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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8942

British Columbia coastal anchor marks

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2023

ISSN 2816-7155
ISBN 978-0-660-47111-2
Catalogue No. M183-2/8942E-PDF

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Permanent link: https://doi.org/10.4095/331346

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Recommended citation
Douglas, K. and Podhorodeski, A., 2023. British Columbia coastal anchor marks; Geological Survey of Canada, Open File 8942, 13 p. https://doi.org/10.4095/331346

Publications in this series have not been edited; they are released as submitted by the author.

TABLE OF CONTENTS **Page**

Abstract:

The marks left on the seabed by the commercial anchoring process can be seen as linear features in high-resolution multibeam bathymetry data. These features have been digitized to polylines for individual marks and polygons for anchor scour zones for British Columbia's (BC) commercial anchorages. They are made available via the Open Government Portal for use in a Geographical Information System (GIS). This feature dataset is complete for published BC commercial anchorages and the multibeam bathymetry data available up until 2021. It does not represent features produced since the collection of each multibeam bathymetry survey nor any features infilled since. The data are intended to be used for scientific research to better understand the cumulative impacts to the seabed from commercial anchoring at a scale of 1:5000 or greater.

The product is available on the Open Government Portal at: https://doi.org/10.23687/3621caea-e018-0749-f8ab-a002bb6e70f4

Introduction:

The anchoring process by commercial ships, in which an anchor and chain are lowered and sometimes dragged, disturbs the seabed and leaves behind a seabed roughness similar to that seen from iceberg and sea-ice scours (Fader and Miller, 2008). High-resolution multibeam bathymetry (≤ 2 m horizontal resolution) provides good visual imaging of these marks in sediments with low acoustic backscatter (e.g. mud-sand). The marks left behind are typically linear in shape, with or without surrounding abrasion or feathering, and are approximately 5-20 cm in relief difference. Older bathymetric datasets of lower resolution typically only pick up the larger anchor drag marks (Fader and Miller, 2008). At those resolutions, a visibly disturbed, stippled surface often accompanies these large anchor drag marks, which may indicate the presence of smaller unresolved marks.

As temporary anchorages in the Salish Sea become used more frequently, we aim to map the disturbances at BC Coastal anchorages as a baseline to detect change over time and better understand how anchoring impacts different types of seabed. This will lead to a better understanding of cumulative effects and, as a result, better informed selections of anchorage sites.

Using a list of both designated and undesignated anchorage locations, and available Canadian Hydrographic Service high-resolution bathymetry, we digitized polylines over the rasterized bathymetry to represent the anchor-related marks (e.g. Figure 1). Where marks could not be individually delineated, either due to dense seabed disturbance or low survey resolution, we created polygons to indicate zones of marks. These were produced for all formalized anchorage sites up the BC Coast as available from the Pacific Pilotage Authority or found in Port Guides.

