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Geographically Widespread Drift Log Destruction of Intertidal Communities on Rocky Shores of Western Canada

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ABSTRACT

The destructive effect of drift logs on several rocky shore intertidal communities first identified in 1971 by Dayton in the north-east Pacific Ocean has received little further attention despite its ecological and conservational significance. Using satellite imagery from 202 sites along western Canada's coastline, we observed widespread log accumulation at the tideline, with an average of 311 logs/km (max: 2718) on sandy shores and 194 logs/km (max: 1238) on rocky shores, independent of proximity to human settlement and industrial activity. Historical analyses of archival photographs reveal a 520% increase in drift log abundance since the late 19th century and an estimated 800% (range 0%–4000%) increase since pre-European settlement, trends that correlate with the expansion of forestry operations over the past century. Populations of key intertidal foundation species, *Balanus glandula*, *Semibalanus cariosus,* which support a taxonomically diverse interstitial community, were 20%–80% lower on log-exposed surfaces compared to immediately adjacent log-protected microhabitats such as crevices, with the most pronounced reductions occurring in middle and upper intertidal zones. During high tides and storm conditions, over 90% of the drift logs stranded at the high tideline can be re-mobilized and transported to other shores, intensifying their abrasive effects on the intertidal habitats. While future higher resolution remote sensing will refine assessments of drift log impacts, our current findings indicate that ongoing log-induced abrasion has significantly degraded intertidal communities across most rocky shores in western Canada. This degradation likely has cascading negative effects on both aquatic and terrestrial species that depend on these habitats for foraging.

1 | Introduction

The narrow intertidal zone of temperate rocky shores is dominated by key foundation species, primarily barnacles (Cirripedia) and mussels (Mytilidae), along with a diverse array of interstitial organisms (Lewis 1964; Connell 1961, 1972; Kronberg 1988; Thompson et al. 1996; Hesketh and Harley 2023; Cameron et al. 2024). The communities exert ecological influence beyond the intertidal zone, contributing to offshore plankton populations through larval production (Connolly and Roughgarden 1999; Leslie et al. 2005) and serving as a food source for terrestrial species such as shorebirds (Campbell et al. 1990). In recent years, however, intertidal ecosystems in the north-eastern Pacific have suffered significant losses due to marine heat waves, which have caused mass die-offs of barnacles and mussels (Hesketh and Harley 2023;

Article Impact Statement: Major reduction in drift logs in the north-east Pacific is essential to reverse the ongoing destruction of rocky shore intertidal communities.

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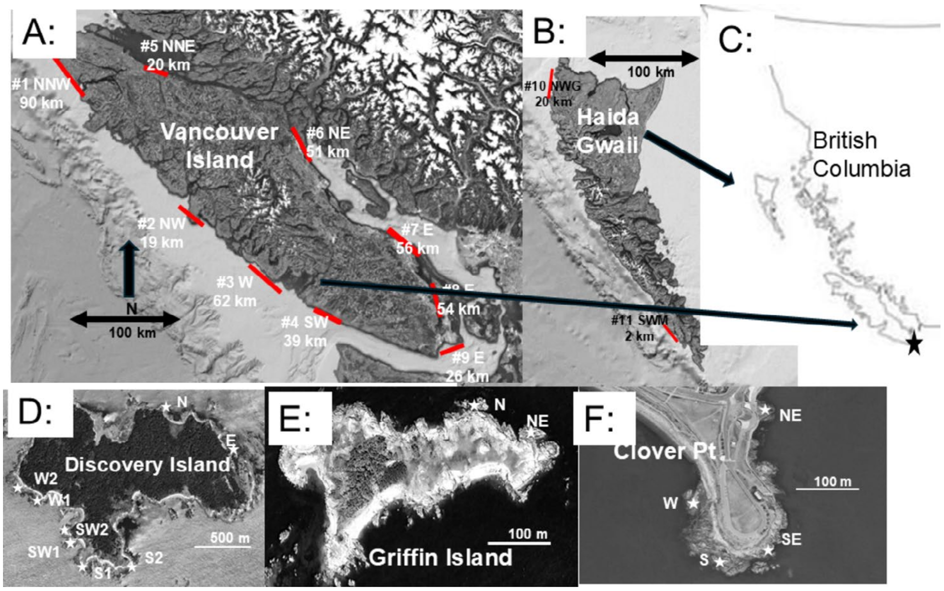

FIGURE 1 | Study sites. (A) Vancouver Island shows 9 regions for log counts. (B) Haida Gwaii showing site on NW Graham Island and SW Moresby Island. The small distance of the SW Moresby Island site was due to the low resolution of the satellite images. (C) Outline map of British Columbia with general positions of study sites, the star showing south Vancouver Island. (D) Discovery Island is on the SE corner of Vancouver Island. (E) Griffin Island is immediately north of Discovery Island. (F) Clover Pt is on the south side of Victoria.

White et al. 2023), likely impacting species that rely on these habitats for foraging. Additionally, other anthropogenic factors, particularly the presence of drift logs, may be further compromising the integrity of the intertidal communities and their associated food webs.

Drift logs, or free-floating logs, are present in marine waters worldwide but are especially common off the heavily forested coasts of western North America (reviews in Thiel and Gutow 2005; Murphy et al. 2021). These logs eventually wash ashore and accumulate along the high tide line. In a pioneering study, Dayton (1971) investigated the ecological effects of drift logs by embedding nails in intertidal rock substrates as proxies for sedentary shelled invertebrates. He found that within a year, most nails had been broken off due to abrasion from drifting logs. Surveys at six locations in Washington State revealed that barnacle densities were markedly lower where logs were abundant at the tideline, whereas barnacle cover was much higher in areas with few logs, such as exposed outer shores facing the open Pacific. However, the broader geographical significance of these findings remains uncertain. If drift log accumulation is highly localized, primarily near logging operations and human activity, as noted by Dayton (1971), the impact on intertidal communities might be limited. Conversely, if logs are more widely distributed, their influence on rocky intertidal ecosystems could be more extensive, potentially disrupting species that depend on these habitats. Despite its potential significance, the geographical distribution and abundance of drift logs on rocky shores remain largely unquantified.

