Forest Disturbance and Disease: Exploring the Effects of Tree Harvesting Area on *Cryptococcus gattii* sensu lato Infection Risk, Vancouver Island, Canada, 1998–2014

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BACKGROUND: The disturbance of colonized trees and soil, such as through forestry activities, has been proposed to disperse soil- and tree-inhabiting fungal pathogens. *Cryptococcus gattii* sensu lato is one such pathogen that was detected on Vancouver Island, British Columbia, Canada, beginning in 1999 and caused human and animal illness.

OBJECTIVES: Our aim was to determine if *C. gattii* s.l. human case incidence on Vancouver Island was correlated with the intensity of landscape-level tree harvesting occurring near human settlement areas.

METHODS: We created buffers around human settlement areas with radii increments of 2.5 km, from 2.5 to 20 km, and summed the area of annual tree harvests occurring within each buffer zone. We then performed Spearman rank–order correlation to measure the association between case incidence and annual tree harvest intensity at each radius from 1998 through 2014.

RESULTS: The incidence of *C. gattii* was positively correlated with tree harvesting intensity only at distances of 7.5 km ($r = 0.66$, $p = 0.004$) and 10 km ($r = 0.64$, $p = 0.005$) from human settlement areas. As annual tree harvesting area increased between 1999 and 2003, so did annual *C. gattii* incidence in humans, before both plateaued around 2002 and decreased after 2007.

DISCUSSION: Our findings suggest that tree harvesting plays a role in the spread of *C. gattii* on Vancouver Island. This may be due to tree cutting or soil disturbance facilitating the aerosolization of spores to increase infection risk. This research also illustrates the contribution that geographic information systems can make to public health research on environmental disturbance and disease outbreaks. https://doi.org/10.1289/EHP12396

Introduction

The disruption of colonized soil and trees has been proposed as a key factor in the dispersal of soil- and tree-inhabiting fungal pathogens. *Blastomyces dermatitidis*, *Coccidioides immitis*, and *Histoplasma capsulatum*, which cause infection through inhalation of aerosolized spores,[1–3] have shown increased dispersal following forest and soil disruption. *Blastomyces* spores are released following mechanical disruption of soil and other organic matter.[4] Coccidioidomycosis (commonly known as Valley fever) outbreaks occurred following archaeological activities,[5,6] an earthquake,[7] and a windstorm[8] in the southwestern United States. Land activities that disturb forests and soil, such as cultivation and urbanization, are predicted to have increased the geographic ranges of *Histoplasma*.[9] The spread of fungal species is aggravated by forestry activities, including tree harvesting, where trees are cut and sold as lumber while the land does not undergo a land-use change.[10]

Another soil- and tree-dwelling fungal pathogen, *Cryptococcus gattii* sensu lato, was detected on Vancouver Island, British Columbia, in 1999 and caused a multispecies outbreak of cryptococcosis.[11,12] Cryptococcosis, a potentially fatal infection of the lungs and central nervous system in mammals, including humans, is caused by inhalation of *Cryptococcus* fungal spores or desiccated yeast cells.[13] The incubation period of *C. gattii* s.l., hereafter referred to as *C. gattii*, ranges from 2 to 11 months, with a median

of 6–7 months,[14] although it has been reported to last up to 3 y.[15] On Vancouver Island, soil and trees are the principal reservoirs of *C. gattii* colonization.[16] Following the Vancouver Island outbreak, the effects of logging on *C. gattii* dispersal were explored, and tree harvesting was found to increase spore dispersal at the neighborhood level. The felling and chipping of individual trees colonized with *C. gattii* on Vancouver Island led to an increase in airborne concentrations of this pathogen.[17] Dogs and cats residing within 10 km of a logging site or other area of commercial soil disturbance on Vancouver Island had an increased risk of developing cryptococcosis.[18] Studies of the spatiotemporal dynamics of forestry activities and *C. gattii* at the landscape scale, however, have not yet been attempted owing to the lack of large-scale forestry data. Moreover, few studies have addressed the maximum potential distance of *C. gattii* spore dispersal.