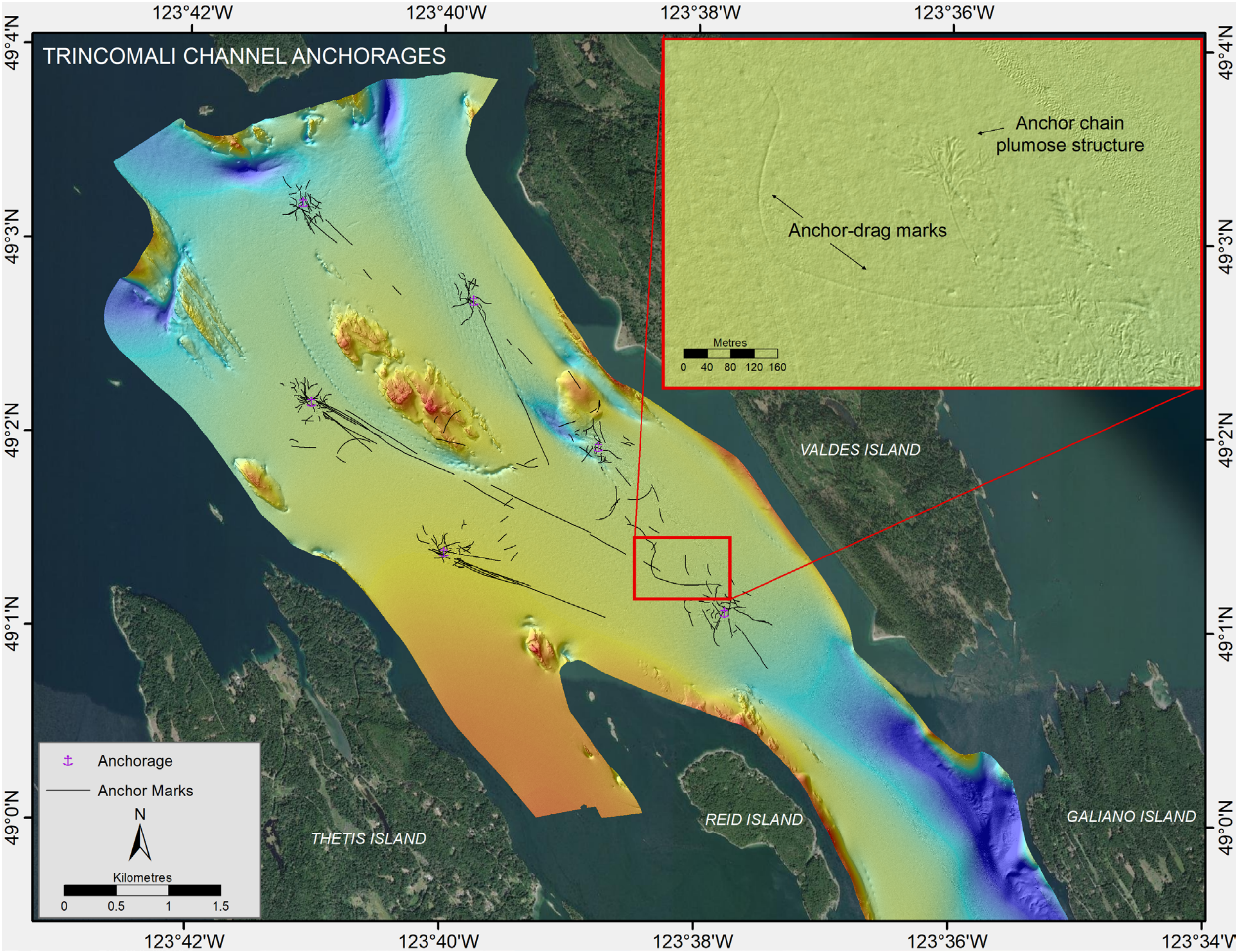

Figure 1: Anchorages and anchor marks in the Southern Gulf Islands, British Columbia. The inset shows a zoomed area where we see both anchor chain "plumose structures" where a feathered appearance is evident and anchor-drag marks in the bathymetry. This figure is produced by Natural Resources Canada and incorporates Canadian Hydrographic Service data, pursuant to CHS MOU# 2021-0505-1260-NRCAN for illustrative, non-navigational purposes only. The incorporation of data sourced from CHS in this product shall not be construed as constituting an endorsement by CHS of this product. Basemap Imagery Source: ESRI World Imagery. Coordinate System: WGS84 UTM 10N.

Methods:

The Canadian Hydrographic Service produces raster grids from bathymetric soundings of individual surveys at the highest resolution possible. From the raw echosounder files, the Geological Survey of Canada also produces backscatter intensity grids. Here, we have digitized 5410 marks from 64 surveys collected between 1997 and 2021. This number of surveys represents those with scours present. Some other surveys do not have resolvable scours, such as older surveys at lower resolution. Anchorages with surveys but no resolvable scours are listed in Table 1.

Table 1. Anchorages with surveys that do not have resolvable anchor-related marks

Latitude	Longitude	Name	CHS Survey Name	Notes
48.33583	-123.36	Constance Bank 1	2005ConstanceBank_5025799	Cannot resolve any scours
48.34383	-123.34467	Constance Bank 2	2005ConstanceBank_5025799	Cannot resolve any scours
48.34833	-123.32617	Constance Bank 3E	2000JuanDeFuca_5025705	Cannot resolve any scours
48.34833	-123.36083	Constance Bank 4	2005ConstanceBank_5025799	Cannot resolve any scours
48.355	-123.34233	Constance Bank 5	2000JuanDeFuca_5025705	Cannot resolve any scours
48.71333	-123.52967	Cowichan Bay E	2005Cowichan_5025881, 2021CowichanBay_9001176	Cannot resolve any scours
54.3405	-130.288	Inner Harbour 3	2005PrinceRupert_5025867	Lots of scours, but not individually resolved
54.32867	-130.31467	Inner Harbour 4	2000PrinceRupert_5025003, 2005PrinceRupert_5025867	Lots of scours, but not individually resolved
54.32317	-130.32883	Inner Harbour 5	2000PrinceRupert_5025003, 2005PrinceRupert_5025867	Lots of scours, but not individually resolved
54.15367	-130.37283	Ridley Island 2	2009MarcusPassage_5027124	Lots of scours, but not individually resolved
54.14667	-130.625	Stephens Island 30	2010TreeKnob_5027553	Lots of scours, but not individually resolved

Echosounder data are collected with 200% coverage from ships or launches and are corrected for tides, sound velocity and navigational errors. Of these 64 datasets, 26 have repeat surveys covering at least 33.33% of the existing survey. An additional 21 datasets have minimal overlap. While relief and slope derivatives from surfaces provide a good visual representation, as seen in Figure 2, backscatter data may also pick up the change in character of the seabed texture as materials with higher backscatter intensity (e.g. coarse sand) may displace above materials with lower backscatter intensity (e.g. mud). Combined, these data provide the basis upon which we digitized the anchor marks. An example of input data is shown in Figure 2.