Building on Dayton's (1971) observations, we conducted field studies on the west coast of Canada, documenting the effects of log abrasion on rocky shores. Combining our observations of log movement during winter storms, we used drift log abundance at the tideline as an indicator of the extent of physical disturbance to sedentary intertidal organisms. Through field surveys, we quantified log abundance and estimated their seasonal and yearly movement on and off the shores. Additionally, we analyzed high-resolution satellite imagery to assess drift log presence across 202 shores in western Canada and examined archival photographs from the late 19th and early 20th centuries to establish historical log accumulation patterns. Our fieldwork also allowed us to distinguish between logs originating from natural versus anthropogenic sources. To assess the direct impact of log movement on intertidal invertebrate communities, we measured barnacle size and abundance in areas of low, middle, and upper tidal zones, predicting that barnacle coverage would be lower in areas more exposed to log abrasion. Our findings indicate that intertidal communities along the west coast of Canada have suffered significant degradation due to the persistent movement of logs.

2 | Methods

Using satellite images from Google Earth, we analyzed log accumulation across 11 geographically distinct regions around Vancouver Island and the west coast of Haida Gwaii covering 439 km of shoreline and 202 localities (Figure 1; Table S1). For each region, we counted the number of drift logs that occurred along the entire length of shore surveyed. For each unique shoreline, from 10 to 40 historical images were examined, with up to three of the clearest images selected for log counts. These were further categorized for visibility from poorest to best (1–5). We subsequently excluded lower-resolution images (categories 1 and 2), as individual drift logs were often not distinguishable. For localities with more than one high-visibility image ($N = 48$), we made counts on each and averaged the log counts. Since drift logs are often fragmented during storms, we focused our counts on logs greater than 2 m in length. In some images, the drift logs at the upper part of the drift line were obscured by tree shadows due to the photographic angle of the satellite image and therefore could not be counted. Additionally, our field surveys indicated that drift logs could be multi-layered but only the upper layers were visible in the satellite images, meaning our total log counts are conservative. For each shore, we also recorded general features such as fetch (the distance of open water perpendicular to the shoreline) and compass orientation (N, W, S, E). Shoreline substrate was classified on a scale from zero, representing sand or gravel beaches, through to five, representing a bedrock shore.

Using the total shore length of each region, we calculated logs per kilometer and extrapolated these numbers to estimate the total number of logs across larger geographical areas. We initially estimated the perimeter of Vancouver Island assuming a simplified ellipse outline using the path tool in Google Earth Pro. This gave a conservative estimate of 1850 km. Secondly, we used online sources (Vancouverisland.travel) that include the full perimeter including inlets, and this yields an estimate of 3440 km. We use the former estimate as this gives a much more conservative estimate of total logs on the shorelines. For Haida Gwaii, we only counted logs on sand and gravel beaches (substrates 0 & 1) on the remote and largely undisturbed west side of the islands to compare with similar beaches on the outer, relatively unmodified shores of Vancouver Island.

We used satellite images (2022) from nine localities on southern Vancouver Island (Figure 1) to quantify the number of logs. Logs were classified as "natural" if they had root systems (Figure S1A) and were assumed to result from landslides, bank erosion, and subsequent downstream movement to marine waters. Logs were considered "sawcut" when they had cut ends and lacked root systems (Figure S1A), indicating a human origin. Logs were classified as "ambiguous" when both ends of the log were either broken or heavily eroded, with no evidence of root systems or cut ends. We initially found that about 5% of the logs had root systems. However, to provide a direct measure, we quantified the sizes of drift logs from field surveys in October and November 2023 at 22 localities in southern Vancouver Island. We measured the length and width of 606 logs and log fragments, excluding the smallest fragments (less than 1 m in length and less than 0.2 m in width; the lower size threshold was arbitrarily chosen). This left us with a sample of 497 logs and log fragments (hereafter referred to as logs).

For historical analysis of log numbers, we used photographs from the Royal British Columbia Museum's digital archives dating from the late 19th and early 20th century. We identified 26 localities from various regions of coastal British Columbia that had images with sufficient resolution to enumerate drift logs. One of the 26 images was an 1864 Emily Carr painting of a village site (Ouchucklesit). These archival photos were then compared with recent Google Earth images. Using visual landmarks in the archival photos, we cross-referenced the localities to Google Earth Pro and measured the shoreline length (m). We then obtained log counts for the archival photos and their current counts from the Google Earth image. We measured the length (m) of the visible beach in the archival photos and counted the number of logs. We classified logs as "natural", "ambiguous", or "sawcut", allowing for a comparison between the two time periods.

Log movement was assessed using three methods. (1) Incidental field observations during winter storms were made over multiple decades (1977 through 2024) in southern Vancouver Island and Haida Gwaii. (2) In October and November 2023, 22 localities in southern British Columbia were surveyed, during which 49 logs (average length = 6.0 m, range 1.1–11.9 m) at the drift-line were marked with a small metal tag nailed to the end of the log. Each log was photographed to ensure accurate positioning for later comparison. In late November and early December 2023, the localities were re-surveyed. If a marked log was not in the same position as in the original photograph, the shore was searched and if the log was found, the distance from its original position was measured (m). (3) Lastly, using satellite images, we also compared numbers (2016, 2022) for each of 84 localities identifying the gains or losses of yearly counts. We excluded 11 of these localities which had less than a 5-log difference between time periods.

Data on barnacle size and abundance were obtained during low spring tides in June and July 2024 from southern Vancouver Island. Blue mussel (*Mytilus* spp.) abundance was not assessed, as these were rare on the sheltered and semi-exposed shores of our study area. Surveys were conducted at 14 localities, including eight at Discovery Island (Figure 1D), two at Griffin Island (Figure 1E), and four at Clover Point (Figure 1F). At each locality, we classified the shore into three zones between upper and lower tide positions. Within each zone, three microsites were selected (typically spanning a total distance of 10 m) containing barnacles both inside and immediately outside of crevices (within 10 cm). Crevices measured approximately 2–5 cm in width and depth, with lengths generally exceeding 10 cm. These small crevices were chosen because drift logs were unable to impact barnacles within them, whereas barnacles on adjacent exposed surfaces were susceptible to abrasion. The proximity of the paired comparisons inside and outside of the crevice reduced confounding effects such as differential desiccation and sun exposure. Barnacle abrasion can also result from predation by the large Purple Sea Star (*Pisaster ochraceous*), particularly at low tidal positions, making it difficult to distinguish from log abrasion (Dayton 1971). However, in our study sites, only a single *Pisaster* was observed, and no abraded areas were detected in crevices or on the undersides of boulders that were vulnerable to starfish predation but protected from log impact. Additionally, boulder movement during storms can cause abrasion (Sousa 1979). Boulders were uncommon at our field sites, but we recorded these when present.