In the province of British Columbia, Canada (population ~5.2 million[19]), soil and tree disturbance are largely due to tree harvesting. British Columbia has the second largest provincial forestry industry in Canada.[20] The province has a total of ~55 million hectares of forest area,[21] nearly equivalent to the area of France, and as of 2014, cuts an average of ~175,000 hectares per year.[22] More than 90% of trees harvested in coastal British Columbia, including Vancouver Island, are coniferous trees, including cedar, fir, hemlock, pine, and spruce.[23,24] On Vancouver Island, trees from which *C. gattii* has been isolated include the western red cedar (*Thuja plicata*), Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and grand fir (*Abies grandis*).[25,26] During first-attempt sampling on the island, even greater proportions of positive *C. gattii* isolations were made from soil samples close to trees rather than direct tree samples (e.g., swabs of tree hollows, stumps, cut logs).[16] It is hypothesized that forestry activities on Vancouver Island may have affected the emergence of *C. gattii* as a human and animal pathogen by disturbing colonized trees and soil. Tree harvesting on Vancouver Island occurring before and during the *C. gattii* outbreak was conducted largely for the British Columbia forestry industry but also included some construction projects, including the construction of the Inland Island Highway, a 125-km highway built between Campbell River and Parksville along the eastern side of the island that was completed in 1999.[27] Although tree disturbance has been directly assessed at the

level of individual trees, broader-scale studies using remotely sensed forestry data have never been compared with *C. gattii* infection risk. Here, we analyze the correlation between human *C. gattii* incidence and the size of tree harvesting areas at various distances and time frames to explore the role of tree harvesting on the emergence of *C. gattii* as a human pathogen on Vancouver Island.

Methods

Study Area

Our study area comprised Vancouver Island, along with the Gulf Islands, occupying $\sim 31{,}285\,\mathrm{km}^2$ (herein referred to as Vancouver Island). As of 2019, the islands had a human population of >870,000.[28] They also have one of the highest annual incidences of *C. gattii* infections worldwide.[29]

Forest Disturbance Data Sets

We used Landsat-derived annual tree harvest layers from 1985 through 2014 with a spatial resolution of 30 m.[10,30–32] These data were derived from a time series of Landsat-derived best-available-pixel image composites of surface reflectance acquired from 1 August ± 30 d each year. These images were combined into a temporal stack from which a break point analysis was conducted across the years for each grid cell.[31] An object-based image analysis approach[10] was used to assess characteristics of each spectral change (i.e., changes in surface reflectance values). These characteristics included the magnitude of change (i.e., the difference in surface reflectance values before and after the change), the duration of the change (i.e., for how many years did the change last), and the change rate (i.e., the ratio of magnitude and duration). Objects (i.e., tree harvest, fire, road construction, or non–stand-replacing change, such as trees with diseases or water stress) would be created using a spatial aggregation of grid cells that experienced similar change characteristics. For example, grid cells characterized as tree harvests would exhibit a relatively large magnitude of change in surface reflectance values over a short period of time, such as only from 1 y to the next, compared with grid cells characterized as trees suffering from disease, where relatively smaller magnitudes of change in surface reflectance values would occur over a longer period, such as several years in a row.[10]

For our analysis, we used tree harvest data, although specific tree species that were harvested were not specified. For each grid cell that represented tree harvesting, we included the year of harvest and the level of confidence that tree harvesting occurred. The harvest year was the year the cell experienced the greatest spectral change between 1985 and 2015. Changes were assigned a high or low-confidence level based on the amount of data missing before, during, and after the change, with confidence decreasing as the amount of missing data increased.[32] Confidence that an object (i.e., aggregation of grid cells) was correctly attributed to tree harvesting was calculated using a random forest classifier.[10] This classifier determined how many votes from individual trees were received for each change type (e.g., tree harvest, fire) and calculated the proportion of votes of the second-most voted class (v2) and the proportion of votes of the assigned class (v1). If v2/v1, which ranged from 0 to 1, was >0.4, the change attribution was considered low confidence. Combined high- and low-confidence harvest area data were used for the present analysis (Figure S1 shows locations and years of harvests). However, high-confidence harvest data alone were tested as part of the sensitivity analysis.