Individual anchor drag marks were manually digitized as polylines where they could be delineated from one another, primarily using the relief from the multibeam bathymetry. Plumose marks (Fader and Miller, 2008), also known as “broomstick-like” features (Watson et al., 2022), are digitized at the centre line only. These marks, where sediment has been re-suspended and deposited by the anchor chain in a “feather-like” or “broomstick-like” structure tailing the mark, creating an abrasion zone (Watson et al., 2022), are illustrated in Figure 1. They are also marked as “plumose” structures in the comments field of the attribute table, following terminology from Fader and Miller (2008). Anchor marks that cannot be delineated from one another are represented by a polygon surrounding the “anchor mark zone”.

The focused scope of this dataset is limited to formal designated and undesignated anchorages, available from the Pacific Pilotage Authority and select Port Guides (Vancouver Fraser Port

Authority, 2019; Prince Rupert Port Authority, 2022). Anchorage locations and names are not standardized across all documents, and these may vary slightly in the list between sources. Some are charted, and others are not. Anchor marks in other areas are not comprehensively digitized, but the odd anchor mark may appear in additional locations where noticed during this work.

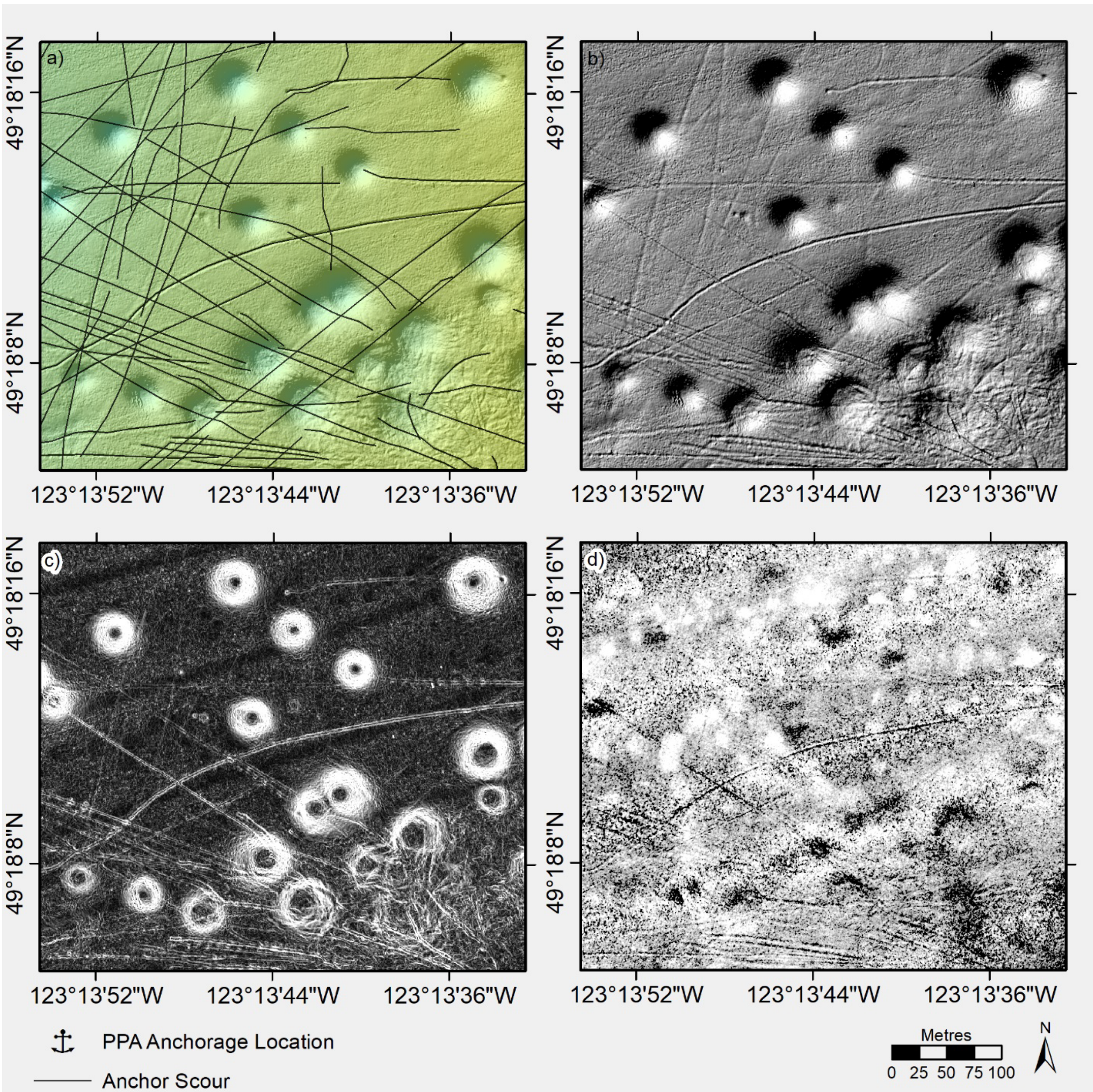

Figure 2. Digitized anchor marks in a section of English Bay and input data used at a scale of 1:5000: a) digitized anchor marks overlaid on bathymetry surface, b) relief, c) slope, and d) backscatter. This figure is produced by Natural Resources Canada and incorporates Canadian Hydrographic Service data, pursuant to CHS MOU# 2021-0505-1260-NRCAN for illustrative, non-navigational purposes only. The incorporation of data sourced from CHS in this product shall not be construed as constituting an endorsement by CHS of this product.

Table 2. Anchorage locations used to search for marks as identified in documents by the Pacific Pilotage Authority (PPA), Prince Rupert Port Authority Port Information Guide (PR), and Vancouver Fraser Port Authority Port Information Guide (PV). Length overall (LOA) refers to the maximum length of the vessel measured. Swing radius is the maximum distance from the anchor to the outermost point of the vessel forming the circular area in