Table 1. Acute toxicity test results for effluent samples collected from the water treatment plants at Snap Lake Mine, 2005 to 2016

		Acute toxicity test results[a]						Water quality			
								Nitrite (mg-N/L)		Chloride (mg/L)	
Year	*n*	Trout LC50[b] (%)	Trout LC25[c] (%)	*Daphnia* LC50[b] (%)	*Daphnia* LC25[c] (%)	*Daphnia* EC50[d] (%)	*Daphnia* EC25[e] (%)	Min	Max	Min	Max
2005	1	>100	>100	>100	>100	>100	>100	0.420		357	
2006	5	>100	>100	>100	>100	>100	>100	0.044	0.301	340	605
2007	5	>100	>100	>100	>100	>100	>100	0.127	0.239	418	527
2008	5	>100	>100	>100	>100	>100	>100	0.010	0.498	293	1 200
2009	4	>100	>100	>100	>100	>100	>100	0.134	0.280	259	297
2010	4	>100	>100	>100	>100	>100	>100	0.122	0.540	216	244
2011	5	>100	>100	>100	>100	>100	>100	0.104	0.244	165	272
2012	5	>100	>100	>100	>100	>100	>100	0.076	0.145	243	295
2013	4	>100	>100	>100	>100	>100	>100	0.082	0.133	234	354
2014	5	>100	>100	>100	>100	>100	>100	0.070	0.107	295	330
2015	4	>100	>100	>100	>100	>100	>100	0.076	0.095	276	321
2016	1	>100	>100	>100	>100	>100	>100	0.019		330	

ECx = concentrations of sample estimated to cause a specified effect to x% of the test organisms; LCx = concentrations of sample estimated to be lethal to x% of the test organisms; *n* = sample count.
[a] Acute toxicity testing was conducted with rainbow trout, *Oncorhynchus mykiss*, following method EPS 1/RM/13 (Environment Canada 2000a), and a water flea, *Daphnia magna*, following method EPS 1/RM/14 (Environment Canada 2000b).
[b] LC50, or median lethal concentration, is the concentration of sample estimated to be lethal to 50% of the test organisms.
[c] LC25 is the concentration of sample estimated to be lethal to 25% of the test organisms.
[d] EC50, or median effective concentration, is the concentration of sample estimated to cause a specified effect to 50% of the test organisms.
[e] EC25 is the concentration of sample estimated to cause a specified effect to 25% of the test organisms.

concentrations (i.e., >10 mg/L). These data provide an extensive field data set that supports the laboratory-observed ameliorating effects of chloride on the toxicity of nitrite. As such, the chloride-dependent BCMOE (2009) WQG is appropriate for water quality assessments in cold climates.

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IS COMMERCIAL HARVESTING OF BEACH-CAST SEAWEED ECOLOGICALLY SUSTAINABLE?

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Common to shorelines worldwide, accumulations of beach-cast seaweeds, seagrasses, and other debris, collectively known as wrack, provide an ecologically important subsidy to intertidal and terrestrial systems. On beaches with little to no primary productivity of their own, wrack offers a source of refuge, food, and nutrients for associated intertidal and terrestrial fauna (Colombini and Chelazzi 2003). Globally, this material is also harvested for both aesthetic and commercial purposes, but literature on the impacts of such activity is limited (Kirkman and Kendrick 1997).

In 2007, the British Columbia Ministry of Agriculture began issuing licenses for a pilot harvest of beach-cast seaweeds within the southern end of Baynes Sound, Vancouver Island, targeting an introduced red alga called *Mazzaella japonica*. Like many red seaweeds, this species is rich in carrageenan, valued as a thickening or gelling agent in a variety of commercial products including foods, pharmaceuticals, and cosmetics. Although perceptions of the commercialization of an introduced or invasive species are often positive, the removal of nonindigenous organisms can have unforeseen consequences on recipient systems (Bergstrom et al. 2009). Invasive seaweeds, for instance, have been known to provide a novel habitat and food source for native herbivores, thereby increasing the biodiversity and abundance of associated fauna (Wright et al. 2014). The Baynes Sound harvest became a source of contention within adjacent communities, where such concerns were cited in calls for a moratorium until the effects of the harvest were better understood.