Previous studies have found that *C. gattii* is unlikely to persist in areas at elevations of >770 m that have daily average winter temperatures below freezing.[26] Specifically, the mountain hemlock and coastal mountain–heather alpine biogeoclimatic zones encapsulate these conditions (see Mak et al.[26]) (Figure 1). We therefore removed tree harvests that occurred within these biogeoclimatic zones.

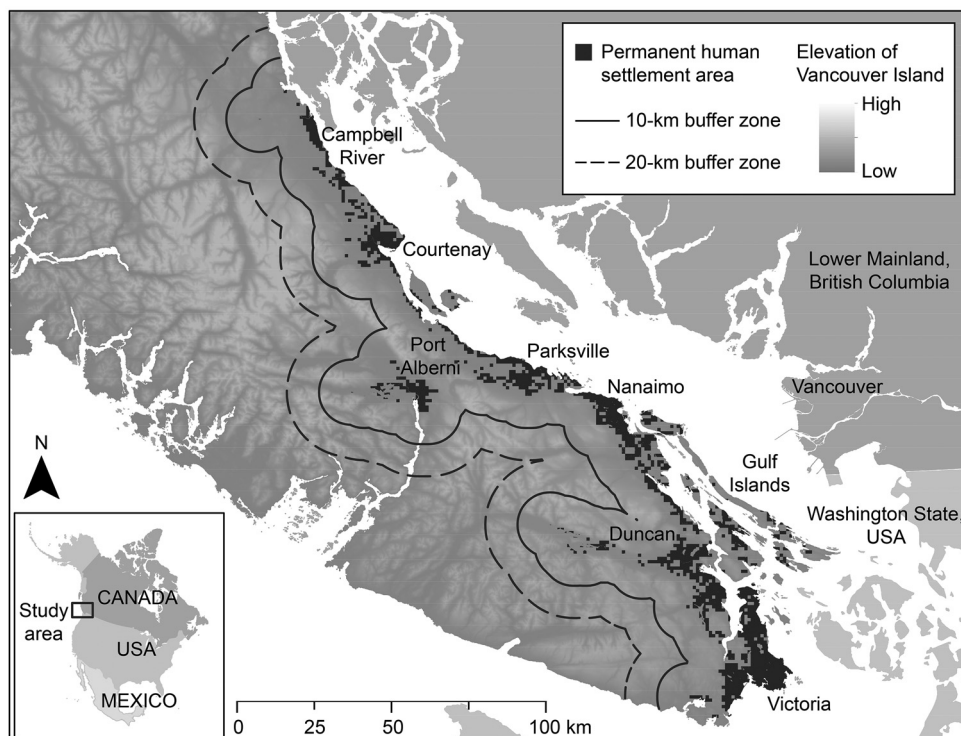**Figure 1.** Permanent human settlement areas on eastern Vancouver Island along with the border lines of the 10- and 20-km buffer zones. Permanent human settlement areas were created based on the 2015 raster data set from the European Commission Global Human Settlement–Settlement Model (SMOD) at a 1-km resolution (https://ghsl.jrc.ec.europa.eu/datasets.php). This figure was created using ArcGIS (version 10.7.1; ESRI).

