.kmz (the seagrass polygons)
3. Adjust the color and transparency as desired so that you can see the underlying imagery:
   - Right click on layer > Properties > Style,Color
   - We used a transparency of 50%
4. The layers will open up under "Temporary Places". Right click each one and click "Save to My Places".
   - Now in the future you won't have to add these layers and change the symbology each time. However, this actually saves a new copy in the GE folder structure, but since we are not editing these layers and worrying about where they are saved, this is not an issue.
5. Click on the Time Slider in the toolbar and make sure you are using the most recent imagery.
   - Google Earth may open up with older imagery.
   - However, some of the most recent imagery is low resolution. Older imagery was used where necessary to get a better idea of polygon bounds to draw - especially for rural residential areas.
6. Open the shoreline modification file, which is the one we will be adding new data to:
   - shoreline_mod_TOEDIT.kmz
7. Adjust color and transparency as desired.
8. Right click each layer and "Save to My Places":
   - The working copy of this file is now saved to the GE folder structure and is no longer associated with the file you first clicked on. This is fine for each session since GE saves your work automatically, whereas it does not save automatically if the layer is kept in Temporary Places.

- **At the end of each session you should right click on the layer and "Save Place As". This will save it as a kmz file again, and you can overwrite the original one you first opened.**
- My Places data is saved here in Windows by default: C:/Users//AppData/LocalLow/Google/GoogleEarth/myplaces.kml.

Shoreline modification digitizing

1. Have the seagrass_buff_coast.kmz layer visible (layer name will appear as sg_103_clipcoast).
2. Zoom into a polygon that you will digitize over.
3. Click once on the shoreline_mod_TOEDIT FOLDER in the left panel so that it is highlighted.
4. Click on Add Polygon in the toolbar.
   - A window will popup, keep this open.
5. Trace around the modified area.
   - You can do individual clicks for a vertex or you can hold down for freehand.
   - A right click will delete that last vertex.
   - Houses were not digitized separately, unless the greenspace/treeline between them was larger than ~20m.
   - If two buffered coastline polygons overlap, you do not need to trace the same feature for each one. This will be dealt with later in ArcGIS.
   - The coastline and polygons we digitized do not always line up perfectly with the imagery depending on the time window used as there is some geographic shifting between imagery of different years (variation in georeferencing of imagery).
   - Logging areas were only digitized if the most recent imagery indicated relatively recent logging activity (~ within the past decade).
6. In the pop-up, for Name, enter the sg_103_clipcoast ID number followed by an understroke and then a sequential integer.
   - This is to keep a unique ID for each polygon added.
   - e.g., 401_1 : the clipcoast ID is 401 and this is the first subpolygon drawn
7. In the description box, enter the category of modification:
   - Chosen from a standard list, see Table 2.
   - If relevant, add a subcategory, see Table 2. Separate each description with a semi-colon but no spaces (e.g. industrial;logging).
8. Click OK

9. At the end of the session, right click on the layer and “Save Place As”. This will save it as a kmz file again, and you can overwrite the original one you first opened.