Disturbance in Small, Fragmented Peat Bogs and its Contribution to *Iris pseudacorus* Colonisation

by

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COMMITTEE APPROVAL

The members of William Lanceley's Thesis Committee certify that they have read the thesis titled Disturbance in Small, Fragmented Peat Bogs and its Contribution to *Iris pseudacorus* Colonisation and recommend that it be accepted as fulfilling the thesis requirements for the Degree of Master of Science in Environment and Management:

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Final approval and acceptance of this thesis is contingent upon submission of the final copy of the thesis to Royal Roads University. The thesis supervisor confirms to have read this thesis and recommends that it be accepted as fulfilling the thesis requirements:

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Abstract

Peat bogs are of global importance as carbon sinks and hotspots of biodiversity. In British Columbia, some peat bogs such as the Galiano Island Ecological Reserve are fragmented by the construction of roadways (Cook Road). This construction impacts the dynamic of the bog, which is also affected by an invasion by *Iris pseudacorus*. It is therefore necessary to determine how the disturbance from Cook Road affects the spread of this invasive species. *I. pseudacorus* individuals in disturbed and undisturbed sections of the bog's periphery were counted and compared, and buffer zone widths between Cook Road and the bog were measured. *I. pseudacorus* numbers were significantly higher in disturbed areas. Areas of the bog beside wider buffer zones were found to have lower *I. pseudacorus* numbers due to them being areas free from disturbance. Predictions were made for future *I. pseudacorus* spread at the bog, and management strategies to prevent this spread and attempt its removal were proposed.

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Acknowledgements

Firstly, and most importantly, I would like to thank my supervisor, David Singer. After much difficulty in finding a supervisor locally, a last-ditch effort of contacting a researcher from a relevant online science paper put me in contact with David at the HES-SO Changins (Switzerland). He agreed to supervise me almost immediately, and through the many months provided me with excellent expertise, feedback, and input, all with kindness and patience. His generosity and willingness to help was a breath of fresh air. Thank you so much David.

I'd also like to thank Dr. Risa Smith, Sarah Joanisse, and Erica McClaren for showing enthusiasm for my project and for helping me attain a permit to work at the Galiano Island Ecological Reserve. After difficulty in finding a suitable study site, and some disheartening bureaucratic processes with other organisations, I contacted Risa with hopes of carrying out my research at GIER and received a warm and encouraging response. From then on, it felt that there was minimal work on my part as Risa, Sarah, and Erica helped to organise my permit, without which this thesis would not have been able to go ahead in its current form. GIER ended up being the absolute perfect study site for my project, with everything lining up geographically and ecologically, and I thoroughly enjoyed the peace and relaxation I felt while out in the field.

Lastly, I'd like to thank Catherine Tarasoff for her careful evaluation and comments on my work. I appreciate her time and effort to step in as a reviewer for this project.

Thank you all!

Introduction

Peat bogs, fens, marshes, and swamps are classified as threatened wetland habitats in British Columbia (MacKenzie & Shaw, 1999; Marshall, 2023). Peat bogs are acidic, low nutrient, and slow-growing wetlands which store large amounts of organic matter. They form over many thousands of years, when floating mats of vegetation (i.e. *Sphagnum)* creep over a pond or lake and slowly deposit debris until the lake is full of saturated, undecayed plant matter. Peat bogs cover approximately 3% of the worlds terrestrial surface and are large carbon sinks, storing up to 21% of global soil carbon (Leifeld & Menichetti, 2018). Eighty-five percent of this carbon is stored in the northern hemisphere (Harris et al., 2021), with Canada having the world's largest peatland carbon stock (Joosten, 2009). Peat bogs are also important actors in the water cycle as they store 10% of global freshwater (Joosten & Clarke, 2002). Peat bogs are also sites of specific and often niche biodiversity on the genetic, species, ecosystem, and landscape levels (Minayeva & Sirin, 2012). It is therefore in the world's best interests to protect peatlands for their diversity, their stores of freshwater, and to reduce carbon emissions. This protection is directly in line with the Government of Canada's (2021) objectives to achieve net-zero emissions by 2050.

The southern regions of British Columbia are estimated to have lost 60-98% of their original wetlands since European colonisation (Cox & Cullington, 2009). This is due to multiple factors such as urbanisation, agricultural development, hydroelectric initiatives, mining, forestry, ranching, outdoor recreation, and the construction of road networks (MacKenzie & Shaw, 1999). Between 1967 and 1982, 30% of all land converted for urban development in British Columbia was wetland (MacKenzie & Shaw, 1999). Before colonization, valley bottoms in the Lower Fraser Basin, like Sumas Prairie, were forested or consisted of extensive wetlands (Boyle et al., 1997). From the 1860s, many rivers were diked and wetlands drained to create fertile land for grazing and agriculture (Boyle et al., 1997; MacKenzie & Shaw, 1999). The construction of road networks, while also occupying significant wetland space, has a less visually obvious but equally damaging impact by contributing to a "disconnected landscape" (MacKenzie & Shaw, 1999). This fragmentation can split the micro-habitats of the bog and can cause ecosystem decay (Trombulak & Frissell, 2000). These aspects of anthropogenic activity, as well as the influence of climate change and pollution, have the highest impact on the function, stability, and extent of all wetlands in British Columbia. (Hebda et al., 2000; Minayeva & Sirin, 2012; Vitt et al., 2020). In peat bogs, these impacts can cause a reduction in carbon sequestration rates or loss of stored carbon (Page & Baird, 2016), a thinning of *Sphagnum* coverage (Vitt et al., 2020), loss of biodiversity (Page & Baird, 2016), changes in the vegetation community (Chasmer et al., 2021), and detrimental changes in hydrological function (Page & Baird, 2016), with each issue having the ability to compound itself or other issues. Moreover, due to these environmental changes potential invasive plant species can colonise the habitat (Houlahan & Findlay, 2004). This leaves the ecosystem less resilient and more susceptible to change following further disturbance (Newman et al., 2013). Exotic plant invasions can have a wide range of impacts at the species, community, and ecosystem level (Vilà et al., 2011). They have been linked to biodiversity loss (Vilà et al., 2011), changes in ecosystem functions like nutrient and carbon regulation

(Ehrenfeld, 2003; Liao et al., 2007), changes in soil microbial processes (Hawkes et al., 2005), and changes in genetic diversity of native species (Lishawa et al., 2019).

Iris pseudacorus, commonly known as yellow flag iris, is a 60-165cm flowering plant native to Europe, which, through introduction for ornamental purposes, has become an invasive species on a global scale (Engin et al., 1998; Gallego-Tévar et al., 2022). *I. pseudacorus* is typically a wetland plant, growing on sites with continuously high water content like at the edges of a water body (Sutherland, 1990), but can also grow and flower in dry, sandy soils (Dykes, 1913). *I. pseudacorus* typically grows in acidic to slightly basic substrates between a pH range of 3.6 to 7.7 (Sutherland, 1990) and is tolerant of anoxic conditions (Schlüter & Crawford, 2001, Wu et al., 2013). This means that *I. pseudacorus* is well-suited to colonise acidic and anoxic bogs. *I. pseudacorus* is also tolerant of a wide range of temperatures, with diurnally fluctuating temperatures being a key component of the species' high germination rates (Gillard et al., 2022). *I. pseudacorus* spreads mainly through seed dispersal (Gaskin et al., 2016), but it also spreads vegetatively and through the dispersal of rhizome fragments (Jaca, 2013). The seeds of *I. pseudacorus* spread through hydrochory – they use water as a medium in which to disperse – and can remain floating and viable for up to seven months (Coops & van der Velde, 1995). The seeds are hardy, and germination can occur even if the seed has previously been submerged in water (Coops & van der Velde, 1995). The rhizomes of *I. pseudacorus* accumulate loose sediment to aid their spread, which becomes compacted and forms dense mats that can influence water table fluctuation and cause drainage issues (Capital Regional District, 2020). Frequent water table fluctuation in bogs has been shown to impede the growth of *Sphagnum* and facilitate fungal proliferation, which accelerates decomposition and ultimately leads to reduced rates of carbon sequestration (Kim et al., 2021). Germination rates in *I. pseudacorus* seeds are higher and occur faster in flooded conditions (Gillard et al., 2021), therefore, fluctuating water levels can benefit the species' distribution. *I. pseudacorus* has also been shown to reduce species richness and diversity in its colonisation range and is known to displace native plants and animals (Gallego-Tévar et al., 2022; Raven & Thomas, 1970; Thomas, 1980). As *I. pseudacorus* is known to contain high levels of glycosides, it is unpalatable and only a few species of insect will feed on it (Jacobs et al., 2010; Tu, 2003). It is even stated that palatable plants growing beside *I. pseudacorus* become unpalatable to grazers (Jacobs et al., 2010). This means there are limited options for biological control of *I. pseudacorus*, making it a particularly troublesome invasive (Tu, 2003). One such bog that is known to contain populations of *I. pseudacorus* is the bog at the Galiano Island Ecological Reserve (GIER).

GIER is predominantly bogland, located towards the north-western tip of Galiano – one of the Southern Gulf Islands in British Columbia (48°58'57.7"N, 123°33'14.3"W) (Figure 1). GIER was originally established in 1990 to preserve the bog (also known as Shaw's Bog) which is 900 m long and 125 m wide. The total area of the reserve is 25 ha (BC Parks, n.d.) (Figure 2). Other larger nearby wetlands such as Burns Bog are well-researched facilities, and the impact of anthropogenic pressure has been extensively studied. On the other hand, smaller bogs are currently less investigated. Therefore, I chose to focus my study on the smaller GIER bog as its management can provide a template for other smaller bogs in the region.