Disease Surveillance Data

C. gattii-related cryptococcosis is a reportable disease in British Columbia. We used human case data reported to the British Columbia Centre for Disease Control between 1998 and 2014 following the University of British Columbia Research Ethics Board approval (H16-00118/2016). Public health officials interviewed each case using a standard questionnaire to record demographic information, travel history, and other factors.[33] A confirmed case was defined as a culture-confirmed *C. gattii* infection using differential media and genotyping.[33,34] A probable case was defined as laboratory evidence of infection in an human immunodeficiency virus (HIV)–negative person using antigen detection, histopathology, or microscopy. The number of new cases was recorded per year.

Case data from 1998 to 2009 included travel history from the 12 months before the onset of symptoms, whereas case data from 2010 to 2014 included travel history for the past 13 months.[35] Travel histories were lacking for 229 of 378 (>60%) of cases from British Columbia. We therefore performed our analyses using all human cases of *C. gattii* infection with residences on Vancouver Island and the Gulf Islands regardless of travel history ($n = 241$). We assumed that individuals spent the majority of their time at home or within the eastern human settlement area of the island. However, as part of our sensitivity analysis, we excluded cases who reported travel outside of British Columbia in the 12–13 months prior to onset ($n = 233$) (Tables S1 and S2) to account for possible exposure to *C. gattii* during travel. For these analyses, cases with no travel history were still included.

Permanent Human Settlement Areas and Buffer Zones

Permanent human settlement areas were mapped using the 2015 raster data set from the European Commission Global Human Settlement–Settlement Model (SMOD) at a 1-km resolution.[36] Given that *C. gattii* has never been isolated in western Vancouver Island except in a porpoise, the human settlement areas were clipped to eastern Vancouver Island and the Gulf Islands (Figure 1).

The potential distance that aerosolized *C. gattii* spores can travel is unknown. We therefore created buffers around each human settlement area on Vancouver Island and the Gulf Islands with radii increments of 2.5 km, from 0 (i.e., within the human settlement areas) to 20 km. We calculated the total area of tree harvesting in square meters occurring within human settlement areas and cumulatively within each buffer zone annually from 1998 and 2014 (i.e., areas of tree harvesting were summed from 0 to 2.5 km, then 0 to 5 km, and so on). Within each buffer zone, we then examined whether annual *C. gattii* incidence was associated with the corresponding size of tree harvesting area for that year. We used 20 km as the maximum buffer radius owing to the presence of the Vancouver Island Ranges, which commence ~20 km from the eastern shoreline, and given that no human cases of *C. gattii* have been reported west of this mountain range. In addition, we calculated the percentage of total annual tree harvest areas per buffer zone that was associated with the construction of the Inland Island Highway from 1991 to 1999. We calculated tree harvests directly associated with the highway by determining high-confidence as well as high- and low-confidence tree harvests occurring within 60 m of the highway.

Statistical Analysis

Our analysis data set consisted of the annual time series of total new cases, plus the corresponding harvest areas for each of the nine increasingly larger buffer zones. The correlation between annual *C. gattii* incidence and annual harvest area was assessed for each buffer zone using Spearman rank–order correlation.[37] We

separately examined confirmed as well as probable + confirmed human cases of *C. gattii* infection with residences on Vancouver Island or Gulf Islands (Table S1). We were uncertain about the exact timing of tree harvests. Although candidate pixels for creating tree harvest data were acquired within July and August, harvests may have occurred within those months or up to a year prior. Owing to this uncertainty, and the potentially lengthy incubation period of *C. gattii*,[14,15] we repeated the analyses comparing annual *C. gattii* incidence to tree harvests that occurred 1 y before case reporting. We therefore analyzed three sets of factors: *a*) travel history (all cases regardless of travel history vs. those who had no evidence of travel outside of British Columbia during their incubation period), *b*) confidence of the accuracy of the harvest data (high- and low-confidence data vs. high-confidence data), and *c*) the year of harvest relative to the time the case was reported (harvest occurred the same year the case was reported vs. harvest occurred the year before the case was reported). In the main analysis, we compared all human cases regardless of travel history with high- and low-confidence harvest data occurring in the same year as case reporting. The sensitivity analyses consisted of all other combinations of the three factors.