Multiple photos were taken (Canon SX740 HS) at 65 microsites using a mm ruler for scale from which barnacle width was extracted and density calculated. Metrics for the barnacles were analyzed with ImageJ software. A virtual grid with over 100 squares (each measuring 36 cm^2) was overlaid on each image. Ten quadrats were randomly selected using a number generator, five inside and five outside the crevice. Barnacles within these quadrats were visually categorized into one of four size categories (<2 mm, 2–9 mm, 9–16 mm, ≥ 16 mm) and individuals in each category counted. For analyses, we used only two categories (<9 mm and ≥ 9 mm). Three dominant barnacle taxa were identified: the small-shelled *Chthalamus dalli*, typically found in upper littoral zones, and the larger *Balanus glandula* and *Semibalanus cariosus*, which inhabit middle and lower littoral zones.

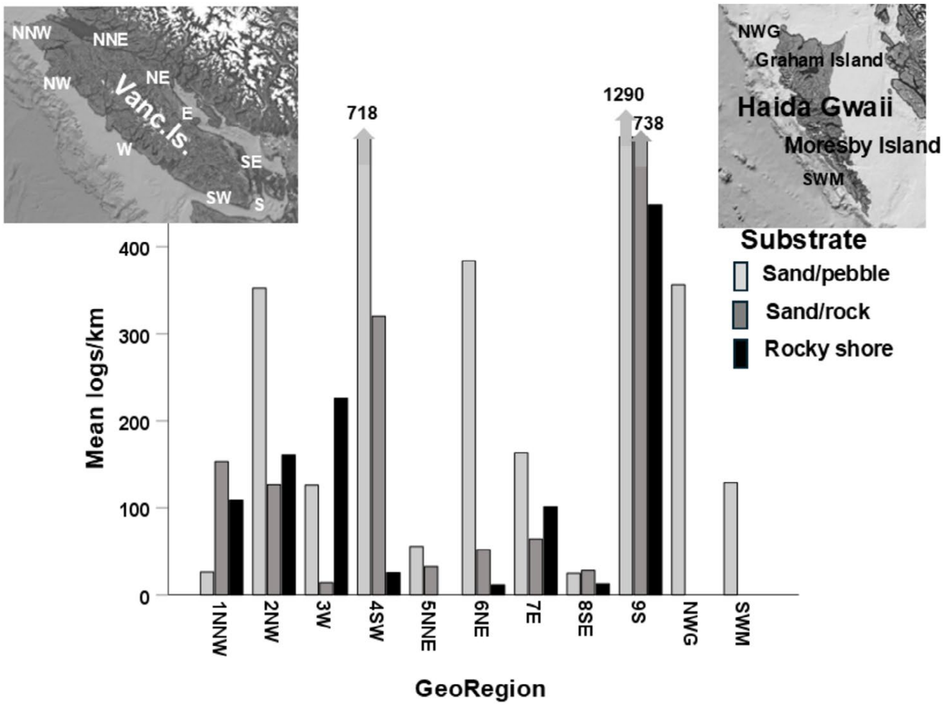

FIGURE 2 | Density (#/km) of drift logs for different shore substrates in coastal British Columbia. Numbers above individual bars indicate total logs for that Georegion. ANOVA for Vancouver Island using ln (logs/km): GeoRegion: $F_{8122} = 14.4$, $p < 0.001$; Fetch: $F_{1121} = 26.4$, $p < 0.001$; Substrate: $F_{2121} = 9.8$, $p < 0.001$. See Figure 1 for GeoRegion.

At each locality, patches of abraded barnacles were identified by the presence of scars, the calcareous base of the barnacle cemented to the substrate (see Figure S1B,C,D). Up to six microsites per locality, each containing both abraded and adjacent unabraded areas (ranging from 1 to 2.25 m^2) were photographed for analysis. A virtual grid of at least 100 quadrats (each measuring 36 cm^2) was overlaid on each image, and 10 quadrats were randomly selected for measurement. Within these quadrats, the area of barnacle scars was quantified. This procedure was replicated across 10 localities.

To analyze our data, we used Analyses of Variance (ANOVA) with SPSS (version 28) to compare (1) the mean number of logs per kilometer among geographic localities, (2) mean abundance and density of large barnacles across the littoral zone, and (3) mean number of barnacle scars across different rugosity categories. The categories for rugosity were assigned through visual observation and represent increments, with the lowest rugosity (1) having 100% exposure to log abrasion and with the most rugose (5) having less than 20% exposure to log abrasion (see Figure 9).

3 | Results

Satellite imagery of the east and west coasts of Vancouver Island and the west coast of Haida Gwaii revealed that logs were present along the drift line on the majority of studied shores. Across the nine regions surveyed around Vancouver Island, the average log density was 243 logs per km, with the highest concentration (1290 logs/km) occurring on southern shores ($F_{8122} = 14.4$, $p < 0.001$; Figure 2 and Table S1). Log density was positively correlated with increased fetch ($F_{1121} = 26.4$, $p < 0.001$) and was significantly higher on sandy and gravel beaches compared with adjacent rocky shores ($F_{2121} = 9.8$, $p < 0.001$). Based on these data and using a conservative estimate of the perimeter of Vancouver Island (1850 km), approximately 450,000 logs are currently present along the shores of Vancouver Island. Using the full perimeter (3440 km), this would increase to 840,000 logs. On the exposed west coast of Haida Gwaii, log densities on sand and gravel shores averaged 356 logs/km on north-west Graham Island and 129 logs/km on south-west Moresby Island, aligning with the 345 logs/km average observed on Vancouver Island's sand and gravel beaches.

At 22 shores on southern Vancouver Island, 497 drift logs were classified based on their source. Of these, 85 (17.1%) were identified as "natural", while 294 (59.2%) had "sawcuts" and an additional 118 (23.7%) were classified as "ambiguous" due to eroded log ends and the absence of root systems. These proportions were relatively consistent across surveyed localities (Figure 3). "Natural" logs were typically larger in diameter and more commonly found at the upper reaches of the tide line as the root systems anchored the drift log from tidal surges.