which the vessel may rotate around the anchorage. Note that these are not necessarily up to date designated anchorages or currently charted. This table does not meet the requirements of the Navigation Safety Regulations, 2020 under the Canada Shipping Act, 2001. Charts and publications issued by or on the authority of CHS, corrected and up-to-date, must be used to meet the requirements of those regulations.

Anchorage name	Source	Latitude	Longitude	Depth (m)	LOA (m)	Swing Radius (m)
Captain's Pass Anchorage 1	PPA	48.82694	-123.43722	18	200	463.3
Captain's Pass Anchorage 2	PPA	48.80861	-123.40444	38	200	463.3
Constance Bank 1	PPA	48.33583	-123.36000	23	400	750.0
Constance Bank 2	PPA	48.34383	-123.34467	50	260	650.0
Constance Bank 3e	PPA	48.34833	-123.32617	50	340	750.0
Constance Bank 4	PPA	48.34833	-123.36083	20	310	570.0
Constance Bank 5	PPA	48.35500	-123.34233	40	230	570.0
Cowichan Bay Anchorage A	PPA	48.74933	-123.59767	55	240	648.6
Cowichan Bay Anchorage B	PPA	48.73367	-123.57250	55	185	481.8
Cowichan Bay Anchorage C	PPA	48.73000	-123.55667	60	310	667.1
Cowichan Bay Anchorage D	PPA	48.72117	-123.54333	65	310	648.6
Cowichan Bay Anchorage E	PPA	48.71333	-123.52967	70	200	574.5
Cowichan Bay Anchorage F	PPA	48.70133	-123.53233	60	260	611.6
Digby Island 11	PR	54.24500	-130.44500	53	270	600.0
Digby Island 12	PR	54.25200	-130.46283	54	270	600.0
Digby Island 13	PR	54.26133	-130.47950	43	270	600.0
Digby Island 14	PR	54.27333	-130.49617	30	270	600.0
English Bay Anchorage 1	PPA	49.29917	-123.23861	48	400	426.2
English Bay Anchorage 10	PPA	49.30528	-123.20083	24	400	426.2
English Bay Anchorage 11	PPA	49.29833	-123.19389	19	260	426.2
English Bay Anchorage 12	PPA	49.29139	-123.18722	14	230	426.2
English Bay Anchorage 13	PPA	49.28466	-123.18033	10	190	426.2
English Bay Anchorage 14	PPA	49.30700	-123.18866	21	400	426.2
English Bay Anchorage 15	PPA	49.30033	-123.18133	17	260	426.2
English Bay Anchorage 16	PPA	49.33250	-123.21883	20	260	426.2
English Bay Anchorage 17	PPA	49.33216	-123.23166	32	260	426.2
English Bay Anchorage 18	PPA	49.33200	-123.24416	32	260	426.2
English Bay Anchorage 2	PPA	49.29250	-123.23133	14	260	426.2
English Bay Anchorage 3	PPA	49.30111	-123.22583	37	400	426.2
English Bay Anchorage 4	PPA	49.29416	-123.21966	28	260	426.2
English Bay Anchorage 5	PPA	49.28750	-123.21166	12	230	426.2
English Bay Anchorage 6	PPA	49.30333	-123.21333	30	230	426.2