Given that each analysis consisted of multiple tests across buffer zones, we evaluated significant associations using Bonferroni adjusted *p*-values. We used ArcGIS (version 10.7.1; ESRI) to map the georeferenced human records and the tree harvest data sets. Statistical analyses were conducted using R (version 3.0.2; R Development Core Team).

Results

The annual incidence of *C. gattii* infection in humans on Vancouver Island (Table 1) increased in step with the annual increase in area of tree harvests within 10 km from human settlement areas from 1998 to 2002–2003 (Figure 2). The number of cases and the area of harvesting reached a plateau at around 2002 (for cases) and 2003 (for harvesting) that lasted until 2007 and both decreased thereafter. In 1999, when *C. gattii* was first confirmed in humans on Vancouver Island, the total annual tree harvesting area on the island was at least 47% higher than in any

Table 1. Summary of confirmed and probable human cases of *C. gattii* infection per year from 1998 through 2014 with residences on Vancouver Island, regardless of any travel history.

Year	Confirmed	Probable	Confirmed + probable
1998	0	1	1
1999	2	3	5
2000	6	11	17
2001	7	6	13
2002	13	11	24
2003	14	6	20
2004	9	11	20
2005	12	6	18
2006	12	12	24
2007	8	11	19
2008	10	1	11
2009	9	3	12
2010	8	7	15
2011	12	2	14
2012	10	3	13
2013	5	1	6
2014	9	0	9
Total	146	95	241

Note: A confirmed case was defined as a culture-confirmed *C. gattii* infection using differential media and genotyping. A probable case was defined as laboratory evidence of infection in an human immunodeficiency virus (HIV)–negative person using antigen detection, histopathology, or microscopy. Case data were provided through the British Columbia Centre for Disease Control Reportable Diseases Data Dashboard (http://www.bccdc.ca/health-professionals/data-reports/reportable-diseases-data-dashboard). Data from this table were used for the human case data in Figure 2.
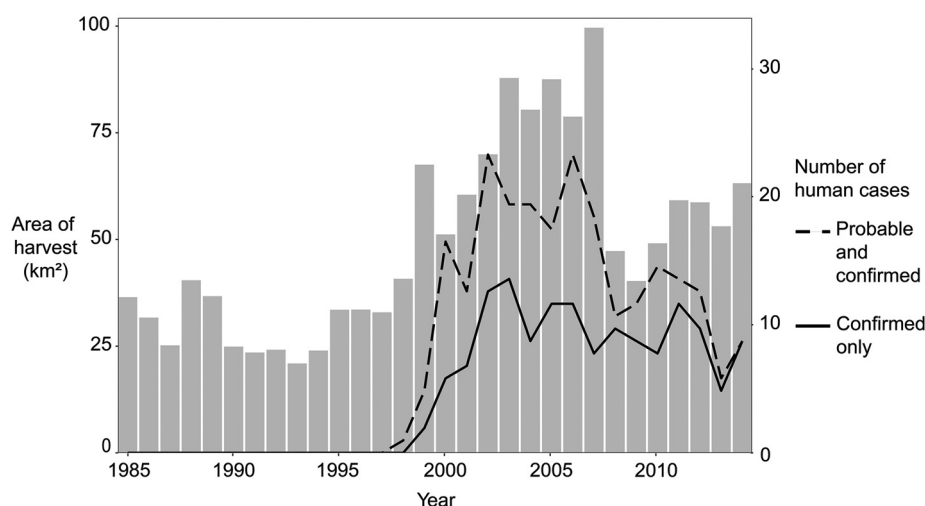
Figure 2. The total area of high-and low-confidence tree harvest events occurring within 10 km of the eastern human settlement area of Vancouver Island (in gray bars) compared with the number of confirmed (solid black line, $n = 146$) and combined probable and confirmed human cases (dashed black line, $n = 241$) with residences on Vancouver Island. Human cases regardless of travel history are shown. Tree harvests were assigned high or low confidence through a random forest classifier, based on how many votes from individual trees were received for each class type (e.g., tree harvest, fire). The proportion of votes of the second-most voted class (v2) was divided by the proportion of votes of the assigned class (v1). Tree harvests were considered high confidence if v2/v1 was ≤0.4 and low confidence if v2/v1 was >0.4. Tree harvest data were provided by Hermosilla et al.[10] (see https://opendata.nfis.org/mapserver/nfis-change_eng. html). Human settlement area data were mapped using the 2015 raster data set from the European Commission Global Human Settlement–Settlement Model (SMOD) at a 1-km resolution (https://ghsl.jrc.ec.europa.eu/datasets.php). Data for annual tree harvest areas is in Table S4 in the "10 km" column. Data for annual human cases is in Table 1.