We compared log abundance in archival photos (pre-1925) for 26 locations with recent satellite images. The shorelines in the archival photos vary in length from 20 to 734 m for an average of 183 m per locality. There was an average of 152 logs per km (range 8–740) in the archival images and an average of 629 logs per km (range 40–2719) in the 2023 satellite images from the same localities (Figure 4A). This represents a 520% increase in log abundance (range: minus 21% to 3550%) (Figure 4B, and Table S2). Excluding

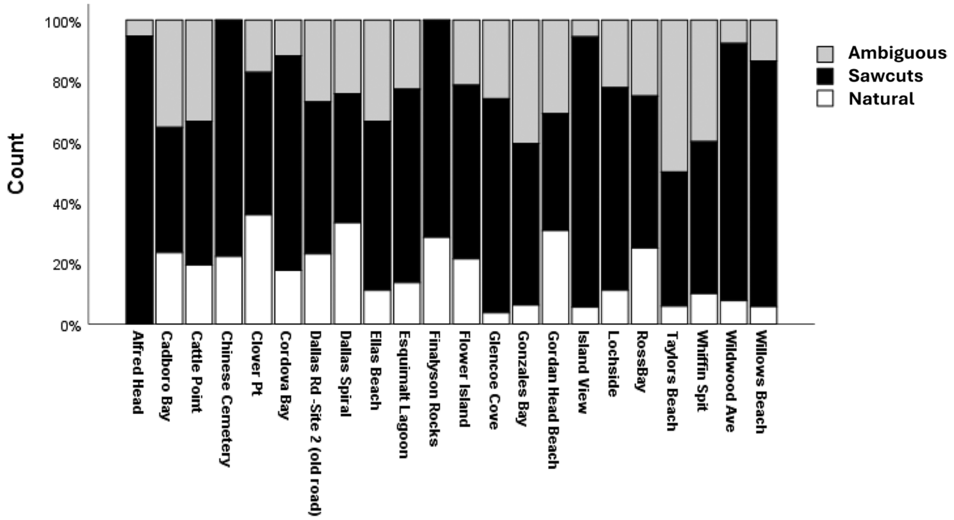

FIGURE 3 | Assessment of 497 drift logs in southern Vancouver Island based on field verification (September 2023). “Natural” has attached root systems (see Figure S1). ‘Sawcuts’ (see Figure S1). “Ambiguous” has eroded ends (Figure S4).

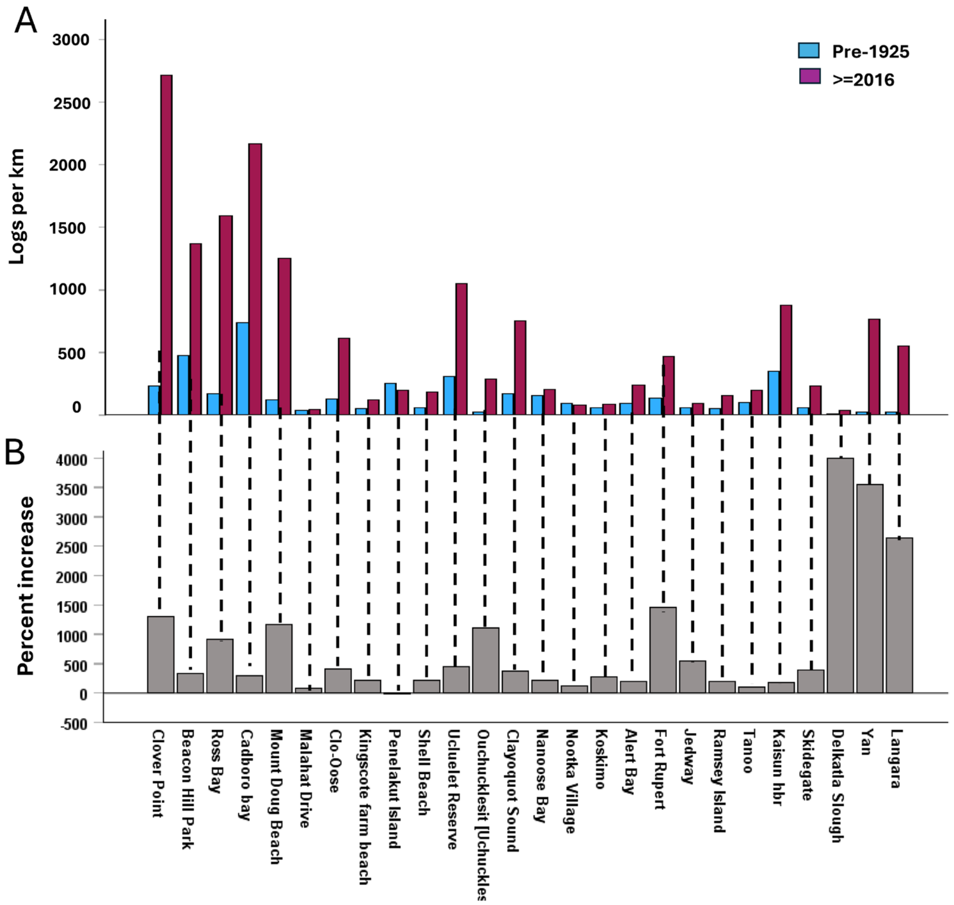

FIGURE 4 | (A) Abundance of drift logs (per km) on 26 geographically diverse localities in British Columbia from archival images (< 1925) and from recent (> 2016) satellite images for each locality. (B) Percent increase in number of logs (root systems and ambiguous) from archival images to all logs in recent (> 2016) satellite images. Dashed lines added to facilitate locality identification for the upper graph. Localities ordered geographically from south to north. Raw data in Table S2.

logs that showed “sawcuts” in the archival images results in an average increase of 800% (range: −21% to 4000%; Figure 4B). We also compared only the “natural” logs (with roots) in the archival photos with current satellite images. Seven of the 26 localities had no “natural” logs, resulting in an impossible increase (division by zero). Consequently, we removed these seven localities and averaged the remaining data for the 19 localities, and this results in an average increase of 6100% (range: −138% to 49,800%) (Figure S2).