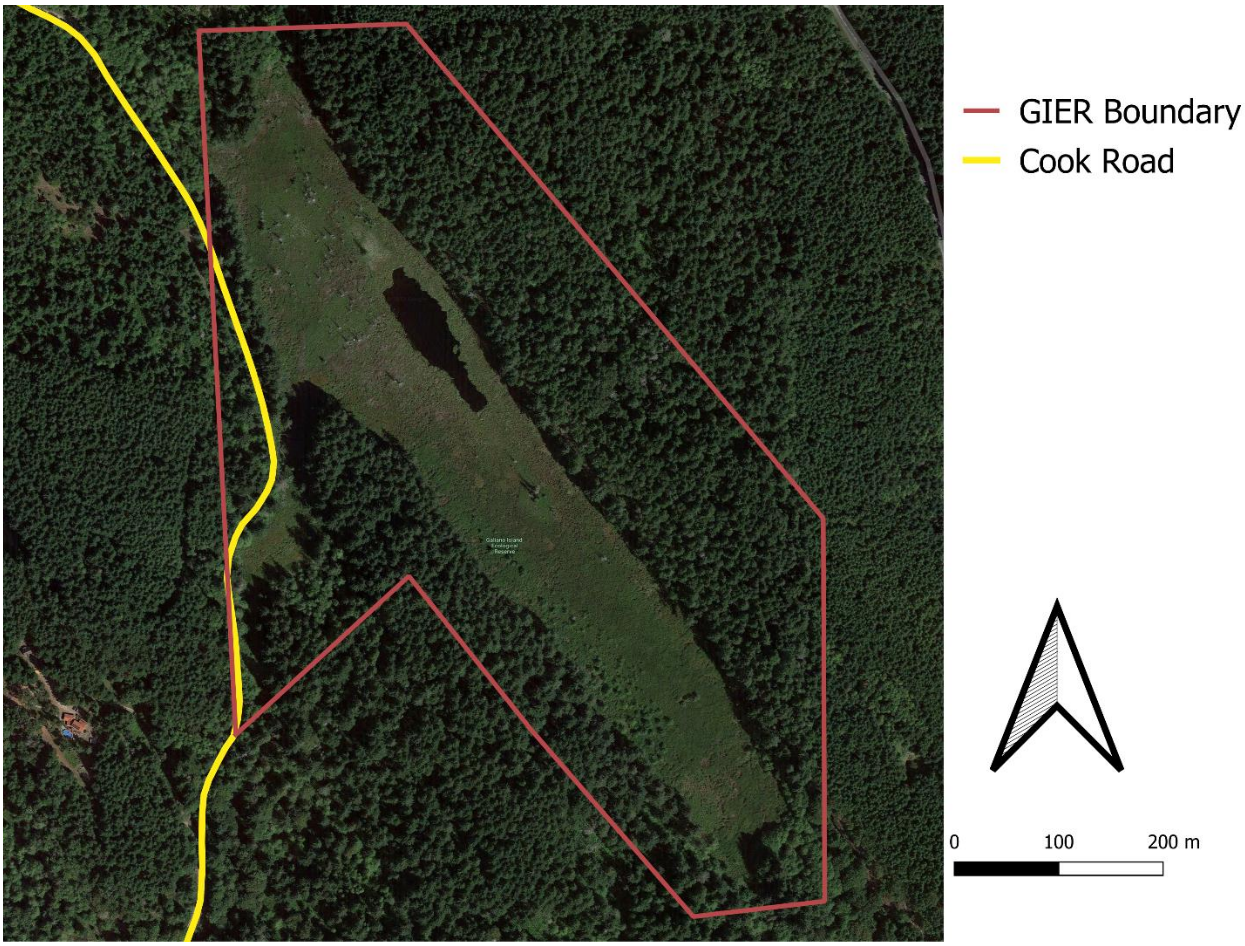
Figure 1

Galiano Island's Location in British Columbia

Note. Galiano Island is highlighted in red, and the location of GIER is shown as a yellow dot on the northwestern end of the island (satellite image obtained from Google Maps).

Figure 2

A Map Showing the Boundary of Galiano Island Ecological Reserve and Cook Road

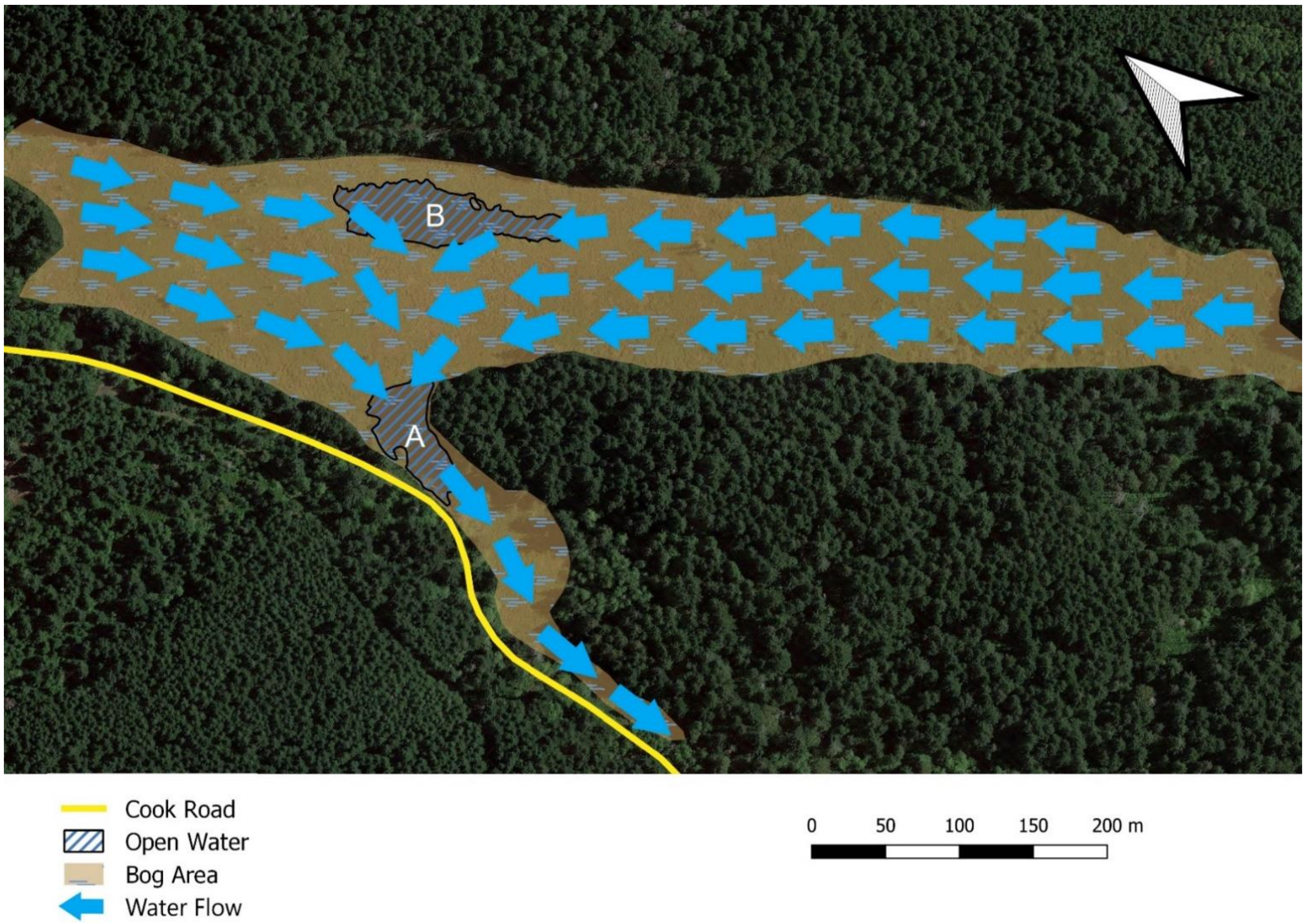


Galiano Island Ecological Reserve Bog

The bog, which is around 14,000 years old (Grier, 2014), sits at approximately 100 m elevation (Kay & Blecic, 2000) and is regionally significant as it forms the source of the 300 ha Jack Creek watershed (Kay & Blecic, 2000). The north-eastern side of the bog is bordered by steep cliffs of Cretaceous sedimentary rock (BC Parks, n.d.), with salal-Douglas fir scrub spreading to the bog's periphery. The south-western side is similar, but there is a flatter section from around the midway point where Cook Road passes. The soils in the bog are primarily fibrisols and mesisols (BC Parks, n.d.). The area of the bog is 11.25ha, with about 0.5 ha being open water (BC Parks, n.d.). There are two main sections of open water, one at the mouth of the drainage channel, hereby referred to as Open Water A, and one in the centre of the bog hereby referred to as Open Water B (Figure 3). As the bog receives all its water from precipitation, the area of open water fluctuates seasonally as the climate is characterised by a precipitation peak in winter, and a drought in summer (BC Parks, n.d.). When the water table rises, the bog drains from the south-western tail, through Open Water A, down an intermittent stream to the sea (Figure 3) (BC Parks, n.d.). The rate of drainage is higher in winter than in summer. The depth of Open Water A and B is unknown as existing information about GIER is limited, but there is 7 metres of sediment built up at the bottom of Open Water B (Grier, 2014). Open Water B is likely considerably deeper than Open Water A as its area does not fluctuate seasonally. Open Water A has a higher seasonal variation in area, so it is likely that much of it is several feet deep rather than several metres. Although a proper bathymetric map of the area cannot be produced due to the lack of existing data, general observation of the hydrometry has been visually represented in Figure 3.

Figure 3

A Map of GIER Showing the Direction of Water Flow and Drainage of the Bog



The dominant vegetation at GIER consists of ericaceous shrubs, herbaceous aquatic plants, and *Sphagnum* moss, with three shrubby bog communities being described: (1) Labrador tea/bog laurel-bog cranberry-*Sphagnum*, (2) Labrador tea-beak rush-*Sphagnum*, and (3) hardhack stands, and three herbaceous wetland communities being described: (4) great bullrush-common reed, (5) slough sedge, and (6) yellow waterlily (BC Parks, n.d.). The bog's moist periphery supports red alder-salmonberry-sword fern communities, and red alder-hardhack-slough sedge/skunk cabbage communities (BC Parks, n.d.). Surrounding the bog are two different forest communities: Douglas fir-arbutus-dull Oregon grape, and Douglas fir-arbutus-salal (BC Parks, n.d.). Figure 4 shows several of these community types.

Figure 4

Plant Communities at GIER

Note. Image 1: stands of beak rush (*Rhynchospora alba*) and slough sedge (*Carex obnupta*); Image 2: yellow waterlily (*Nymphaea mexicana*) in Open Water A surrounded by *I. pseudacorus*; Image 3: common bullrush (*Typha latifolia*) amongst great bullrush (*Schoenoplectus tabernaemontani*); Image 4: Douglas fir (*Pseudotsuga menziesii*) and salal (*Gaultheria shallon*) at the bog's periphery; Image 5: skunk cabbage (*Lysichiton americanus*); Image 6: red alder (*Alnus rubra*) and sword fern (*Polystichum munitum*) at the bog's periphery; Image 7: slough sedge (*Carex obnupta*).

Ten rare species of plants have been identified in the reserve, with one of these – *Juncus acutus* (pointed rush) – having only been identified in five other locations in British Columbia (BC Parks, n.d.). *J. acutus* is perhaps best known as a coastal plant, growing on sand dunes and salt marshes, so its presence at GIER is of interest. Regionally uncommon plants like *Andromeda polifolia* (bog rosemary), *Vaccinium oxycoccos* (bog cranberry), *Drosera rotundifolia* (round-leaved sundew), *Eriophorum chamissonis* (Chamisso's cottongrass), and *Trientalis europaea* (artic starflower) have also been observed at GIER (BC Parks, n.d.). Beavers are present at GIER, and they periodically dam the outlet stream (BC Parks, n.d.). There is clear evidence of beaver in this area and on the north-eastern side of the bog, as some trees have been gnawed away at the base.

Disturbance and Change at GIER

The bog at GIER has recently been undergoing changes with the spread of invasive species (R. Smith, personal communication, 20^{th} November 2021). A species of note is *I. pseudacorus*, patches of which can be seen within the bog, and in large clusters near the periphery of Cook Road (Figure 5), which runs down the southwestern side of the bog, at times coming within feet of the water's edge. The warden of GIER has stated that they are unsure of when *I. pseudacorus* was introduced to the reserve (R. Smith, personal communication, 10th October 2022), but that it was certainly at least 10 years ago. This can be corroborated by imagery from Google Street View taken in 2012, where it appears that *I. pseudacorus* is present at the site but in lower numbers (Figure 6).

I. pseudacorus populations are present throughout the southern Gulf Islands and southern Vancouver Island (Capital Regional District, 2020) and are known to cause ecological problems in other local wetlands (Thomson et al., 2021). In order to understand the impact of this change on the bog, it is crucial to do an evaluation of the current state of *I. pseudacorus* in GIER, as there is little existing literature about this specific bog.

Figure 5

Iris pseudacorus *Clusters at the Periphery of Cook Road in GIER*

Figure 6

A Comparison of I. Pseudacorus *Presence in the Same Section at GIER in 2012 and 2022*

Note. I. pseudacorus appears in the lower half of each image. Although not flowering in the 2012 image, it is possible to see greater numbers of *I. pseudacorus* in 2022 in the foreground of the image and on the other side of Open Water A. (2012 image obtained from Google (2012)).