other prior year since 1985 across all buffer zones outside the human settlement area (Tables S3 and S4).

The tree harvesting area was positively correlated with *C. gattii* incidence among Vancouver Island residents within 7.5 km ($r = 0.66$, $p = 0.004$) and 10 km ($r = 0.64$, $p = 0.005$) (Table 2) from human settlement areas on Vancouver Island. When only

Table 2. Spearman rank–order correlation results of annual high- and low-confidence harvest events occurring from 0 to 20 km of the human settlement area of eastern Vancouver Island and annual *C. gattii* cases on Vancouver Island occurring from 1998 through 2014 where cases were included regardless of travel history ($n = 146$ and 241 for confirmed and combined confirmed and probable cases, respectively).

Buffer radius (km)	Confirmed cases		Probable and confirmed cases	
	Correlation	*p*-Value	Correlation	*p*-Value
0	0.19	0.47	0.50	0.041
2.5	0.15	0.56	0.46	0.061
5	0.23	0.38	0.55	0.022
7.5	0.42	0.091	0.66	0.004*
10	0.43	0.085	0.64	0.005*
12.5	0.44	0.080	0.61	0.009
15	0.46	0.063	0.59	0.012
17.5	0.43	0.088	0.57	0.018
20	0.41	0.098	0.54	0.027

Note: Annual human case numbers for confirmed and probable *C. gattii* infections are provided in Table 1. Here, harvest events occurring the same year as case reporting were assessed. A confirmed case was defined as a culture-confirmed *C. gattii* infection using differential media and genotyping. A probable case was defined as laboratory evidence of infection in an human immunodeficiency virus (HIV)–negative person using antigen detection, histopathology, or microscopy. Case data were provided through the British Columbia Centre for Disease Control Reportable Diseases Data Dashboard (http://www. bccdc.ca/health-professionals/data-reports/reportable-diseases-data-dashboard). Tree harvests were assigned high or low confidence through a random forest classifier, based on how many votes from individual trees were received for each class type (e.g., tree harvest, fire). The proportion of votes of the second-most voted class (v2) was divided by the proportion of votes of the assigned class (v1). Tree harvests were considered high confidence if v2/v1 was ≤0.4 and low confidence if v2/v1 was >0.4. Tree harvest data were provided by Hermosilla et al.[10] (see https://opendata.nfis.org/mapserver/nfis-change_eng.html). Annual human case numbers for confirmed and probable *C. gattii* infections are provided in Table 1. The *p*-values were obtained from the Spearman correlation coefficient test. *Statistically significant after Bonferroni adjustment ($p < 0.0056$, where p was adjusted as 0.05/9).