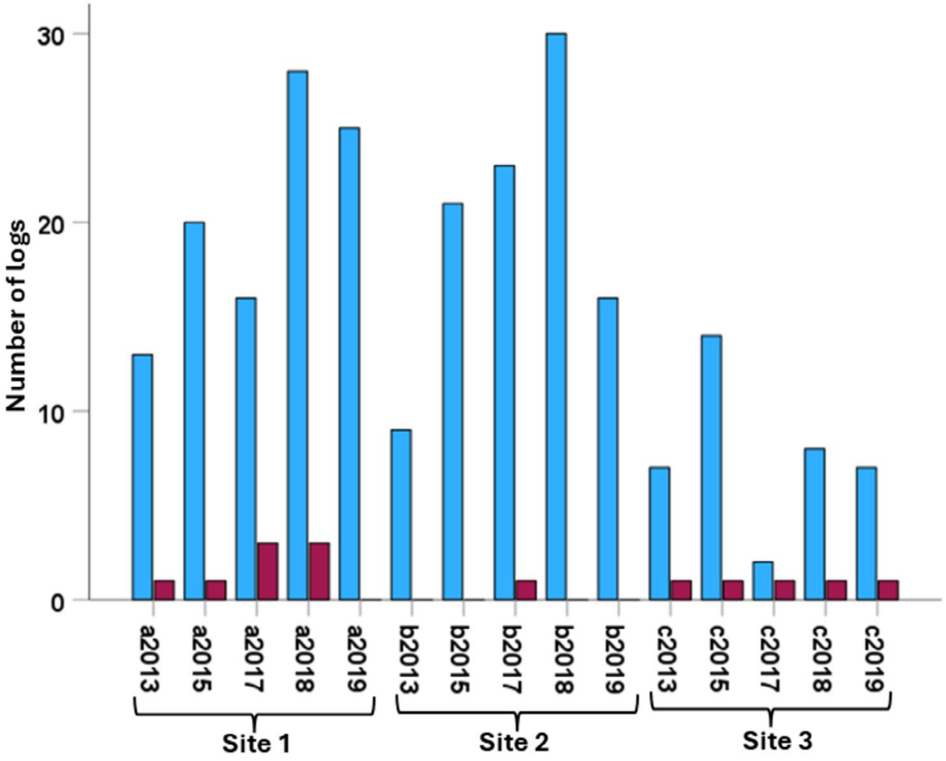

FIGURE 5 | Movement and replacement of drift logs on sequential years at three localities at Victoria, British Columbia. The second bar on each pair represents the number of logs that were in the same position as in the previous year.

In multiple years on both Vancouver Island and Haida Gwaii, we observed storm-induced log displacement across the littoral zone resulting in extensive substrate impact (see Videos S1, S2 and Figure S3). During both rising and receding tides, log movement and intertidal impact occurred repeatedly, approximately 15 wave impacts per minute on any vertical transect of a beach. As the tide recedes, some logs are transported offshore, while others settle on the intertidal. Conversely, during the rising tide, these logs become remobilized, perpetuating abrasion, and substrate disturbance. During some storms, nearly all logs at the high tide line (hundreds) were transported offshore, leaving the shoreline largely devoid of logs until the following month, when onshore winds transported a new assemblage of drift logs across the intertidal. Tagging of 49 randomly chosen logs at the tideline on several shores revealed that after only one month, 22 logs (45%) remained in their original positions, 11 logs (22%) had relocated within the same shoreline (mean displacement = 31 m, range 1–80 m), and 16 logs (33%) had refloated and were no longer present on the study site.

Analysis of satellite imagery for 84 shorelines around Vancouver Island between 2016 and 2022 showed that 21 sites exhibited a reduction in the number of drift logs ($\bar{x} = 38$ logs/km, maximum = 291 logs/km), 52 sites showed log accumulation ($\bar{x} = 69$ logs/km, maximum = 568 logs/km), while 11 sites had less than 5 log differences in either direction. Further tracking of log assemblages using sequential yearly imagery for southern Vancouver Island demonstrated that, on average, 90% of logs (range = 50%–100%) identifiable in a given year did not remain in the same position in subsequent years (Figure 5, see also Figures S4A,B, and S5A–E). These findings suggest that most logs at the tideline are mobilized during winter storm events, transported offshore, and subsequently redeposited on the same or different shorelines during later storms. The cyclical offshore and onshore log movement contributes to sustained abrasion of the rocky intertidal communities.

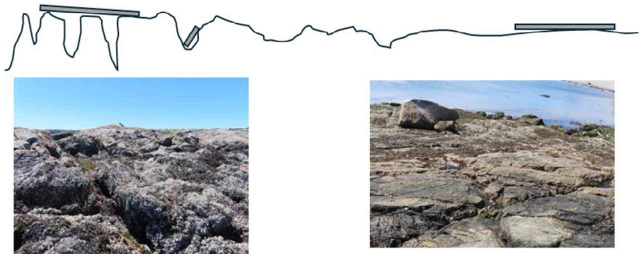

FIGURE 6 | Schematic x-section of a shoreline differing in rugosity. Long logs tend to have more contact on flat areas, while log fragments can abrade substrates protected from longer logs. Photos of shores are representative of higher and lower rugosity.

Shores characterized by flat substrates (low rugosity) experienced the highest levels of abrasion, with impacts being most pronounced in the middle and upper intertidal zones. In contrast, increased rugosity provided refugia in the form of spaces between boulders or within large and small crevices, which were shielded from direct impact. General log length also played an important role in determining impact extent (see schematic in Figure 6). Longer logs (> 10 mm) had extensive contact with the substrate on low rugosity shores; however, as vertical shore profile increased, contact was largely confined to exposed upper surfaces. During storm events, longer logs frequently fragmented into smaller pieces, which could

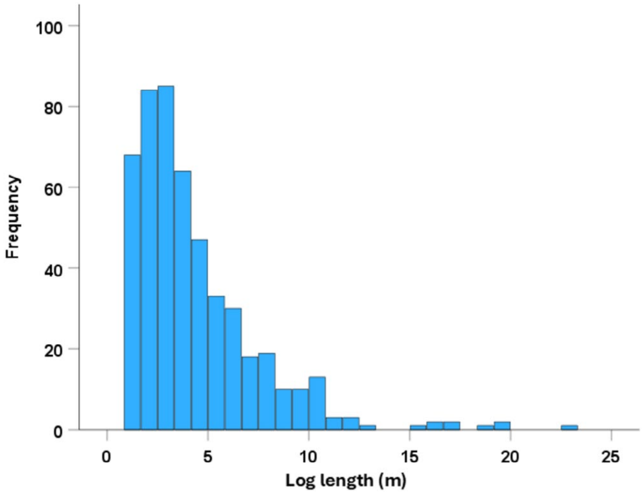

FIGURE 7 | Frequency distribution of log length (m) at 22 localities near Victoria, British Columbia. Log fragments < 1 m length and < 0.2 m width excluded.

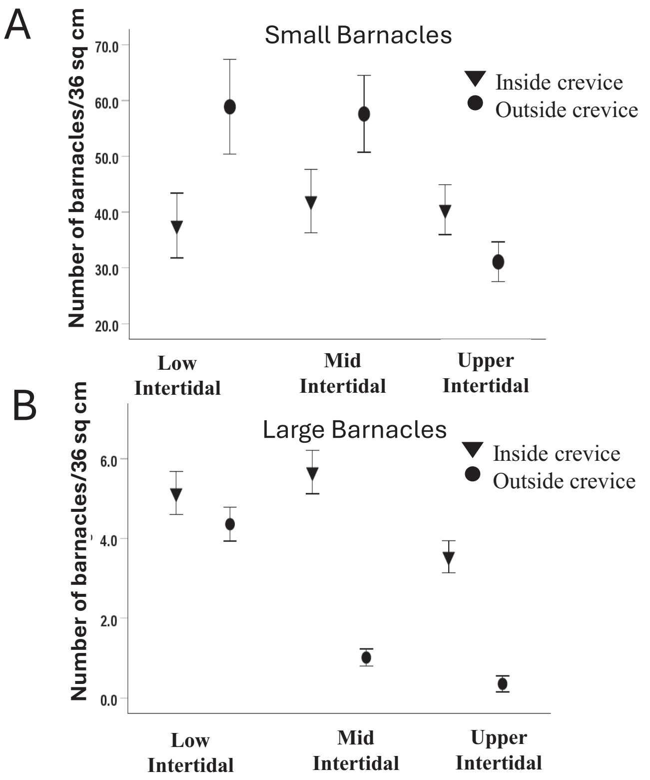

FIGURE 8 | Density of small (A) and large (B) barnacles for crevices (protected) and flat (log susceptible) substrates at three tidal positions on southern Vancouver Island.