Another cause for concern at GIER is the proximity of Cook Road to the edge of the bog (Figure 7). Cook Road is a ‘skid road’, constructed for the purposes of logging. The age of the road is difficult to determine, though it is known that logging was happening in the Jack Creek watershed in the early 1900s (Erickson, 2000). There is no accessible information regarding Cook Road’s maintenance schedule, though as there are residential properties along the road, there are certain safety standards that the road must meet according to the Island Trust’s community plan for Galiano Island (2024). Therefore, regrading of Cook Road will have to occur periodically. In some sections, the road passes directly beside the bog, the open water areas and the drainage channel, having been constructed over what was once part of the bog or its shrubby boundary. There is already concern about the road’s use polluting the bog, altering its hydrology and causing sedimentation, particularly if there is increased usage by industry and developers in the future (BC Parks, n.d.). The impact from the construction of the road has caused physical changes to the bog’s periphery, but its maintenance and continued use may have the potential to allow the colonisation of *I. pseudacorus* in the bare substrate at the water’s edge (Jodoin et al., 2008). However, for much of its length Cook Road is separated from the bog by varying widths of Douglas-fir and salal dominated forest: from 5 to over 20 metres. These areas act as a buffer zone between the road and the bog. Buffer zones of 15-25 metres in width have been shown as effective methods to improve habitat quality in riparian ecosystems (Ferris et al., 2012). There is currently no existing literature that determines how the buffer zones at GIER are impacting the spread of *I. pseudacorus*.

It is essential to monitor the ongoing colonization of *I. pseudacorus* from Cook Road into non-impacted areas. It is important to give particular attention to assessing the impact of *I. pseudacorus* in the drainage channel, as uncontrolled expansion could significantly alter hydrology and restrict water flow in this region, potentially leading to the degradation of the entire bog. BC Parks (n.d.) has already made note that beaver damming in the drainage channel periodically affects the water table of the entire bog, demonstrating that region's hydrological importance. Therefore, this initial assessment is critical to providing stakeholders with the necessary information to implement appropriate management practices aimed at restoring biodiversity and the natural function of the peat bog.

Figure 7

Cook Road's Passage Beside Open Water A

Note. Image obtained on Google Street View (Google, 2012).

Objectives

In the context of global climate change and increasing anthropogenic pressure, significant changes are anticipated in small bogs like GIER. A useful indicator for assessing these changes is the presence of the invasive species *Iris pseudacorus*. The combination of undisturbed and highly impacted habitats near Cook Road provides an effective model for evaluating and quantifying these environmental changes. This thesis is structured into three main chapters to address this theme.

1. Evaluate the current distribution of *I. pseudacorus* at GIER;
2. Compare the abundance of *I. pseudacorus* in disturbed sections of the bog's periphery with undisturbed sections to determine the effects of disturbance; and
3. Measure buffer zone widths along Cook Road and compare the abundance of *I. pseudacorus* in the bog beside them.

Methodology

To conduct research at GIER, an Ecological Reserve Permit was first obtained from BC Parks which delineated the type of work that could be done at the site. Research was entirely observational, and the collected data was quantitative, discrete data: population counts of *I. pseudacorus*. Observational data was also collected for the purposes of mapping the reserve.

Creating a Multilayer Map

A multilayer map is an important tool for visually displaying the various features of a research location, and for easily displaying research findings without exhaustive description.

All maps were created using QGIS version 3.22.10 (QGIS, n.d.) (e.g. Figure 8) with data highlighting the area of peat bog, Open Water A and Open Water B, disturbed sections, and *I. pseudacorus* locations, as well as the surrounding forest types in the area. The study focused on two main research locations: the Drainage Channel and Cook Road Buffer Zone, but another area of the bog was designated for referral: Undisturbed Cliff Side (Figure 9).

Data from the map was used to conduct analysis - to determine if there is a difference in *I. pseudacorus* numbers in disturbed and undisturbed areas - and the map was used to accurately measure the width of the buffer zone between sections of Cook Road and the bog.

Figure 8

A Multilayer Map Showing the Extent of the Bog at GIER with Two Open Water Sections (A and B) Highlighted

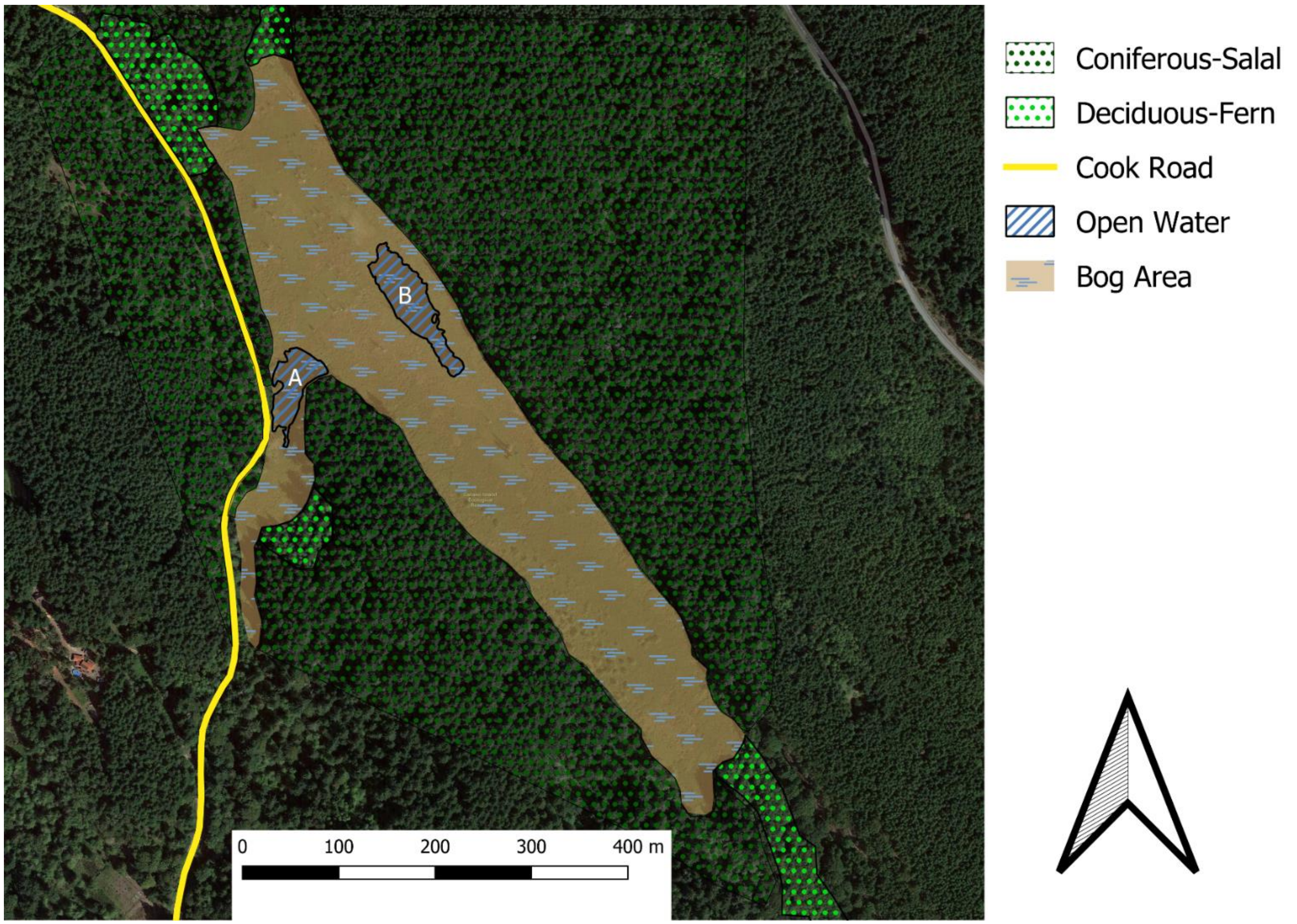
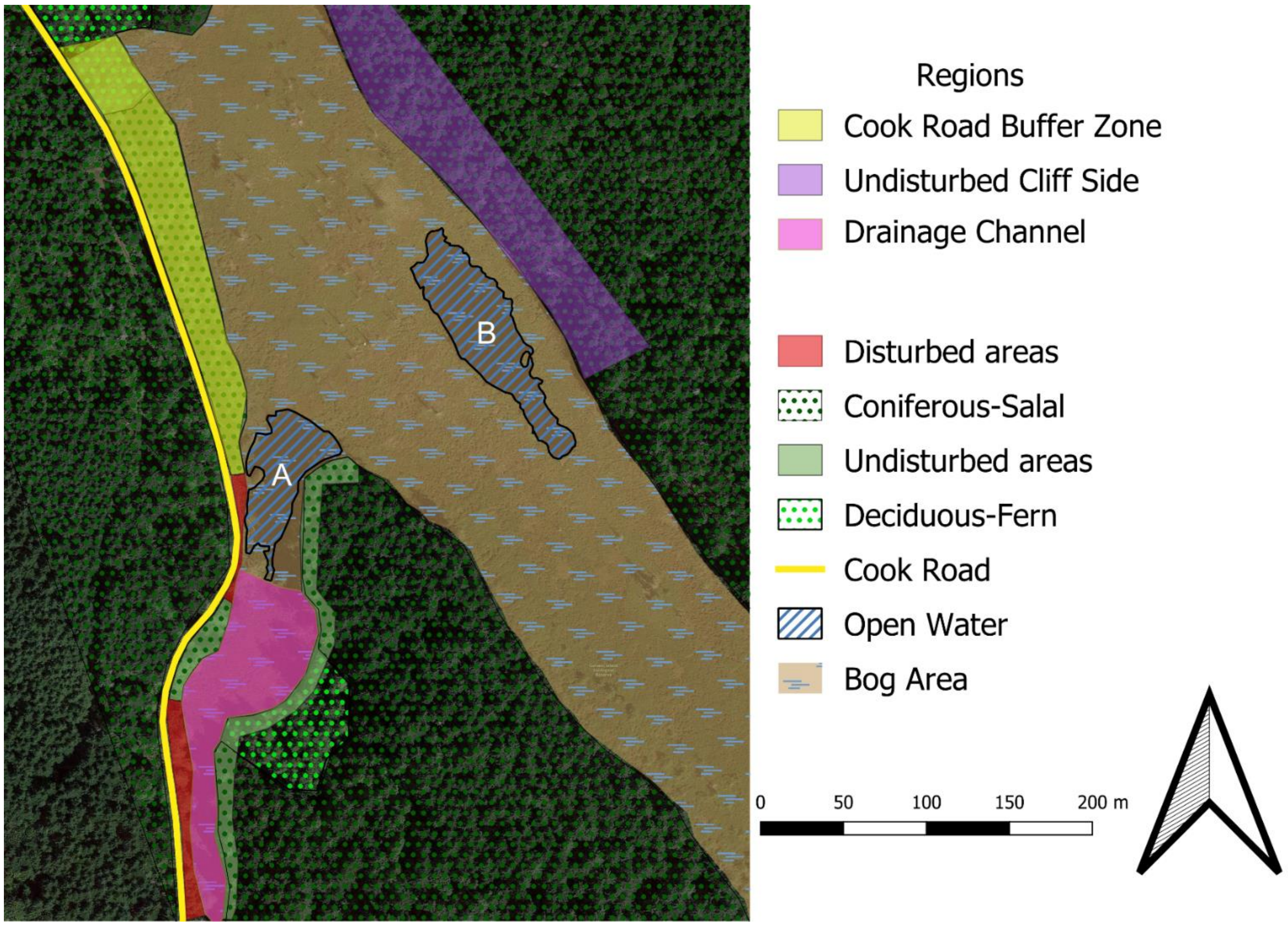