English Bay Anchorage 7	PPA	49.29633	-123.20700	23	260	426.2
English Bay Anchorage 8	PPA	49.28950	-123.19966	16	230	426.2
English Bay Anchorage 9	PPA	49.28216	-123.19250	10	190	426.2
English Bay Anchorage U	PPA	49.29583	-123.25366	28	400	556.0
English Bay Anchorage Z	PPA	49.28583	-123.16666	9	100	240.9
Houston Pass Anchorage 1	PPA	48.95633	-123.61783	24	200	463.3
Houston Pass Anchorage 2	PPA	48.94466	-123.61800	31	183	370.6
Houston Pass Anchorage 3	PPA	48.93483	-123.61700	28	200	463.3
Indian Arm Anchorage K	PPA	49.30083	-122.94472	15	185	370.6
Indian Arm Anchorage L	PPA	49.29972	-122.93500	15	250	407.7
Indian Arm Anchorage M	PPA	49.30639	-122.93800	18	250	407.7
Indian Arm Anchorage N	PPA	49.29389	-122.96750	15	185	315.0
Indian Arm Anchorage O	PPA	49.32866	-122.93333	47	110	203.9
Inner Harbour 2	PR	54.35183	-130.27567	48	225	550.0
Inner Harbour 3	PR	54.34050	-130.28800	39	225	550.0
Inner Harbour 4	PR	54.32867	-130.31467	39	225	550.0
Inner Harbour 5	PR	54.32317	-130.32883	39	225	550.0
Inner Harbour 6	PR	54.31733	-130.34250	37	250	600.0
Inner Harbour 7	PR	54.31333	-130.35817	55	250	600.0
Kulleet Bay Anchorage 1 (Ls8)	PPA	49.02300	-123.77233	37	180	463.3
Kulleet Bay Anchorage 2 (Ls9)	PPA	49.01717	-123.76050	55	180	463.3
Ladysmith Anchorage A	PPA	48.98250	-123.78833	18	200	463.3
Ladysmith Anchorage B	PPA	48.97630	-123.77490	35	225	463.3
Ladysmith Anchorage C	PPA	48.97300	-123.75570	60	225	556.0
Ladysmith Anchorage D	PPA	48.96450	-123.74110	50	225	556.0
Ladysmith Anchorage E	PPA	48.95420	-123.73000	50	225	556.0
Ladysmith Anchorage F	PPA	48.94380	-123.71880	60	225	556.0
Lucy Islands 18	PR	54.27667	-130.59533	60	325	750.0
Lucy Islands 19	PR	54.26633	-130.60867	60	325	700.0
Lucy Islands 20	PR	54.25717	-130.62667	52	325	700.0
Lucy Islands 21	PR	54.25650	-130.64917	54	325	700.0
Lucy Islands 22	PR	54.26850	-130.65167	42	325	700.0
Lucy Islands 23	PR	54.28000	-130.64533	30	325	700.0
Nanaimo Anchorage 1	PPA	49.14600	-123.84800	55	225	463.3
Nanaimo Anchorage 2	PPA	49.17400	-123.90133	50	300	556.0
Nanaimo Anchorage 3	PPA	49.18333	-123.89967	45	225	463.3
Nanaimo Anchorage 4	PPA	49.19283	-123.90150	80	300	556.0
Nanaimo Anchorage 5	PPA	49.20150	-123.90733	63	225	463.3
Nanaimo Anchorage 6	PPA	49.20533	-123.91950	35	225	463.3
Plumper Sound Anchorage A	PPA	48.80083	-123.23533	35	200	407.7