then contact substrates between boulders or within large crevices that are typically shielded from the impact of intact logs (Figure 6 and Video S3). Length data for 795 logs across 26 localities revealed that most logs were fragmented (Figure 7). The average log length was 4.2 m (maximum = 22.9 m) with locality-specific mean values ranging from 2.4 to 6.7 m; $F_{25,769} = 3.6$, $p < 0.001$.

Extending from our observations during storm events, we hypothesized that sessile macroinvertebrates, such as large barnacles, would persist primarily in microhabitats protected from log abrasion. Smaller barnacles, primarily *Chthalamus*, in the upper intertidal and newly settled *Balanus* and *Semibalanus* in middle and lower intertidal zones, were present across all microsites and were more prevalent on flat surfaces than adjacent crevices apart from upper tidal positions (Figure 8A). However, large barnacles were significantly less abundant on flat substrates, with 14% fewer individuals outside crevices in the low intertidal zone, 82% fewer in the middle zone, and 90% fewer in the upper zone compared with abundance within crevices (Figure 8B [Barnacle size × Tidal position $F_{2984} = 44.2$, $p < 0.001$]).

Barnacle abrasion was evident across all localities. Analysis of 65 photographed microsites, each covering an area of approximately 1–2 m^2, revealed that abraded regions comprised an average of 32% of each image (range 15%–44%) with significant variation among localities ($F_{9590} = 18.9$, $p < 0.001$). The lowest levels of abrasion were observed at Clover Point East (Figure 1F), a site characterized by high vertical rugosity with numerous boulders throughout the intertidal zone. A rough assessment of rugosity at focal microsites, based on crevice density and crevice depth, across the 11 localities demonstrated show a strong negative correlation with the percent abrasion ($F_{4576} = 25$, $p < 0.001$) (Figure 9).

4 | Discussion

Our findings suggest that drift log abundance along coastal regions of Western Canada has increased by an average of 800% since European colonization, with some localities exceeding a 10,000% increase, leading to significant abrasion of intertidal habitats. While the ecological impacts of drift logs on estuaries, mudflats, eelgrass, and coral community beds are previously documented (review in Edgell and Ross 1983; Wohl and Iskin 2021), their influence on rocky shores has been largely overlooked. Our study builds on Dayton's (1971) foundational research, which demonstrated that log abrasion resulted in the loss of large sessile invertebrates on rocky shores. Dayton observed that metal pins inserted into rocks experience up to 100% annual "mortality" in areas where drift logs were common compared to less than 10% in areas where logs were scarce. Similarly, barnacle cover was as low as 5% where logs were abundant but exceeded 95% in areas with few logs. This was an important observation as throughout temperate latitudes, barnacles dominated the intertidal zones except in highly exposed shores where mussels prevail or in sheltered environments where macrophytes are more common (Lewis 1964).

Despite the significance of Dayton's early findings, there has been little subsequent research into the geographical extent of log impacts on rocky shores or their effects on foraging habitats for other species, including resident and migratory shorebirds. Notably, major reviews of rocky shore conservation and human impact (Morgan et al. 1992; Thompson et al. 1996; Doong et al. 2011) have ignored the role of drift logs and log debris and have interpreted the recent global decline in log discharge from rivers as a potential negative impact on the environment (Wohl and Iskin 2021). Utilizing newly available high-resolution images recently available from Google Earth, we quantified drift

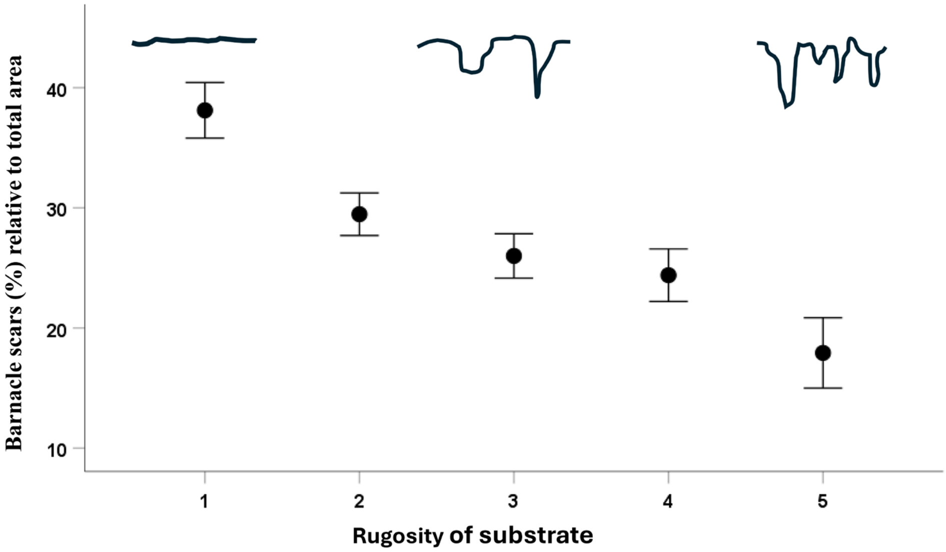

FIGURE 9 | Percent area of barnacle scars relative to total area against substrate rugosity. Rugosity classified from digital photographs ranked from smooth (1) to most rugose (5). Sketches exemplify approximate condition (see also Figure 6).

log abundance across 202 diverse coastal sites spanning 439 km of British Columbia's shoreline. Surprisingly, even remote shorelines, such as the Scott Islands, off northwestern Vancouver Island and the west coast of Haida Gwaii, exhibited log densities comparable to heavily developed (e.g., industrial logging) regions, indicative of the major movement of logs away from their original terrestrial sources (see also Doong et al. 2011). Extrapolating from this data, we estimate that approximately 450,000 logs are present along the high-tide line of Vancouver Island. This figure is conservative, as it does not account for the stacked multi-levels of logs, those obscured from satellite view, or the small log fragments. Moreover, this phenomenon is not confined to western Canada; cursory examination of satellite imagery of remote Alaskan coastlines, including the Alexander Archipelago wilderness, reveals similar patterns of drift log accumulation.