assessing cases with no evidence of travel outside of British Columbia (Table S2), tree harvesting area was also positively correlated with *C. gattii* incidence among Vancouver Island residents, or approached significance, within 7.5 km ($r = 0.65$, $p = 0.005$) and 10 km ($r = 0.63$, $p = 0.007$) (Table S5). When assessing high-confidence tree harvesting area alone,[10] tree harvesting area was positively correlated with *C. gattii* incidence among Vancouver Island residents, or approached significance, within both 7.5 and 10 km. This was true for cases regardless of travel history ($r = 0.63$, $p = 0.007$ and $r = 0.65$, $p = 0.005$, respectively) and for cases with no evidence of travel outside of British Columbia ($r = 0.62$, $p = 0.009$ and $r = 0.63$, $p = 0.007$, respectively) (Tables S6 and S7). Across all tests comparing harvest events occurring the same year as case reporting, confirmed cases alone showed no strong or significant correlations with tree harvesting area (Table 1; Table S5–S7). Tree harvest events occurring 1 y prior to case reporting showed no strong or significant correlations in any test (Tables S8–S11). However, correlations remained highest within distances of 7.5 and 10 km from human settlement areas in all sensitivity tests, consistent with analyses of tree harvest events occurring the same year as case reporting. Tree harvesting within 60 m of the highway construction zone from 1991 to 1999 was minimal compared with overall tree harvesting, consisting of <5% of total high- or high- and low-confidence tree harvesting occurring within either 7.5 or 10 km of the human settlement areas (Figure S2 and Tables S12 and S13).

Discussion

Summary of Results and Interpretation

Human *C. gattii* incidence on Vancouver Island was correlated with the tree harvesting area from 1998 through 2014. As the annual tree harvesting area increased between 1999 and 2003, so did the annual incidence of disease in the population. The correlation was strongest when tree harvesting occurred in the same year within 7.5 and 10 km from human settlement areas on the island. Our results support previous findings that tree disturbance

may increase aerosolization of *C. gattii* spores. For instance, the felling and chipping of individual colonized trees has been shown to increase the concentration of *C. gattii* spores,[17] whereas residing within 10 km of a logging or commercial soil disturbance site on Vancouver Island was a significant risk factor for the development of cryptococcosis in dogs and cats.[18] Our results show the highest correlation between tree harvesting area and human *C. gattii* incidence occurred within 7.5 and 10 km from human settlement areas (and declined thereafter up to 20 km), suggesting, as Duncan et al.[18] did, that *C. gattii* spores may travel a few kilometers to cause infection in mammals.

In our study, the relatively low correlation between tree harvesting area and human *C. gattii* incidence that was found between 0 and 5 km could also suggest that microhabitats for *C. gattii* are most abundant 10 km from the coast. These findings may also suggest that, relative to broader-scale logging and commercial soil excavation, soil and tree disturbance activities that occur in (sub)urban areas are not intense enough to cause sufficient aerosolization of spores to increase infection risk. For instance, although living within 10 km of a commercial soil disturbance area was the most significant risk factor for the development of cryptococcosis in domestic dogs and cats, vegetation and soil disruption at the residence of these animals, such as chopping wood, gardening, or home construction, were not identified as significant risk factors.[18,38] It is also possible that tree harvesting occurring within less than a 5-km radius is not sufficient in intensity to increase disease risk.

Possible Mechanisms of C. gattii *Emergence and Spread*

In 1999, when the first confirmed case of *C. gattii* was recorded on Vancouver Island, tree harvesting areas outside human settlements were at least 47% higher than in any prior year since 1985 across all buffer zones (Table S4). The increase in harvesting beginning in 1999 may have been related to the construction of the Inland Island Highway[39] (Figure S1). Tree harvesting directly caused by the highway construction was minimal compared with general tree harvesting occurring in the area (Figure S2 and Tables S12 and S13). However, the highway construction may have indirectly contributed to *C. gattii* dispersal by facilitating the development of side roads for further construction and tree harvesting projects or by providing vehicle traffic that may have increased mechanical dispersal of spores.[17]

The consistent correlation found between tree harvesting area and human *C. gattii* incidence in our study suggests that soil and tree disturbance may have played a role in the emergence of *C. gattii* human and animal infections on Vancouver Island in 1999. The relative increase in tree harvesting beginning in 1999 may have aerosolized and spread fungal colonies that had previously experienced little to no disturbance. Harvested colonized trees may have also been chipped and transported to other areas of the island for landscaping, further introducing the fungus to new locations.[17] However, determining the exact cause of the emergence of *C. gattii* on Vancouver Island is challenging given the uncertainty regarding when the fungus first appeared on the island, what source(s) introduced it, and its full geographic distribution.