Plumper Sound Anchorage B	PPA	48.79267	-123.22883	20	26	426.2
Plumper Sound Anchorage C	PPA	48.78367	-123.22450	18	230	407.7
Plumper Sound Anchorage D	PPA	48.77250	-123.22117	15	310	648.6
Plumper Sound Anchorage X	PPA	48.76350	-123.20933	40	230	463.3
Qlawdzeet	PPA	54.21147	-130.77312	unknown	unknown	unknown
Rachel Islands 15	PR	54.19583	-130.51667	41	270	650.0
Rachel Islands 16	PR	54.20700	-130.52083	39	270	650.0
Rachel Islands 17	PR	54.21133	-130.53967	42	270	650.0
Ridley Island 1 and 8	PPA and PR	54.19717	-130.36833	38	270	650.0
Ridley Island 10	PR	54.13117	-130.35250	66	350	725.0
Ridley Island 2 and 9	PPA and PR	54.15367	-130.37283	66	350	725.0
Roberts Bank Anchorage R	PPA	49.00000	-123.20000	40	320	463.3
Royal Roads Anchorage A	PPA	48.39600	-123.45166	unknown	150	unknown
Royal Roads Anchorage B	PPA	48.40200	-123.46150	unknown	150	unknown
Royal Roads Anchorage C	PPA	48.40350	-123.44600	unknown	150	unknown
Royal Roads Anchorage D	PPA	48.40616	-123.43283	unknown	150	unknown
Royal Roads Anchorage E	PPA	48.41183	-123.44483	unknown	150	unknown
Royal Roads Anchorage F	PPA	48.41466	-123.43466	unknown	150	unknown
Sandheads S	PV	49.12917	-123.30806	70	320	463.3
Stephens Island 24	PR	54.12250	-130.55250	60	350	725.0
Stephens Island 25	PR	54.09600	-130.56533	53	325	700.0
Stephens Island 26	PR	54.10600	-130.57633	50	270	600.0
Stephens Island 27	PR	54.11267	-130.59217	38	325	650.0
Stephens Island 28	PR	54.12083	-130.60500	54	270	600.0
Stephens Island 29	PR	54.13167	-130.61217	66	350	675.0
Stephens Island 30	PR	54.14667	-130.62500	80	350	675.0
Stephens Island 31	PR	54.16000	-130.64000	72	350	675.0
Trincomali Anchorage 1	PPA	49.01816	-123.62950	43	310	556.0
Trincomali Anchorage 2	PPA	49.02316	-123.66633	36	310	556.0
Trincomali Anchorage 3	PPA	49.03233	-123.64616	38	265	556.0
Trincomali Anchorage 4	PPA	49.03600	-123.68383	43	310	556.0
Trincomali Anchorage 5	PPA	49.04483	-123.66266	41	265	556.0
Trincomali Anchorage 6	PPA	49.05316	-123.68516	55	310	556.0
Trincomali Anchorage 7	PPA	49.08866	-123.69633	57	260	556.0
Trincomali Anchorage 8	PPA	49.10139	-123.71278	58	260	556.0
Trincomali Anchorage 9	PPA	49.11533	-123.72833	55	260	556.0
Vancouver Harbour Anchorage A	PPA	49.30283	-123.09050	24	300	296.5
Vancouver Harbour Anchorage B	PPA	49.30166	-123.07950	19	260	259.4

Vancouver Harbour Anchorage C	PPA	49.30030	-123.06950	16	260	259.4
Vancouver Harbour Anchorage D	PPA	49.29416	-123.08416	30	300	296.5
Vancouver Harbour Anchorage E	PPA	49.29528	-123.06472	16	230	203.9
Vancouver Harbour Anchorage W	PPA	49.29533	-123.09800	32	300	296.5
Vancouver Harbour Anchorage X	PPA	49.30466	-123.10133	16	185	185.3
Vancouver Harbour Anchorage Y	PPA	49.30033	-123.05966	15	260	259.4

Attributes include the location, name of the survey where the mark is identified and its year, comments about the type of mark observed and uncertainty where applicable. When marks have repeat multibeam coverage, the survey assessed corresponds with the earliest year in which the mark can be observed.

Quality control includes visually assessing the bathymetric datasets for errors in the data that can be mistaken for anchor marks such as: survey limit seams, artefacts that run perpendicular to the survey collection, or positive relief linear features such as disposal at sea sites. Some lines appear too wide, in the range of 4 m to 10 m width, to likely be an individual anchor mark compared to the majority of surrounding ones. However, these are collocated with the anchorages. Rogers and Garrison (2001) and Boudouresque et al., (2009) show that anchor scour tracks can be several metres in width, although none were identified in their studies to be this wide. These are included and identified in the comments field, and uncertainty exists as to whether they are distinct anchor marks. Another possibility is trawl marks from fishing (Broad et al., 2020).

Lines are quality controlled at a 1:5000 scale against their source bathymetry, establishing the minimum intended scale for use. Sometimes it is apparent that lines connect through surveys or pockmarks, but unless there is continuous marking, we have left these as separate features in most cases.