Figure 9

A Multilayer Map Showing the Northwestern Area of the Bog with Highlighted Named Regions

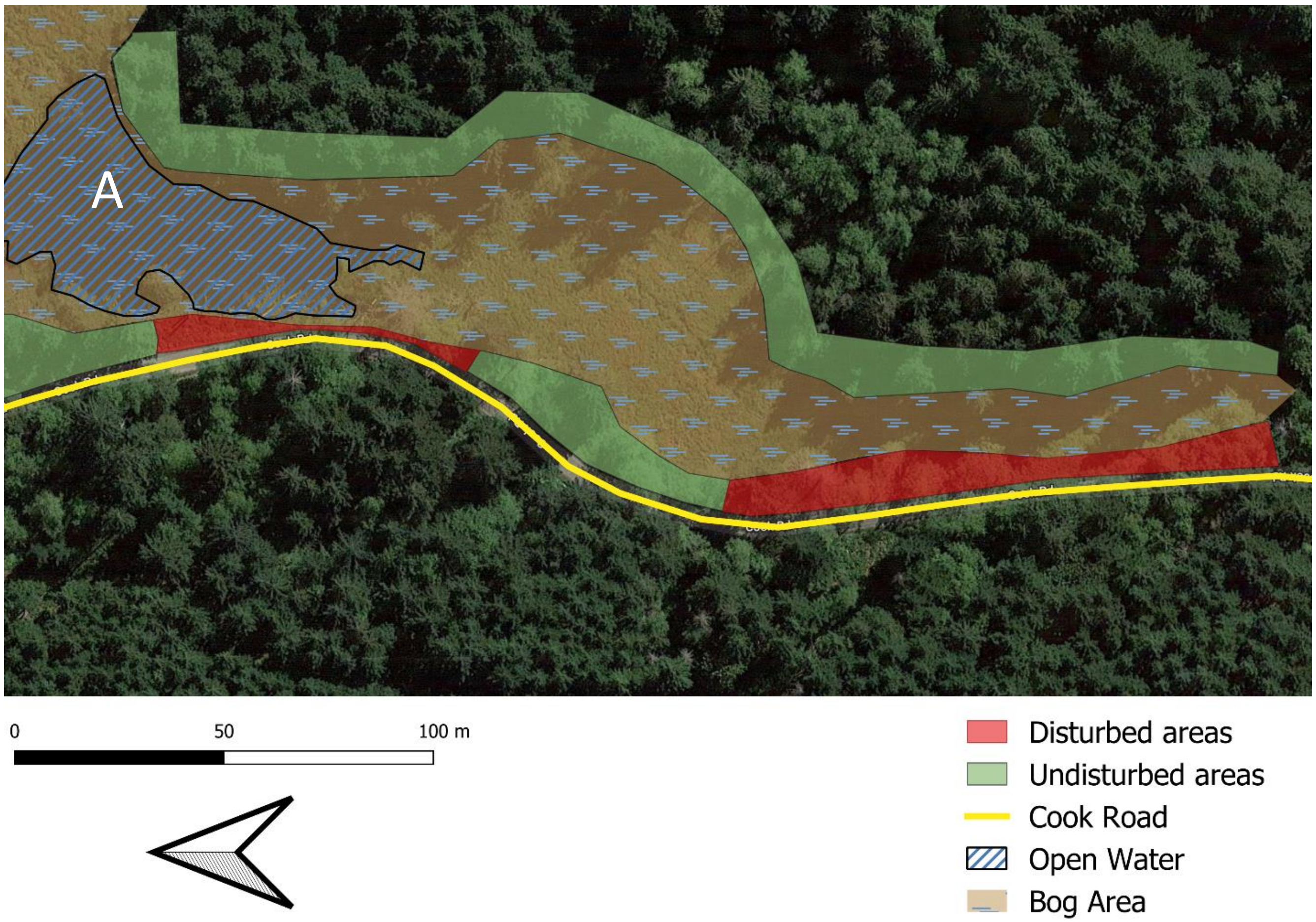


Determining Disturbed and Undisturbed Areas

Before counts of *I. pseudacorus* could be recorded, it was first necessary to classify areas at the drainage channel's boundary as either 'disturbed' or 'undisturbed'. This designation was made through observation. Where Cook Road passes directly beside the bog, there is clear signs of disturbance. There is exposed soil, often mixed with gravel from the road and breaching the water's edge in places, pioneer species such as dandelions, clover, fireweed, and small grasses, and a lack of mature plants. Disturbed areas were typically narrow, with Cook Road passing within a few metres of the bog's boundary. Undisturbed areas had none of these characteristics – they were more established areas with trees such as Douglas fir and alder, mature salal shrubs, ferns, an herbaceous undergrowth, little if any exposed soil, and intact boundaries with the water bordered with slough sedge, common reed and great bullrush – classic examples of the community types described in the literature (BC Parks, n.d.). Undisturbed areas were typically broader than disturbed areas, with more space between Cook Road and the bog's boundary. The disturbed and undisturbed areas are shown in Figure 10.

Figure 10

A Map of the Disturbed and Undisturbed Sections Beside Cook Road



Counts of *I. pseudacorus*

The first field campaign to GIER was on 12th June 2022, during the flowering period of *I. pseudacorus*. Counts of each individual iris were taken from along Cook Road and from points along the periphery of the bog and the buffer zones. Each individual iris was recorded as a data point. Photos were also taken for reference and to ensure counting accuracy. For the purposes of mapping, the geographical coordinates for each individual iris were required. Rough geographical recordings were taken on site, but it was necessary to corroborate reference photos with satellite imagery to determine exact coordinates. In total, 697 individual irises were counted (Appendix C). The number, location, and spatial extent of all *I. pseudacorus* at GIER can be seen in the map in Figure 11, and a closer, more detailed view of iris clusters can be seen in Figure 12. These results satisfy the first objective of this research project, which is to evaluate the current distribution of *I. pseudacorus* at GIER's bog.

Figure 11

Location and Extent of All Individual Iris pseudacorus *at GIER*

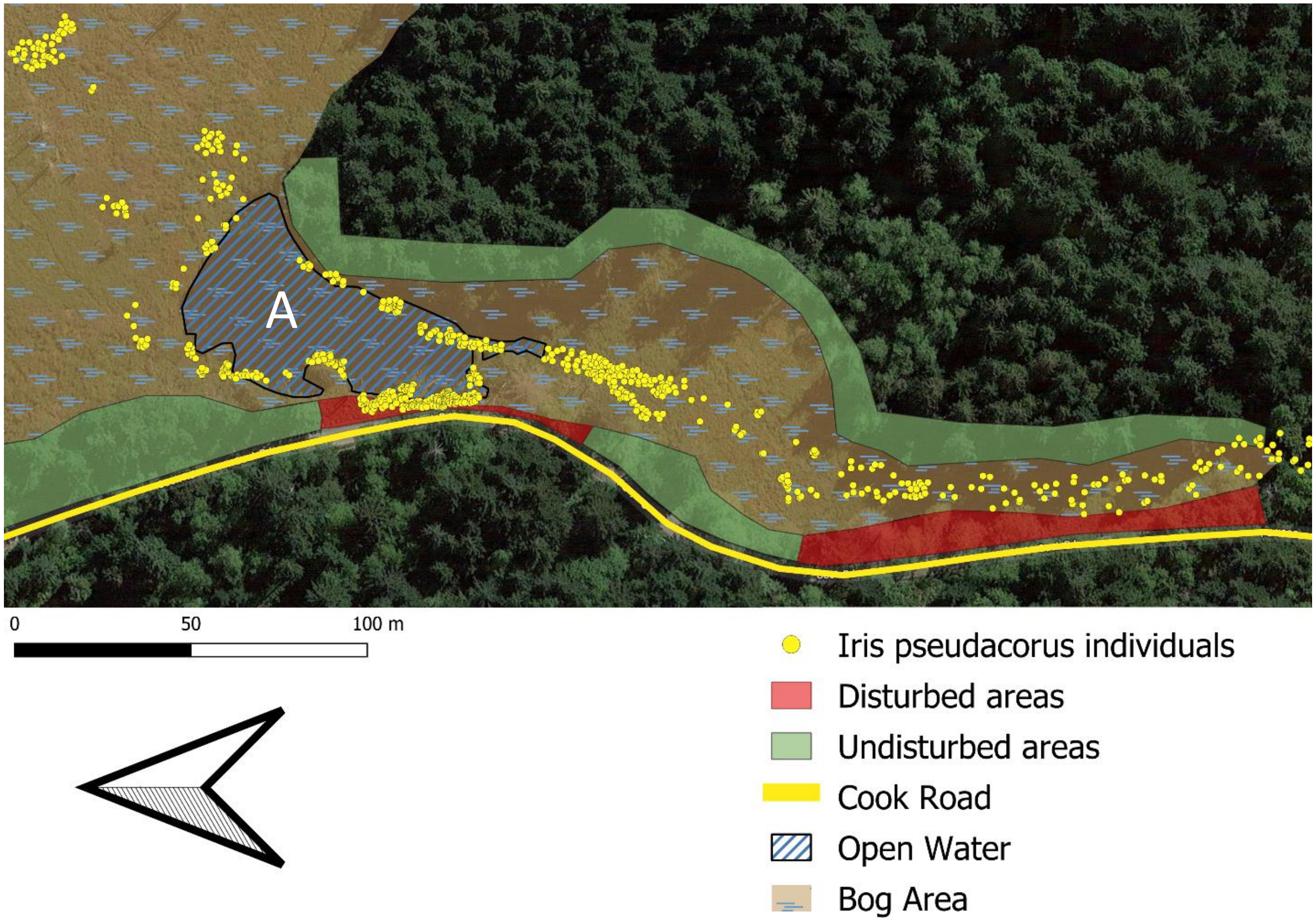
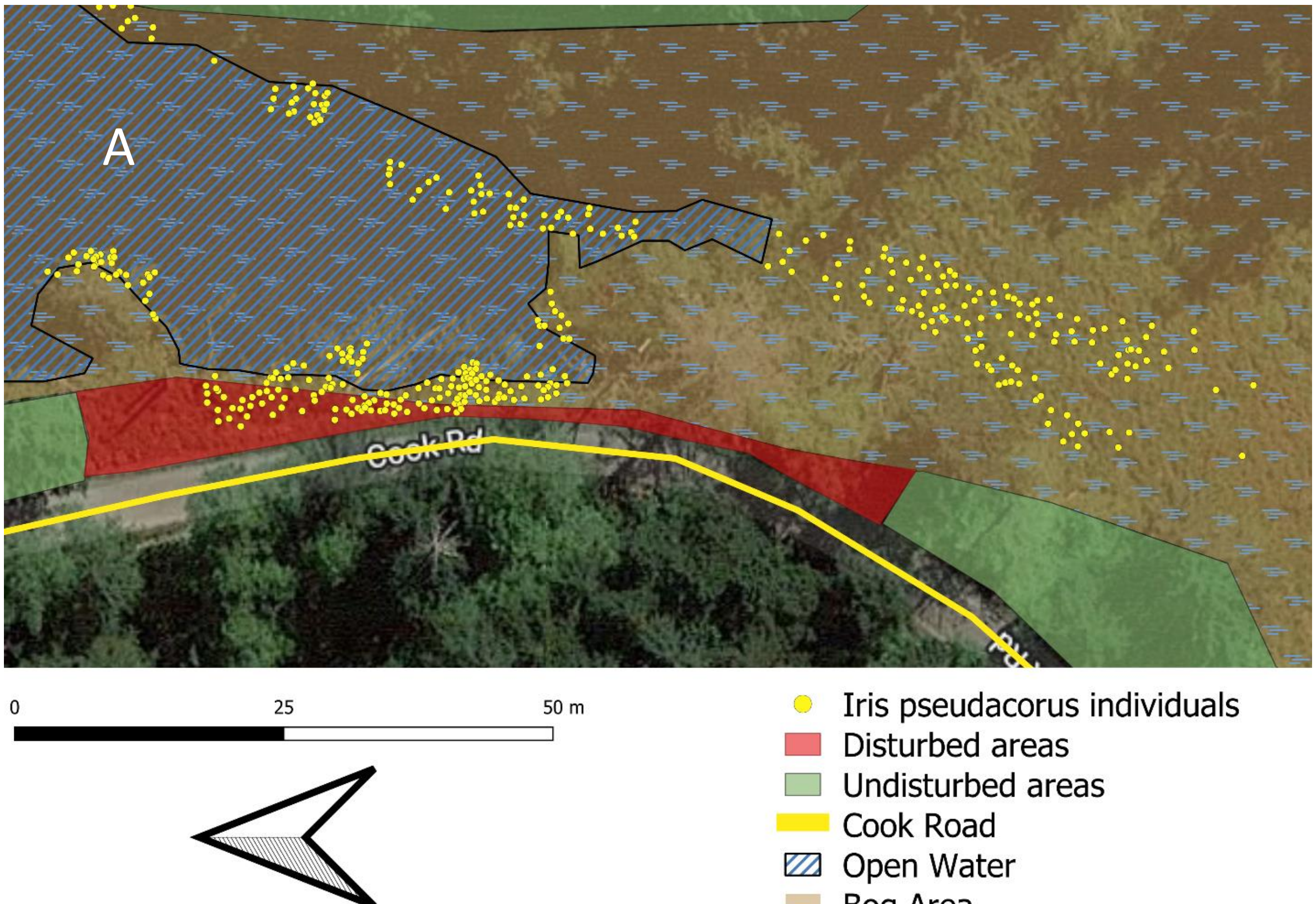