Limitations and Future Work

Although some georeferenced environmental isolates of *C. gattii* on Vancouver Island and mainland British Columbia exist,[16,26] *C. gattii* has not been systematically sampled across the island. We therefore do not know the full geographic extent of *C. gattii* colonization, nor do we know all the areas that may be permanently, intermittently, or only transiently colonized by *C. gattii*.[17] This limited our ability to compare *C. gattii* cases with targeted forest areas of

C. gattii colonization. We therefore assumed that *C. gattii* was present anywhere in the natural environment around and within human settlement areas along eastern Vancouver Island,[17] and that physical disturbance of these environments through tree harvesting would increase the likelihood of dispersing these spores. For the purposes of this study, we examined the effects of overall tree harvesting area on *C. gattii* incidence. We summed all tree harvesting areas across each buffer zone and could therefore not discern the effects of harvest areas occurring within each zone. However, future research may analyze individual tree harvests along with their area and proximity to cases to account for the spatial complexity of harvests across a landscape. In addition, harvest events, although measured around 1 August of each year,[10,30,32] could have occurred at any point between September of the previous year and August of the current year. It is possible that tree harvests recorded in a given year were compared with cases that were reported prior to the harvesting. Tree harvesting could also occur at any time of year in British Columbia and were not necessarily occurring in the same season each year, with summer months offering warmer conditions for workers and winter months providing harder grounds for the easier passage of machinery.[40]

The *C. gattii* case data used in this study do not necessarily represent the location where humans contracted the infection. Given the high mobility of humans, the lengthy incubation period of *C. gattii*, and the lack of complete travel histories, we were unable to assign exact locations of exposure. Instead, we accounted for travel where possible and calculated distances from eastern human settlement areas, as opposed to creating buffer zones around each specific location of residence. We assumed that most people infected with *C. gattii* on the island spent most of their time living and working within the eastern human settlement area, where most of the island population resides. We also did not have access to data specifying whether individuals developed *C. gattii* infections following immunocompromised status (e.g., cancer patients, organ transplant recipients). If we had removed these individuals from our analyses, we likely would have found stronger correlations between tree harvesting and *C. gattii* incidence. It is also important to note that we did not assess potential interactions between soil and tree disturbance and climatic factors, such as temperature. Future research should focus on how climatic changes, including climatic oscillations and global climate change, may interact with soil and tree disturbance to affect incidence rates of *C. gattii* and other fungal infections. Attention should also be paid to human settlement areas farther from the eastern coastline of the island to determine whether 10 km is indeed an optimal dispersal distance for spores or whether it indicates a distance from the shoreline where microhabitats for the fungus are most abundant. Tree harvest data sets with a finer temporal resolution would also be beneficial to better estimate timings between soil and tree disturbance and subsequent infection.

Conclusions

To the best of our knowledge, our study is the first to demonstrate a correlation between broad-scale tree harvesting and human *C. gattii* incidence. We found that annual tree harvesting within 10 km of human settlement areas on Vancouver Island were correlated with *C. gattii* incidence in the same year. Our findings suggest that tree harvesting may have played a role in the emergence of *C. gattii* on Vancouver Island by facilitating the aerosolization of spores. These findings further suggest that tree and soil disturbance activities may play a role in infection risk caused by similar fungal species that rely on spore aerosolization for dispersal. This research also illustrates the contribution that geographic information systems and remote sensing data can make to public health research on environmental disturbance and disease outbreaks.

Acknowledgments

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