What are the sources of drift logs? A typhoon in Taiwan in the west Pacific resulted in more than 3 million logs entering the ocean and subsequent wide geographical dispersal (Doong et al. 2011). Dayton (1971) estimated that around 50% of the beached logs in the Salish Sea, between southern Vancouver Island and the mainland, came from logging compared to only 15% on the more wave-exposed shores of the Olympic Peninsula. While specific counts were not available, Heathfield and Walker (2011) suggested that most drift logs found along the eastern shores of Haida Gwaii in Northern British Columbia originated from the logging industry. This aligns with a broader consensus for the entire coast as summarized by Murphy et al. (2021, 2024). Using Google Earth imagery, we observed that over 95% of drift logs along the southern British Columbia coast lacked root systems. However, after ground-truthing, where we individually classified 497 drift logs, we revealed that 17% had root systems suggesting a "natural" origin. A significant portion of the remaining logs showed clear signs of logging activity, such as "sawcuts". Additionally, landslides associated with clear-cut logging (Guthrie 2002) and the subsequent transport of trees downstream to the ocean suggest that even some of the "natural" logs with root systems may have originated from human activities. As a result, our estimate of 17% for naturally occurring logs could be an overestimation.

Are there any data to assess the historical abundance of drift logs? This would provide valuable insight into the timeline of habitat loss on rocky shores. Our analysis of archival photographs taken between 1860 and 1920 from various localities along the British Columbia coast revealed that drift logs were present, although at densities less than 20% of those observed today. Evidence of "sawcuts" on beach logs dates to 1860 when European settlement had begun, preceding the large-scale expansion of the logging industry in the late 19th and 20th centuries (Edgell and Ross 1983). The archival photographs showed uncut logs (ambiguous+natural) at low densities (113 logs/km) reflecting a 460% increase to the 629 logs/km in current periods. When we restricted our archival logs only to those with a clear root system (natural), this indicated a density of 24 logs per km and a remarkable increase of 2600%. Seven of the 26 localities in the archival photos had no "natural" logs, which resulted in an impossible estimate of an infinite percent increase in logs from the pre-contact period. It is probable that the absence of these "natural" logs was simply due to the relatively short linear distance visible in those photos (20–734 m) and was not representative of the actual logs per km. It is also possible that the absence of "natural" logs in these archival sites is a consequence of their traditional use by First Nations. Beach logs from downstream river drift were an important component of Inuit culture in the high arctic (Alix 2005).

Historically, log booms were the primary method of transport, leading to significant log loss during marine transit. Before 1980, annual loss was estimated at approximately 680,000 m^3 in southwestern British Columbia (Sedell et al. 1991). The largest log we measured in our field surveys had a volume of roughly 7.9 m^3 (length 22.9 m, width 0.8 m). If this size is representative of logs in transport, it suggests that by the mid-20th century, around 87,000 logs were being swept across the intertidal zones each year. While improvements in sorting and transport techniques have reduced yearly loss (Edgell and Ross 1983), our six-year comparison of satellite imagery (2016–2022) indicates continued log accumulation in about 70% of the localities. These results for the north-west coast of North America are contrary to global trends that indicate a reduction in wood export from rivers to the ocean (Wohl and Iskin 2021).

How frequently are stranded drift logs at the tide line remobilized? Our field observations during autumn and winter storms revealed significant log movement both onto and off of intertidal zones. Previous studies have documented driftwood transport ranging from a few meters to hundreds of kilometers (Murphy et al. 2021). Through direct tagging, we found that in autumn, spanning four tide cycles, 55% of tagged logs were displaced with half reaching other shorelines. Additionally, high-resolution annual satellite imagery showed that more than 90% of logs were replaced each year, only those at the highest position on the drift line remaining in situ among years. If these findings are representative, a substantive portion of the estimated 450,000 logs currently at the tideline around Vancouver Island are remobilized annually, perpetuating the intertidal abrasion during high tides and storm-driven winds.

Our studies of barnacle populations at 14 sites on southern Vancouver Island revealed considerable variation in barnacle coverage both within and among locations. Differences in barnacle densities can be due to multiple factors, including the amount of wave exposure and recruitment (Lewis 1964), competition with mussels (Connell 1961, 1972), predation (Paine 1966; Robles et al. 2021), and log abrasion (Dayton 1971; this study). We had no evidence that competition with mussels was occurring as these were rare or absent on all of the shores. Predatory echinoderms, including *Pycnopodia helianthoides* and *Pisaster ochraceus*, were uncommon but occurred in the lower intertidal zones. Barnacles were more, rather than less, abundant in this predatory zone. The middle and upper littoral zones were especially susceptible to log abrasion, resulting in up to 80% fewer large barnacles (*Balanus*, *Semibalanus*) compared with densities in adjacent shallow crevices that were shielded from abrasion. At Clover Point W (see Figure 1F), where the rocky intertidal is broad and flat, barnacles were almost entirely absent except in the lowest tidal areas. Signs of recent log abrasion, evident from barnacle scars, were less evident in areas with higher rugosity, such as boulders, crevices, and near lower intertidal zones but were prevalent on flat rock surfaces with low rugosity.

While log abrasion reduces habitat, including the interstitial spaces between large barnacles and mussels, it can also provide ecological benefits by exposing barren surfaces and facilitating new colonization. Similar benefits have been observed in other studies, such as starfish predation on mussel beds or storm-driven movement of intertidal boulders (Paine 1966; Sousa 1979) as well as ice-scouring in the north-west Atlantic (Scrosati et al. 2025). This process parallels terrestrial systems, where occasional wind-throw in mature forests creates canopy openings that support early seral stages including ground vegetation (Pontailler et al. 1997; Mitchell 2013). In the intertidal zone, barnacle and mussel larvae settle on abraded surfaces, growing at approximately 1 cm per year (Crisp 1960; Freeman and Dickie 1979; Bayne and Worrall 1980; Connell 1961). Over time, this would allow re-establishment on abraded surfaces. However, our direct observations of log movement, combined with low barnacle cover on most shores except those with high rugosity, suggest that frequent intertidal abrasion prevents succession beyond the earliest seral stages. Shorebirds, including resident Black Oystercatchers (*Haematopus bachmani*) and migratory species such as Surfbirds (*Calidris virgata*), Black Turnstones (*Arenaria melanocephala*), Ruddy Turnstones (*A. interpres*), Wandering Tattlers (*Heteroscelus incanus*), Rock Sandpipers (*Calidris ptilocnemis*), and occasionally plovers (*Pluvialis* spp.) depend on rocky intertidal zones for foraging (Recher 1966; Campbell et al. 1990; Paulson 1995; Bergman et al. 2013; Smith et al. 2015; Handel and Gill Jr 2001; Senner and McCaffery 2020, TER, personal observation, see Figures S6 and S7). While barnacles and mussels serve as a direct food source (Delany et al. 2003; Carney et al. 2023), shorebirds also rely heavily on the smaller organisms that inhabit the interstitial spaces between these larger sessile species. These microhabitats support a diverse array of invertebrates, including amphipods, isopods, copepods, mites, mussel larvae, barnacle larvae, polychaete worms, nemerteans, gastropods, chitons, nematodes, bryozoans, collembolas, and other taxa (Lewis 1964; Connell 1972; Kronberg 1988; Alerstam et al. 1992; Thompson et al. 1996; Cameron et al. 2024). Additionally, shorebirds may benefit from biofilm, an energy-rich resource extensively studied in mudflats (Sutherland et al. 2000; Kuwae et al. 2008; Schnurr et al. 2020).