Figure 12

A Detailed View of Iris pseudacorus *Clusters in the Drainage Channel*



Measuring Buffer Zone Width

To determine the effect of buffer zone width on *I. pseudacorus* presence it was necessary to measure the width of the buffer zones along Cook Road. The most accurate method of doing this is to use a measuring tool on the produced multilayer map. The measuring tool allows measurements to be made to the nearest tenth of a metre, and an average buffer zone width over a 25 m section can be determined for use in data analysis.

Data Analysis and Results

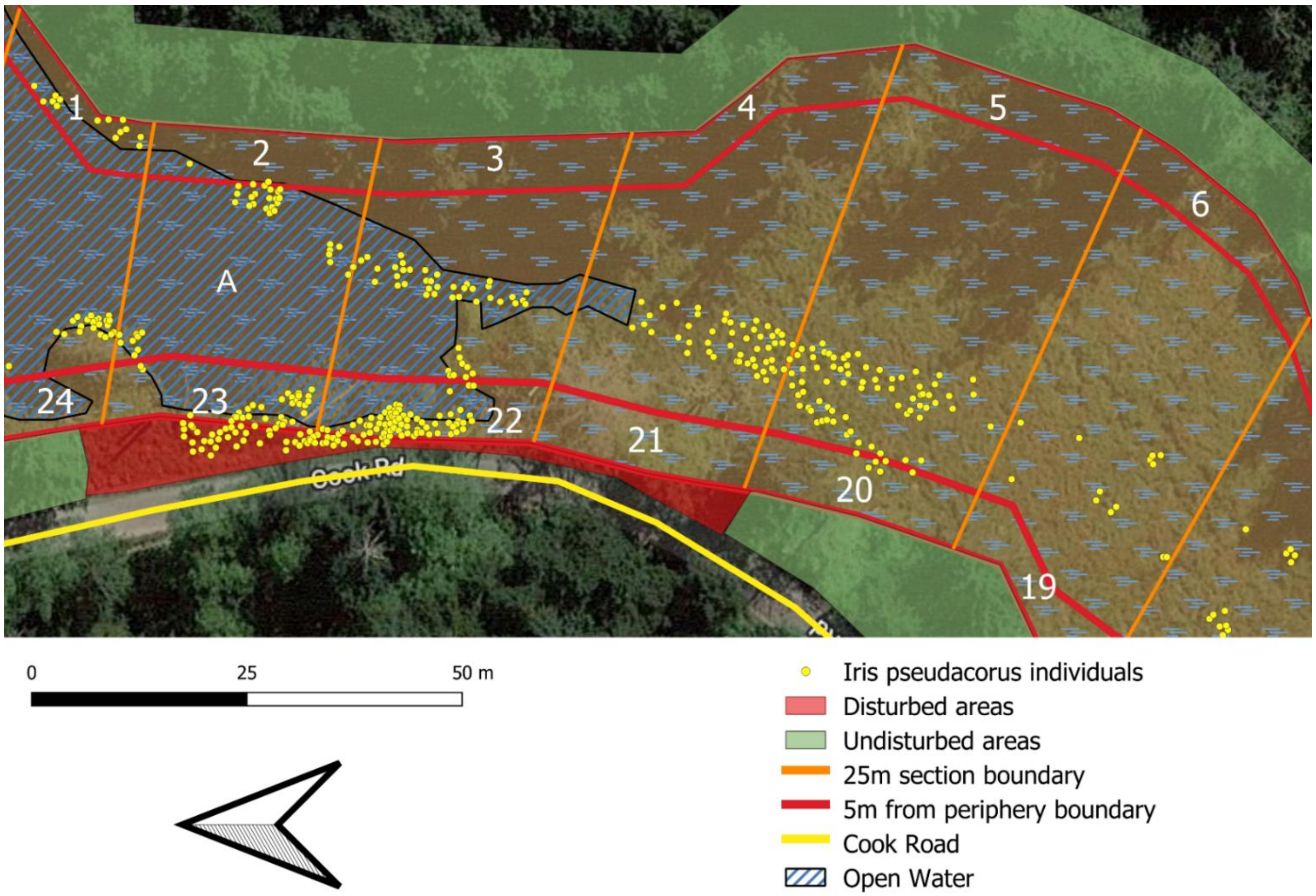
All statistical analyses were carried out using ‘R (4.2.1) software (R Core Team, 2023).

Analysis of *I. pseudacorus* Numbers in Disturbed and Undisturbed Areas

The first analysis was to determine whether there is a significant difference between *I. pseudacorus* abundance in disturbed and undisturbed areas. Data was recorded by counting individual *I. pseudacorus* in numbered 25 m sections from around the periphery of the drainage channel, of which there were 24 in total (Figure 13) (see Appendix A). Since the majority of *I. pseudacorus* individuals - and the only disturbed areas in the bog - were in the drainage channel, only counts of flowering plants from the drainage channel were used for data analysis. Had the entire periphery of the bog been designated as ‘undisturbed’ and counts of iris in those sections been analysed (zero), the data would be significantly skewed. Only counts of flowering plants growing within 5 m of the drainage channel’s periphery were used in the data analysis as any further away than this may not necessarily be influenced by disturbance.

Figure 13

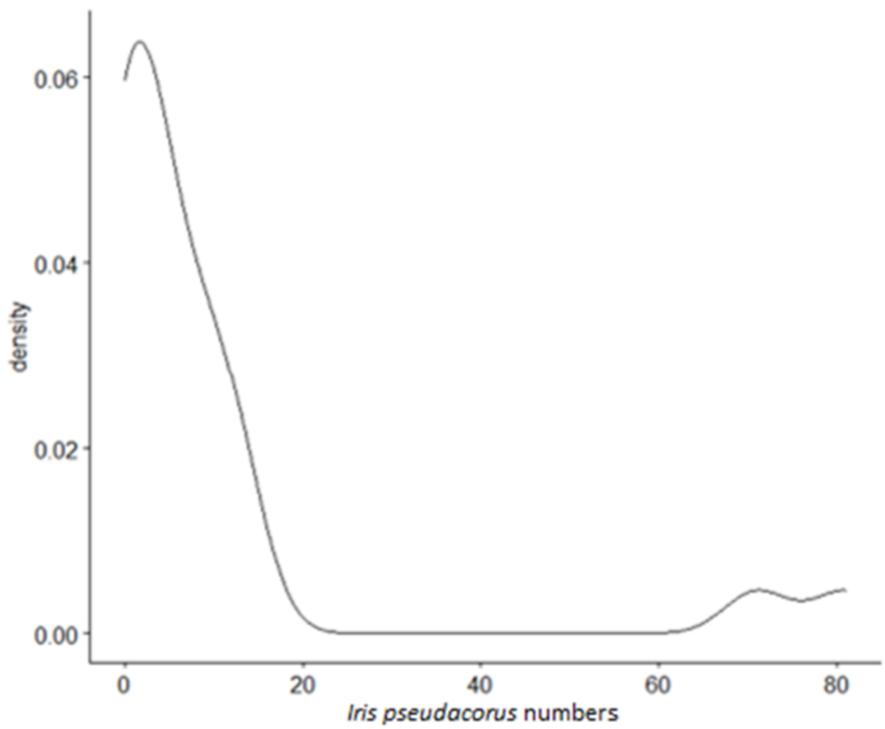
The Drainage Channel with Sections Designated for Data Analysis



To first assess whether the collected data was normally distributed, a figure presenting the instances of *I. pseudacorus* numbers in each section was prepared (Figure 14), and a Shapiro-Wilk normality test was carried out. The data was shown to be not normally distributed (w=0.48, p=>0.05), meaning a non-parametric test will be used for data analysis.

Figure 14

A Graph to Show the Normality in the Dataset of I. pseudacorus *Numbers in Disturbed and Undisturbed Areas*

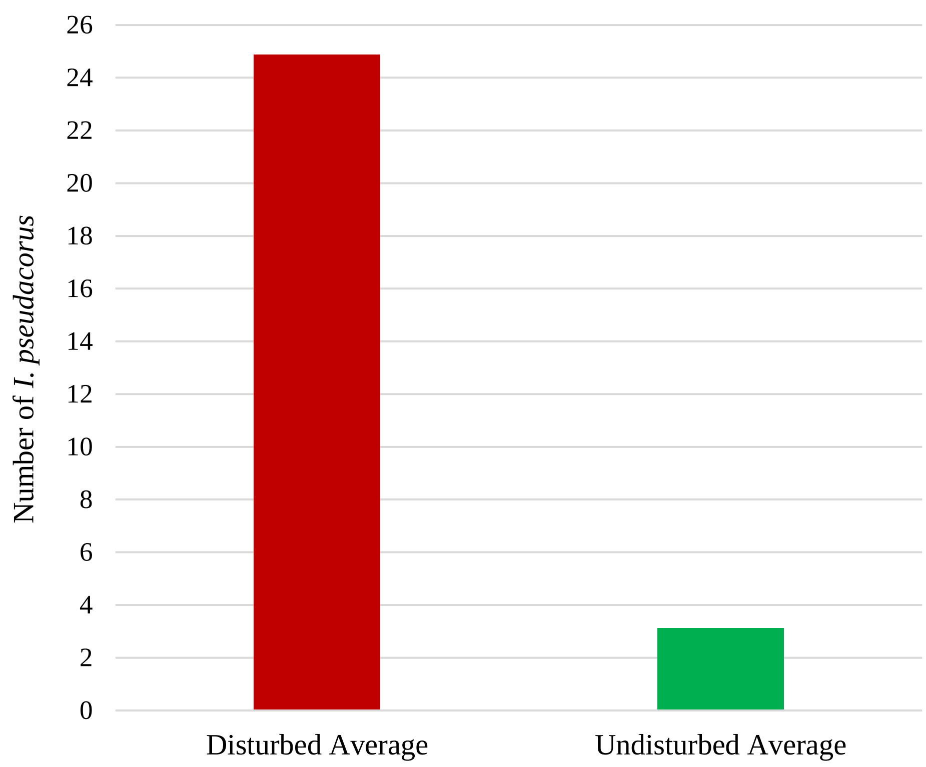


Individual *I. pseudacorus* were categorised into being within 5 m of either disturbed or undisturbed land. The ‘disturbed’ category was recorded as ‘1’, and the undisturbed category was recorded as ‘2’. Since the data is not normally distributed, and a comparison of the means of two sets of continuous data was to be made, the non-parametric Kruskal-Wallis test was carried out. The null hypothesis for this test was that there is no significant difference in *I. pseudacorus* numbers between disturbed and undisturbed areas.