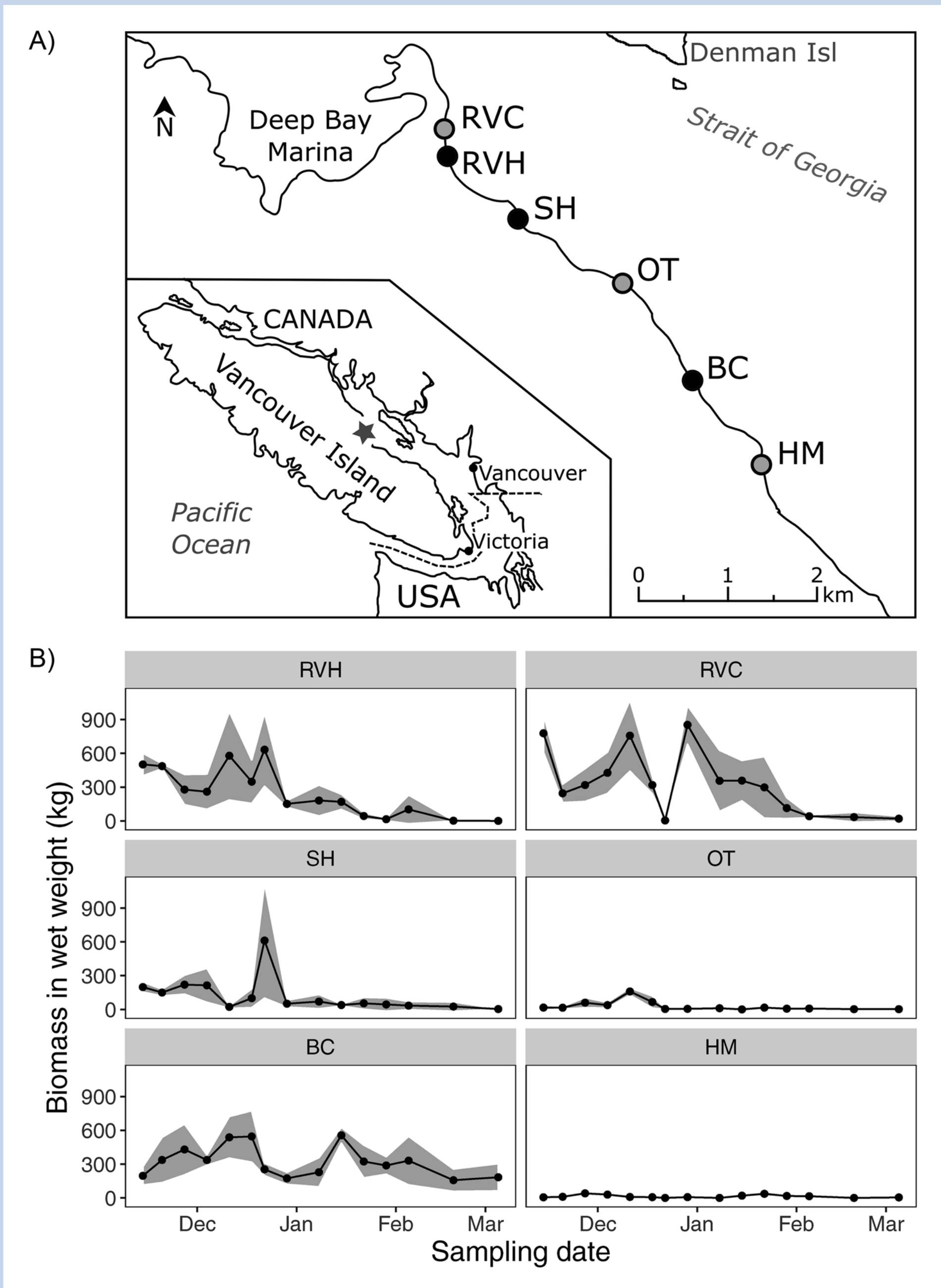

Figure 1. (**A**) Map of study area in Baynes Sound, British Columbia. Licensed harvest region extended from RVH to BC. Potential harvest sites accessible to harvesters are indicated by black circles, unharvested comparison sites are indicated by grey circles. (**B**) Mean biomass of wrack (wet wt in kg) per meter of shoreline, shaded region represents SD. Means calculated from 3 transects at each site per sampling date, visited from November 2014 until March 2015. A total of 78% of the 674.5 tonnes of harvested seaweeds were collected from RVH.