Our direct observations of log movement, coupled with the widespread presence of drift logs along coastal British Columbia, suggest that shorebird foraging habitat on rocky shores has been significantly impacted. The severity of this impact will be inversely related to shoreline rugosity, with smoother rocky shores experiencing greater disruption. Our density measurements revealed up to 80% fewer large barnacles and their associated interstitial spaces at middle and upper tidal zones, key foraging areas for shorebirds during receding and rising tides. Given the history of industrial logging in British Columbia (Edgell and Ross 1983), it is likely that the rocky intertidal community was already significantly impacted by the mid-20th century. As a result, shorebirds relying on these habitats would have already been negatively affected by this time. Although population estimates for shorebirds using the rocky intertidal were not taken during the first half of the 20th century, global shorebird populations are known to be in decline (Andres et al. 2012; Rosenberg et al. 2019; Warnock et al. 2021; Smith et al. 2023). Recent data (Anon 2024) indicate that Surfbirds (*Calidris virgata*) have experienced a 50% reduction since 1970. We propose that some proportion of this decline may be linked to the widespread loss of the rocky intertidal foraging habitats, and we suspect this may also contribute to the declines in other rock-foraging species, such as the Wandering Tattler (*Heteroscelus incanus*), Ruddy Turnstone (*Arenia interpres*), Black Turnstone (*A. melanocephala*), and Rock Sandpiper (*Calidris ptilocnemis*). The ongoing increase in log densities and the remobilization of these logs during high tides and autumn storms will likely continue to exacerbate the loss of the intertidal habitats, especially on shores with low rugosity.

In conclusion, our study highlights the widespread presence and abundance of drift logs along shores throughout western Canada, spanning areas with urban and industrial development to the relatively pristine outer coasts. We show that the iterative movement of these logs both on and off the shores presents a persistent threat to intertidal communities and the species, such as shorebirds, that rely on these habitats for foraging. The anticipated increase in storm intensity due to global warming (Change 2007) could further amplify the remobilization of drift logs. Unlike the sporadic but severe mortality events of intertidal organisms caused by extreme heat waves (Hesketh and Harley 2023; White et al. 2023), drift log damage is largely yearly cyclical, perhaps equivalent to ice abrasion in the north Atlantic (Scrosati et al. 2025), preventing the recovery of the complex intertidal communities typically seen in later seral stages. Our preliminary findings emphasize the need for a more detailed understanding of the impacts of drift logs on rocky shores, an acknowledgment of the ecological costs they impose on the intertidal communities throughout the north-east Pacific, and the urgent need for comprehensive conservation efforts in these dynamic environments.

Author Contributions

T.E.R.: conception and design. E.P.A., T.E.R., M.G.M.: data collection. T.E.R., E.P.A., and M.G.M.: data analysis. T.E.R., E.P.A.: editing and manuscript preparation.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All raw data are available from T.E.R. on reasonable request and will be archived with Dryad.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:**. Location of all study sites including geographical region (see Figure 1), shore ID, photo year, substrate (0 = sand, 5 = rock), shoreline angle (^{o}), fetch (km), shoreline length (km), logs (number), and logs/km. **Table S2:**. Raw data of drift logs on 26 geographically diverse localities in British Columbia from archival images (< 1925) and from recent (> 2016) Google Earth satellite imagery for each locality displaying numbers of cut and naturally occurring logs. Localities are shown in alphabetical order, and the averages are presented at the bottom of the table. **Video S1:** Storm and log movement video taken February 25, 2024 at Ross Bay, Victoria, British Columbia. 123°20′48.40″W, 123°20′48.40″W. **Video S2:** Storm and log movement video taken November 04, 2024 at Spiral Beach, Victoria, British Columbia. 48°24′20.75″N, 123°21′7.00″W. **Video S3:** Wave and log movement video taken December 03, 2023 at Clover Point, Victoria, British Columbia. 48°24′13.14″N, 123°20′53.89″W. **Figure S1:** A: Examples of "natural" log with root system and "logged" (cut ends), Clover NE (see Figure 1F). B, C, D: Representative newly abraded barnacles. **Figure S2:** Percent increase of "natural" logs (with roots) in archival photos relative to all logs in recent satellite images from the same localities. Seven localities with unshaded bars had no "natural" logs resulting in an impossible infinite increase. Excluding these seven localities yields a 6100% average increase in logs from pre-contact periods if all of the "ambiguous" logs (no roots, no "sawcuts") were from human influences. **Figure S3:** South-east storm at Lawn Hill, Graham Island, Haida Gwaii, February 1978. **Figure S4:** Google Earth images for Clover W, Victoria (see Figure 1E) showing changes in log numbers between 2015 and 2018. The "reddish" logs on the upper image are still moist and are recent accumulations. **Figure S5:** Representative Google Earth images to show yearly differences in log abundance and position on shores on southern Vancouver Island. surfaces. (A) Clover Pt, 2015, (B) Clover Pt, 2018, (C) Ross Bay, 2018, (D) Ross Bay, 2019, (E) Ross Bay, 2019. **Figure S6:** Representative rocky shore with drift logs and plovers (location at Figure 1F SE). **Figure S7:** Middle intertidal rocky shore foraging of Black Turnstones (*Arenaria melanocephala*) and Surfbird (*Calidris virgata*) at Clover Pt, Victoria, British Columbia (see Figure 1F SE). Note: The presence of small (< 5 mm) barnacles in protected vertical surfaces. **Figure S8:** maec70054-sup-0013-FigureS8.png.