The results of the Kruskal-Wallis test confirm that there is a significant difference between the number of *I. pseudacorus* growing in disturbed and undisturbed areas of the drainage channel (Kruskal-Wallis chi squared = 27.655, df = 2, p value = <0.05), with *I. pseudacorus* numbers in disturbed areas being significantly higher (Figure 15).

Figure 15

A Graph Showing the Average Number of I. pseudacorus *Individuals in Disturbed and Undisturbed Sections*

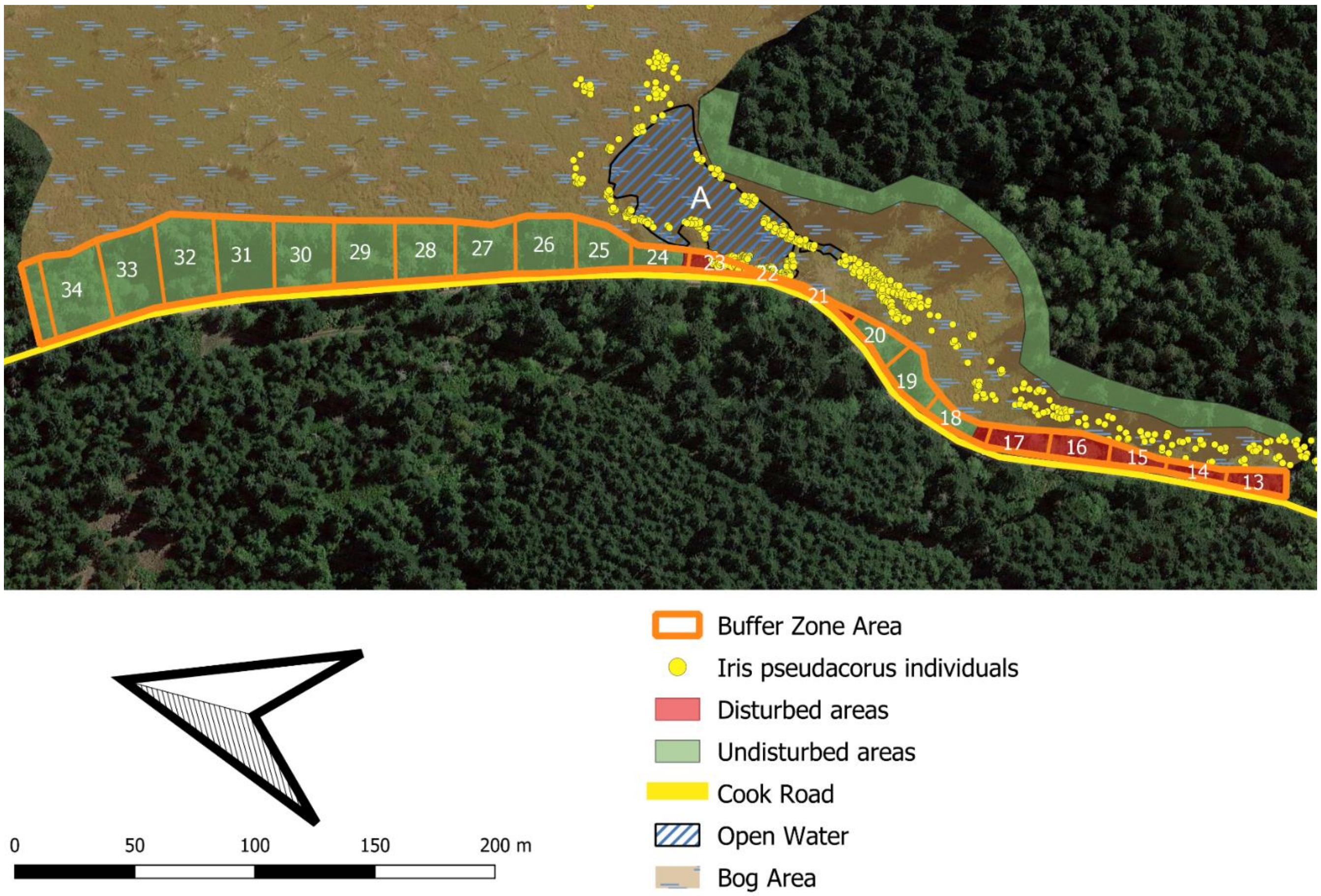


Analysis of Buffer Zone Widths and Adjacent *I. pseudacorus* Numbers

The second test was taken to determine whether the number of *I. pseudacorus* at the bog's periphery changes depending on the width of the adjacent buffer zone between Cook Road and the bog. Measurements of the buffer zone width and *I. pseudacorus* numbers within 5 m of the periphery of the bog were taken in 25 m sections from the southernmost point of the drainage channel to the northernmost point of the bog (see Appendix B) (Figure 16).

Figure 16

A Map of the Buffer Zone Area Along Cook Road, Split Into 25 m Sections



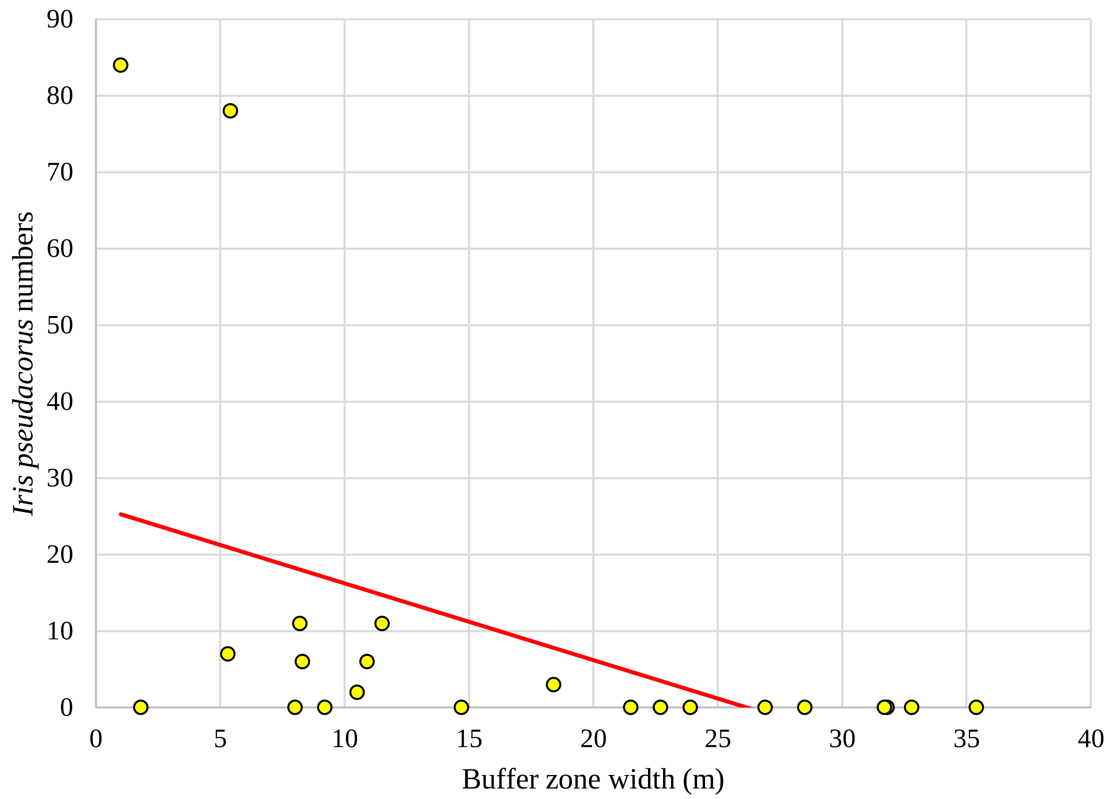
To test whether the collected data was normally distributed, a Shapiro-Wilk normality test was carried out. The data was shown to be not normally distributed (w=0.48, p=>0.05), meaning a non-parametric test will be used for data analysis.

Since a comparison between two quantitative variables was to be made, the non-parametric Spearman's Rank Correlation was used. The null hypothesis for this test was that there is no correlation between buffer zone width and *I. pseudacorus* numbers 5 m from the adjacent periphery of the bog.

The results of the Spearman's Rank Correlation confirm that there is a significant negative correlation between buffer zone width and *I. pseudacorus* numbers 5 m from the adjacent periphery of the bog (S=2870.9, p value=0.002, ρ = -0.621). This means that as buffer zone width increases, the number of *I. pseudacorus* found within 5 m of the adjacent periphery of the bog decreases (Figure 17). However, the results of the test should be interpreted with caution, as two zones with a high number of *I. pseudacorus* individuals (>75) may bias the analysis (Figure 17). Additionally, some samples show no presence of the invasive species even in the absence of a buffer zone. Notably, *I. pseudacorus* is completely absent when the buffer zone exceeds 20 meters.

Figure 17

A Graph Showing the Negative Correlation Between Buffer Zone Width and Adjacent Iris pseudacorus *Numbers*



Analysis of Disturbance, Buffer Zone Width, and Adjacent *I. pseudacorus* Numbers

A third test was carried out to determine whether *I. pseudacorus* abundance differs in disturbed and undisturbed sections as buffer zone width differs. Each section was given two categories based on disturbance (disturbed or undisturbed) and buffer zone width. Buffer zones were categorised as ‘narrow’ (being less than 10 m in width), ‘medium’ (being greater than 10 m but less than 20 m in width), or ‘wide’ (being greater than 20 m in width). For example, a section may be categorised as being narrow and disturbed, or medium and undisturbed.

To test whether the collected data was normally distributed, a Shapiro-Wilk normality test was carried out. The data was shown to be not normally distributed (w=0.48, p=>0.05), and since a comparison was to be made between two or more continuous sets of data, the non-parametric Kruskal-Wallis test will be used for data analysis.

The results of the Kruskal-Wallis test determined that there is no significant difference in iris numbers in disturbed and undisturbed areas across the three buffer zone categories (Table 1).