Discussion

Fader and Miller (2008) assessed the surficial geology of Halifax Harbour and described in detail the anchor-related marks seen there. The harbour at the time had only coarse-resolution bathymetry available, and side-scan sonar was used in lieu. Fader and Miller (2008) classified anchor marks into three major types: anchor pits, anchor-drag marks, and anchor-chain marks. We have combined anchor-drag marks and anchor-chain marks into one class, as the level of disturbance often does not allow for distinct classification. Anchor drag marks occur after the anchor has been deployed and is subsequently dragged into place, resulting in a linear or curvilinear feature on the seabed (Fader and Miller, 2008). Anchor-related marks average 186 m long in our dataset but can be quite a bit longer, exceeding 2.2 km, or as short as 2.2 m.

There is an observed strong roughness to the seafloor in Halifax Harbour, similar to that seen from sea ice and iceberg scouring (Fader and Miller, 2008). The term “anchorturbation” is used by Fader et al. (1991, p.18) and Fader and Miller (2008) to describe this roughness and impact to the seabed, as mixing and turbation occur to the upper unit. English Bay appears similar to Halifax Harbour in places where the seabed is heavily scoured, with 2452 digitized anchor drag marks in our dataset over ~ 32 square kilometres (Figure 3). As this is the site of Port of Vancouver’s main anchorages and the Bay has been used for anchoring for many hundreds of years, this level of disturbance is not unexpected. In contrast, the Gulf Island anchorages are temporary anchorages and have been used commercially only more recently, starting around the 1970s (Cowichan Bay Ship Watch Society, 2022). Here, we see clusters of anchor drag marks in the soft sediments radiating from the anchorage centre points (Figure 1).