The goals of our study were 3-fold: 1) to quantify the contribution of *M. japonica* to wrack inputs within the harvest region, 2) to explore how wrack characteristics influence macrofauna communities, and 3) to determine whether the commercial removal of beach-cast seaweeds has a detectable effect on wrack characteristics and macrofauna assemblages. To address these questions, we established a series of permanent transects at 6 sites across the licenced harvest region (Figure 1A). Three of these were "harvest" sites: RV Park harvest site (RVH), Shoreline Drive (SH), and Buccaneer Beach (BC), from which the harvesters collected seaweeds in years past and anticipated using again. The remaining locations: RV Park comparison site (RVC), Ocean Trail (OT), and Henry Morgan (HM), were comparison sites from which no beach-cast seaweeds were harvested. Transects were visited weekly from November through March during the harvest season of 2014–2015. At each transect, we recorded the length and depth of every band of wrack, its level of decomposition, and the weight of a 1-L sample. Samples from every 3rd week were processed in the laboratory to determine macrophyte and macrofauna composition.

In November and December, when wrack biomass was greatest, we recorded as much as 853 kg (wet wt) of wrack ($\pm$172.9 SD) per meter-wide transect of shoreline (Figure 1B). *M. japonica* comprised approximately 90% of the identifiable wrack biomass in dry weight across all 6 sites. Both the biomass and composition of wrack deposition within this region appears to be unprecedented in British Columbia. Although literature on the characteristics of beach-cast seaweeds in the province is limited, previous studies have reported maximum quantities an entire order of magnitude lower, dominated by a greater diversity of native species (Orr et al. 2005).

A total of 674.5 tonnes of wet beach-cast seaweeds was collected by harvesters (75% of the 900 tonne quota issued by the BC Ministry of Agriculture) in 2014–2015. Compared to other beach-cast harvests, this biomass is relatively low; in Ireland, for instance, hundreds to thousands of tonnes are permitted per license daily (McLaughlin et al. 2006). The conditions of licensing for the Vancouver Island harvest were also consistent with recommended environmental protection measures outlined by McLaughlin et al. (2006). The collection of beach-cast seaweeds, for example, is done using pitchforks rather than mechanical means, and any removal of sand, sediment, or substrate is prohibited.

Our ability to disentangle the effects of site, wrack characteristics, and harvesting pressure was largely limited by a concentration of harvesting effort at a single location (RVH), from which 78% of the harvested biomass was collected. Despite this concentration of activity, wrack biomass and temporal trends were similar between this location and the neighboring RVC comparison site. In fact, the biomass recorded at RVH often exceeded that at other locations such as OT, HM, and SH, suggesting that harvesting did not deplete the availability of beach-cast seaweeds below naturally occurring quantities.

Differences in macrofauna communities between harvested and unharvested sites were also unclear. When collection site, mean depth, percent cover, band biomass, and age class of the wrack were included as explanatory variables in a multivariate regression tree, using Bray–Curtis distances, nodes were only defined by combinations of sites. This statistical method uses repeated splitting of the data to group similar samples into clusters, where each node of the tree is defined by a rule based on one of the explanatory variables. Given their spatial proximity, it was expected that assemblages collected from RVC and RVH (the primary harvest site) would be clustered together if there was no effect of harvesting. RVH samples, however, formed a cluster with those from BC, which went unharvested during this monitoring period, while samples from RVC clustered with those from SH, which experienced 2 d of harvesting during the monitored period.

Age class of the wrack emerged as a significant explanatory variable for the variation in macrofauna assemblages in a constrained analysis of principal coordinates (pseudo-$F = 3.53$, $df = 1$, $p < 0.01$), which partialled out the effects of site. Overall, both the species richness and diversity of macrofauna samples increased in older bands, which were always located within the supratidal zone. Although this older wrack only represented a small proportion of the total recorded biomass, it clearly serves an important ecological role. If older bands are permitted to form at the landward boundary, the harvesting of the highly transient, fresh wrack from the intertidal zone may therefore have fewer consequences for wrack-dwelling macrofauna. This harvesting strategy aligns well with the interests of the harvesters who have subsequently told us that fresh wrack is of greater economic value due to its higher carrageenan content.

Although our ability to draw conclusions from this work is limited by the fact that we had only 1 primary harvest site, our results suggest that current harvesting activities do not deplete wrack biomass below naturally occurring quantities within the region. Furthermore, effects on wrack-dwelling macrofauna assemblages appear to be minimal. This apparent lack of impact may be due in part to the lesser economic value, and therefore harvesting, of aged wrack, which appears to be serving a more substantial habitat role. However, wrack biomass, distribution, and removal should continue to be monitored in this region to better understand potential long-term effects due to the harvesting of beach-cast seaweeds as well as the presence of the introduced *M. japonica*.

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