Table 1

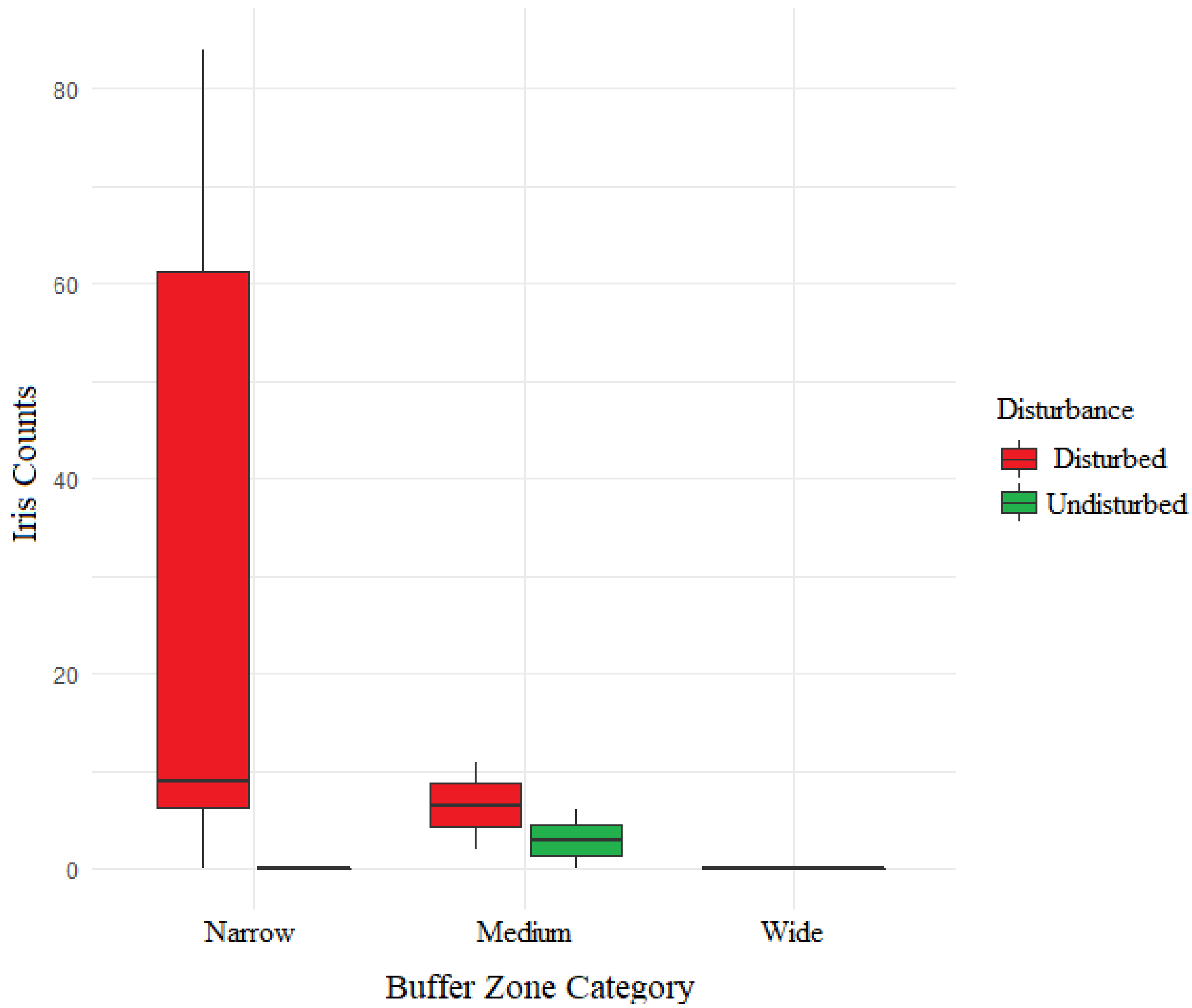
Results of the Kruskal-Wallis Test to Show the Difference in I. pseudacorus *Numbers in Disturbed and Undisturbed Areas*

	P values	
Buffer Zone Widths	**Undisturbed**	**Disturbed**
Narrow (n=186)	0.333	0.088
Medium (n=22)	2.920	0.564
Wide (n=0)	N/A	N/A

As there were no records of *I. pseudacorus* being present in any section with a buffer zone wider than 20 m, no data was present for the analysis and no result was produced. These results are presented graphically in Figure 18.

Figure 18

A Boxplot Showing Counts of Iris pseudacorus *in Disturbed and Undisturbed Areas in Three Different Buffer Zone Width Categories*



Discussion

The first objective of this research – to evaluate the current status of *I. pseudacorus* in GIER's bog – was satisfied in the production of the multilayer maps shown earlier in the document (Figures 11, 12, 13 & 16). The maps have highlighted all 697 individual *I. pseudacorus* plants at GIER and shown their geographic location. The maps will provide the site's stakeholders with valuable information for the purposes of invasive species management.

***Iris pseudacorus* at GIER**

A simple answer to the second and third research objectives would be: yes, the disturbance from Cook Road's presence beside GIER's bog does influence the spread of *Iris pseudacorus* at the bog's periphery; and that buffer zone width does not significantly affect *Iris pseudacorus* numbers in disturbed and undisturbed areas. The results of the data analysis show that *I. pseudacorus* numbers are higher in areas that are either disturbed or within 5 m of the disturbance periphery, and that they are lower in areas adjacent to a buffer zone (Figure 18). The results also showed that there is no significant difference in the number of *I. pseudacorus* between undisturbed and disturbed areas as buffer zone width differs (p value > 0.05), though according to the graph in Figure 18 there are considerably more individual irises in disturbed areas beside buffer zones that are less than 10 m in width. However, it is important to consider the geography and hydrology of the site to fully understand the distribution of this spread and the effects that disturbance is having on *I. pseudacorus* colonisation. In this case, the results of the data analysis alone do not provide an accurate answer to the objectives of the research, so some further insights have been made that highlight the limitations of the research.

Insights into the Geographical Distribution of *I. pseudacorus* at GIER

As can be observed from the map in Figures 11, *I. pseudacorus* is present along the drainage channel, in the body of open water at the mouth of the drainage channel (Open Water A), and in a few clusters northeast of there. The drainage channel is also the site for disturbance at GIER as Cook Road runs parallel to it until Open Water A, after which a buffer zone separates the road and the periphery of the bog. An initial glance may lead to the conclusion that disturbance is the source of *I. pseudacorus* spread at GIER, because *I. pseudacorus* is mainly present along the disturbed drainage channel, and once the buffer zone begins *I. pseudacorus* presence greatly declines. However, considering that *I. pseudacorus* likely spread from Open Water A down the drainage channel, the proximity of Cook Road and adjacent buffer zones to the areas of *I. pseudacorus* invasion is coincidental. Although the statistical analysis showed that *I. pseudacorus* numbers are significantly higher within 5 m of disturbed areas than undisturbed areas, *I. pseudacorus* is still present throughout the entire width and length of the drainage channel. As Open Water A and the drainage channel are areas of water runoff, during times when the water table is high the water from the bog will flow towards this area, potentially transporting *I. pseudacorus* seeds that will germinate along the banks (Figure 19). Since Cook Road sits directly beside Open Water A, when the road is regraded gravel is pushed down its sides and into the water, forming an exposed bank in which *I. pseudacorus* can grow, with no other plants forming a physical boundary for *I. pseudacorus* seeds to reach colonisable areas (Figure 19). This is likely the reason why there is such a dense cluster of *I. pseudacorus* directly beside Open Water A. However, it can be presumed that even if Cook Road hadn't been constructed and the periphery of the bog remained intact, *I. pseudacorus* could still be present at GIER. It is impossible to determine the exact cause for *I. pseudacorus* introduction at GIER, but it can be assumed that a rogue seed or rhizome was somehow introduced to the reserve, and the invasion proliferated from there. *I. pseudacorus* seeds spread through hydrochory, so a colonisable area will likely only be reached if there is water flowing to it, as opposed to plants that use wind as the vector in which they transport their seeds for example, where physical disturbance in a nearby area may cause seeds to be knocked loose and transported to the colonisable area. In this way, it is likely that disturbance is not the source of *I. pseudacorus* spread at GIER, but disturbance along the bog's periphery is absolutely creating an environment in which *I. pseudacorus* can more easily spread and is increasing the rate at which the bog's ecological function is being compromised.

Figure 19

I. pseudacorus *Beside Open Water A, with Gravel from Cook Road's Regrading Forming a Bank*

Similarly, the statistical analysis found that as a buffer zone widens, *I. pseudacorus* numbers within 5 m of the periphery between the bog and the buffer zone decrease. This is likely an example of correlation not causation, at least at GIER. Coincidentally, the drainage channel is an area where buffer zones are the narrowest and *I. pseudacorus* numbers are the highest. Again, considering that *I. pseudacorus* is likely spreading from sources within the bog, the buffer zones are not necessarily limiting internal invasive species spread the way they limit external species introduction. The fact that the buffer zone happens to widen past Open Water A, and that *I. pseudacorus* numbers are lower in this section, is coincidence. *I. pseudacorus* likely hasn't spread along the bog's periphery past Open Water A because there is not a suitable level of water in which to transport its seeds, not because the buffer zone widens. However, this statistical analysis was still deemed a valuable inclusion in this thesis because buffer zones accommodate undisturbed areas at the bog's periphery where invasive species colonisation is less likely. The wider these buffer zones were, the further from the disturbance of Cook Road the bog's periphery was, and therefore the lower *I. pseudacorus* numbers are not necessarily a result of data skew but a demonstration of a buffer zone's importance in limiting internal invasive species spread at a bog by being an area free from disturbance. Buffer zones can therefore improve the ecological resilience of an ecosystem even if the threat of invasive species spread is internal.

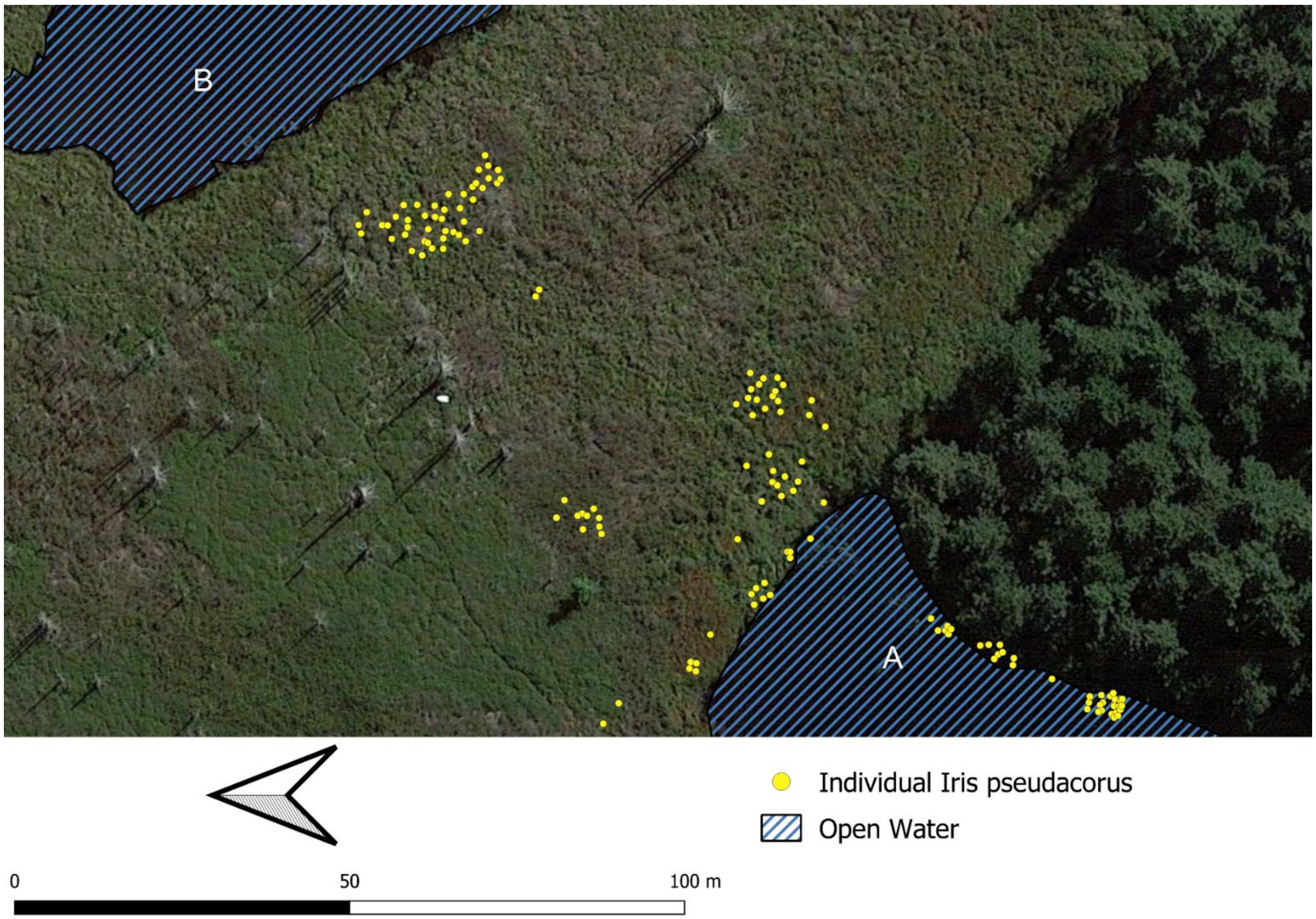
Predictions for Future *I. pseudacorus* Spread at GIER