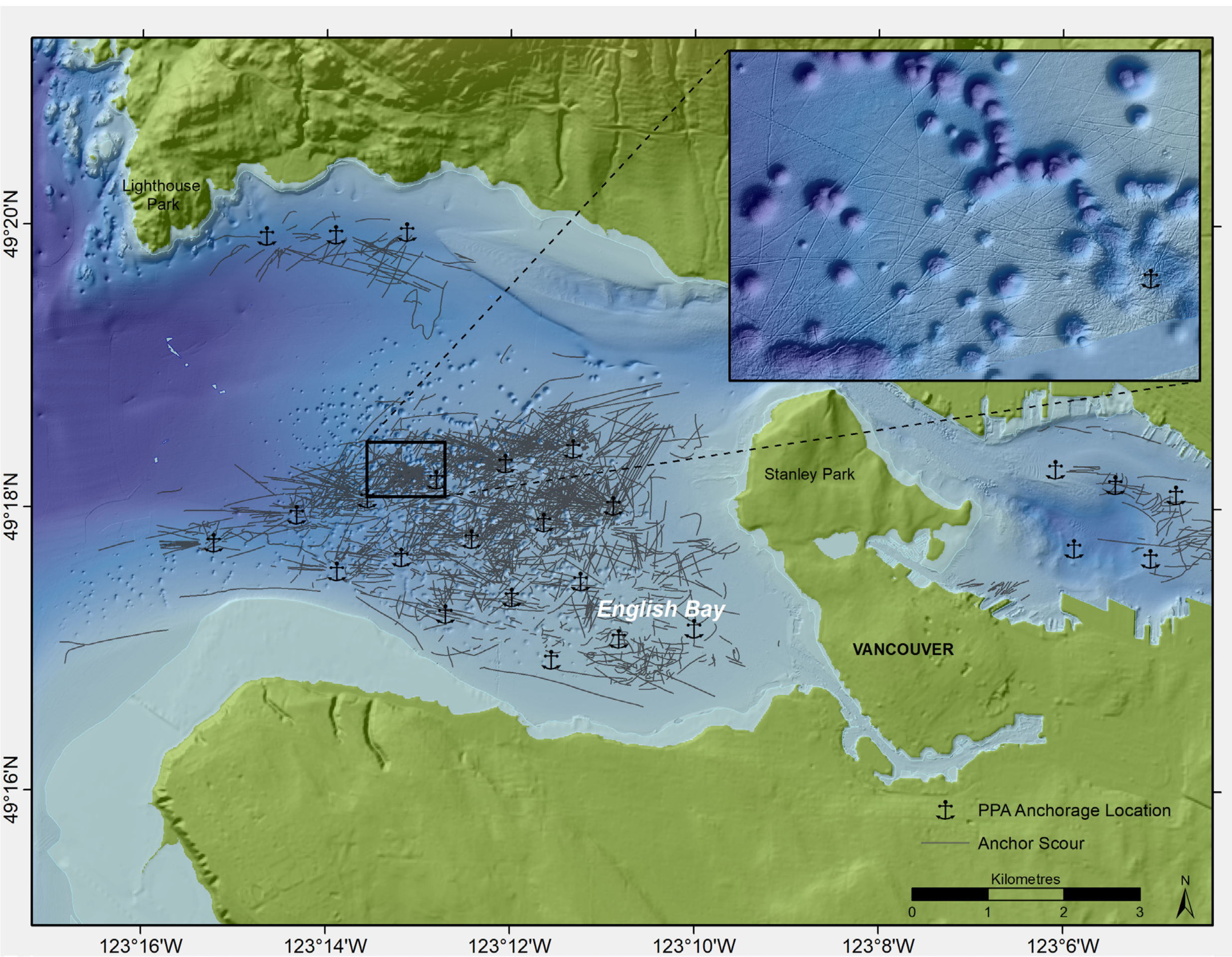

Figure 3. English Bay heavily scoured with marks concentrated near designated anchorages. This figure is produced by Natural Resources Canada and incorporates Canadian Hydrographic Service data, pursuant to CHS MOU# 2021-0505-1260-NRCAN for illustrative, non-navigational purposes only. The

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The dataset provided here is a starting point to investigate change over time and better understand anthropogenic impacts to the seabed, particularly when combined with grainsize data to look at the impact in varying seabed types. One known limitation of the dataset is the availability of high-resolution multibeam bathymetry data at all anchorages, as only some have been covered by modern surveys. Future improvements could be made using higher resolution data such as that obtained with an autonomous underwater vehicle (AUV). Figure 4 shows this potential with some anchor-related marks imaged in Bedford Basin using the Gavia AUV by the GSC Atlantic Division. Repeat launch-based surveys were collected in 2022 by the Canadian Hydrographic Service at some of the Gulf Island anchorages. These will allow for updates and investigation of change detection.

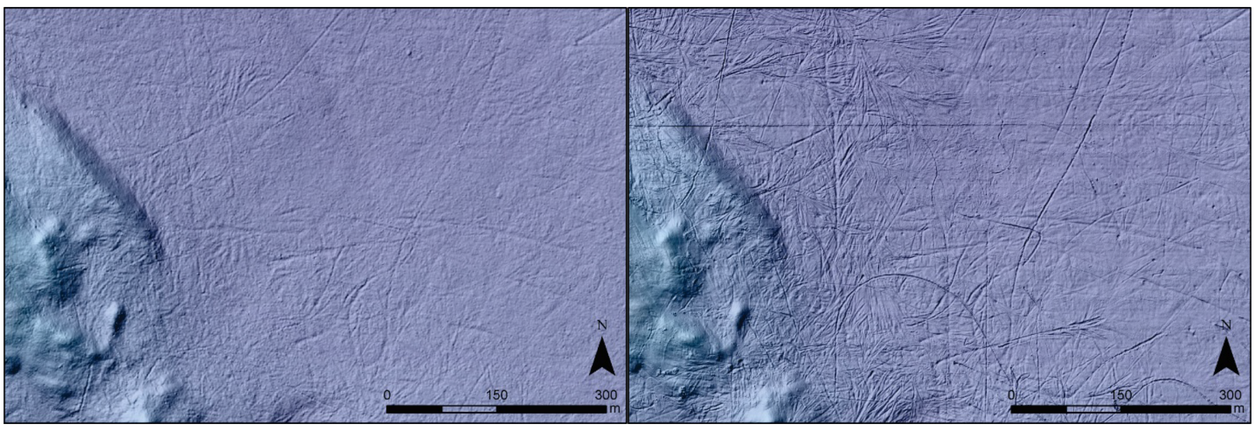

Figure 4. A) Ship-based multibeam echosounder data and B) 50 cm resolution multibeam bathymetry data collected in Bedford Basin in 2022 with a Gavia autonomous underwater vehicle by the Marine Technical support team of Geological Survey of Canada Atlantic Division.

Conclusion

5410 anchor-related marks are digitized in this dataset, focusing on a formalized 116 commercial anchorages in 2021 on the BC Coast. We aimed to map these marks to create a baseline to detect change over time and to better understand how anchoring impacts the seabed. Coupled with seabed characterization information, this will lead to an improved understanding of cumulative effects and, as a result, better informed selections of anchorage sites.

Acknowledgements:

We thank the Salish Sea and BC North Coast Nations whose traditional territory on which we conducted these surveys for their participation and support in planning and carrying out these expeditions. We thank the Canadian Hydrographic Service for our continued partnership in sharing data and fieldwork initiatives. We thank our Transport Canada colleagues for their help in locating anchorages and attribute information. We thank our Fisheries and Oceans Science colleagues for our continued collaborations in understanding the cumulative effects of activities with respect to the seabed. In particular, we thank Fiona Francis and Cathryn Murray for their help with the anchorages list. We thank Kyle Yun, Julia Onderwater, and Felix Parkinson for their participation in first-pass digitization.

This work was completed under Natural Resources Canada's Marine Geoscience for Marine Spatial Planning Program.

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