The current distribution of *I. pseudacorus* at GIER has demonstrated that as a species it naturally spreads only where a certain level of water is available, since it mainly spreads through hydrochory (Gaskin et al., 2016). It has spread along the drainage channel where there is a small stream of water running from the bog, and it has spread extensively in Open Water A beside Cook Road. It appears to have barely spread along the periphery of the bog past this section, suggesting there are insufficient levels of water at the periphery for hydrochory, though it has spread into the centre of the bog in the direction of Open Water B (Figure 20). Although this is against the general flow of draining water in the bog, the rate of water flow is observably so low that in times where the water table is high or where beaver may have dammed the drainage channel it is possible for *I. pseudacorus* seeds to flow in any direction if the bog's water remains standing. As the drainage channel is the area in which water from the bog drains when the water table is high, it is thought that Open Water A and B are connected by small streams running underneath the vegetation which allow *I. pseudacorus* enough water to spread. Since this area of the bog was inaccessible on foot, the depth of the streams were not measured, but small lines within the stands of hardhack can be observed by mapping software, confirming their presence (Figure 20). A likely prediction is that *I. pseudacorus* will eventually spread further along these small streams and into Open Water B - particularly at times when the water table is high - where it has the potential to flourish. A timeline for this occurrence is difficult to produce, but since *I. pseudacorus* has been present at GIER for at least ten years and has spread noticeably in this time, it is not inaccurate to say that within the next five years *I. pseudacorus* will have established itself in Open Water B.

If this spread is allowed to occur there is potential for negative impacts to hydrological and ecological function of the bog.

Figure 20

Open Water A and B and the Individual I. pseudacorus *Growing Between Them in Small Streams*



Impact on Hydrological Function

I. pseudacorus rhizomes form dense mats which can impede water flow (Capital Regional District, 2020), alter hydrological processes, and contribute to shifts in community composition (BC Parks, n.d.). As there are small streams connecting Open Water A and B there is a high likelihood that populations of *I. pseudacorus* could prevent drainage and cause flooding in this section of the bog, particularly in the winter months when rainfall is higher. Flooding in peat bogs initially causes loss of above-ground vegetation and a net decrease in carbon stores (Asada et al., 2005), clearing more colonisable space for *I. pseudacorus*, which would likely outcompete native bog plants in claiming this space. *I. pseudacorus* also traps sediment with its rhizome mats, enabling it to create drier, compacted areas of soil that can act as shorelines for new areas of flooding (Jacobs et al., 2011; Minuti et al, 2020). In this way, *I. pseudacorus* creates a positive feedback loop for its own spread (Jacobs et al., 2011), utilising flooded areas for hydrochory and compacted sediment as germination sites.

Impact on Ecological Function

Grzybowski & Glińska-Lewczuk (2020) listed invasive species as one of the most significant threats to bog habitat. *I. pseudacorus* has been shown to reduce native species richness and increase invasive species richness in its invaded range (Gallego-Tévar et al., 2022; Hayasaka et al., 2018). For example, *I. pseudacorus* is listed as one of only three invasive species causing the extirpation of *Howellia aquatilis* in the Pacific Northwest, previously listed as a federally threatened species (US Fish and Wildlife Service, 2021). It is already apparent that *I. pseudacorus* is gaining dominance around Open Water A, particularly in disturbed areas where there are few other established species. There could also be cause for concern with *I. pseudacorus* potentially not integrating with the biogeochemical processes of the bog, further impacting native species in the area. Nitrogen is scarce in bogs, so bog-dwelling plants adapt to conserve nitrogen where possible, with high resorption efficiencies, low quality leaf litter, and symbiosis with nitrogen-providing mycorrhizal fungi (Stackpoole et al., 2008). *I. pseudacorus* has been shown to have a high nitrogen removal efficiency in soils (Wang et al., 2016) and is frequently utilised in constructed wetlands for its strong abilities in removing pollutants (including nutrients and metals) from wastewater (Huang et al., 2018; Gu et al., 2022). There is therefore potential that *I. pseudacorus* could disrupt nutrient cycling within the bog and outcompete native plants for accessibility to those nutrients. Invasive species have also been shown to negatively impact mycorrhizal plant communities by altering their structure and reducing their diversity (Řezáčová et al., 2021). Mycorrhizal fungi are suggested to play a significant role in maintaining biogeochemical cycles in bogs, especially during periods of nutrient deposition (Shao et al., 2022), so any impact to these networks may produce adverse effects in the bog's function. Further research into this area is required, however, for the sake of caution, limiting the spread of *I. pseudacorus* at GIER for these reasons is of high importance.

Recommendations for Management

Although known to reproduce vegetatively and through rhizome fragmentation (Jaca, 2013), *I. pseudacorus* spreads mainly through seed dispersal (Gaskin et al., 2016). This is unusual for an aquatic invasive (Gaskin et al., 2016), but likely allows *I. pseudacorus* to spread across large areas quickly. The seed pods are buoyant, and float across the surface of water to establish themselves in substrate at the water's edge. With this knowledge, it is recommended that seed heads or flowers are removed during springtime. This is already a typical practice when it comes to managing invasive *I. pseudacorus*. Although in this scenario it is still possible for *I. pseudacorus* to reproduce vegetatively, the removal of flowers or seed heads requires little manual labour, is low-cost, and depletes the source of long-range spread. It is also a method which involves little disturbance to the surrounding habitat.

To fully remove *I. pseudacorus* from GIER, it is necessary to incorporate more intensive management strategies. Tarasoff et al. (2016) demonstrated the effectiveness of rubber benthic barriers as a treatment for *I. pseudacorus* invasion. After *I. pseudacorus* vegetation was cut down to the rhizome, rubber mats were laid on top of the rhizomes to prevent the formation of leaves, which then prevents gas exchange, and the mats were kept in place for 70 days (Tarasoff et al., 2016). No regrowth was observed 150 days after the barriers were removed and *I. pseudacorus* rhizomes were found to be in the advanced stages of decomposition (Tarasoff et al., 2016). After one year, the sites where the barriers were placed were 93-95% bare ground, with the plant regrowth coming from newly sprouted seeds of cattail and *I. pseudacorus* (Tarasoff et al., 2016). This demonstrates the importance of maintaining or replanting sites with desirable species after the disturbance from benthic barrier treatment, and of continually removing the seed heads and flowers of *I. pseudacorus* in the area to prevent recolonisation.

Tarasoff et al. (2016) found that where *I. pseudacorus* rhizomes were growing underwater a benthic barrier was not required to create an environment anoxic enough to kill the rhizomes. After cutting back vegetation, 15 cm of water for a continuous 280 days appeared to provide the same results as a rubber benthic barrier (Tarasoff et al., 2016). This was due to the plant not being able to diffuse toxic acetaldehyde in water, causing a fatal accumulation to occur in the rhizomes (Tarasoff et al., 2016). Ongoing research recreated this finding, showing promise for a low-disturbance, low-labour yet highly effective management strategy (preprint, Tarasoff & Gillies, 2021).

Nevertheless, the potential effects of disturbance from the construction and maintenance of Cook Road are difficult to mitigate. Currently, it would not be possible to relocate the road, but one solution to overcome this issue will be to narrow the road to a single, one-way lane for the 50-metre stretch that passes directly beside Open Water. This will potentially help to provide adequate space between the disturbed, invasive-species-dominated soil and the water. The road is not a thoroughfare and has very low traffic levels, so this could be envisaged. Planting areas beside the road with native, soil retaining plants could also help prevent soil erosion at the sloped roadsides, reducing disturbance and limiting the amount of open space for invasive species to colonise.

Conclusion

Through this study, it was determined that *I. pseudacorus* has gained a significant foothold in the bog at GIER, particularly in the drainage channel. The disturbed sections of the bog's periphery provided areas which *I. pseudacorus* could easily colonise, with undisturbed sections being more resilient to its spread. Disturbance caused by the construction, maintenance, and continuing physical presence of Cook Road enabled *I. pseudacorus* to grow in large clusters, harbouring more seeds with which to further its spread. Wider buffer zones between Cook Road and the bog helped limit the internal spread of *I. pseudacorus* by hosting undisturbed areas, but it was found that there was no threat from external invasion, so they did not fulfil their common function in this scenario.

Since the majority of *I. pseudacorus* spread at GIER is in quite a concentrated area, a combination of vegetation removal, deep water cutting, and, where rhizomes are not growing underwater, rubber benthic barrier treatment would be an effective strategy at removing the invasive from the site. However, this research has demonstrated the capability of *I. pseudacorus* to colonise disturbed areas, so the execution of the removal and continuous management of the site will have to be done in a way to minimise disturbance and mitigate the effects of disturbance where it is made.

Additionally, the produced map of *I. pseudacorus* distribution at the GIER bog is an important tool for site managers to investigate and monitor the extent of colonisation, with future updates to the map being a possibility. Although *I. pseudacorus* has spread significantly throughout the drainage channel and is beginning to gain a foothold in the bog's centre, it is not yet too late to act on preventing future spread and from completely removing *I. pseudacorus* from GIER.

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Appendix A

Table A1

Iris pseudacorus *Counts in Disturbed and Undisturbed Sections of the Drainage Channel*

Section	Disturbed/Undisturbed	*Iris pseudacorus* count
1	2	14
2	2	4
3	2	0
4	2	0
5	2	0
6	2	0
7	2	0
8	2	8
9	2	6
10	2	2
11	2	2
12	2	8
13	1	6
14	1	7
15	1	11
16	1	11
17	1	2
18	2	0
19	2	0
20	2	6
21	1	0
22	1	84
23	1	78
24	2	0

Note. A disturbed area is categorised with the number 1 and an undisturbed area is categorised with the number 2.

Appendix B

Table B1

Iris pseudacorus *Counts and Buffer Zone Width Measurements Along the Periphery of Cook Road and the Bog*

Section	Average Buffer Zone Width (m)	Disturbed/Undisturbed	*Iris pseudacorus* count
13	8.3	1	6
14	5.3	1	7
15	8.2	1	11
16	11.5	1	11
17	10.5	1	2
18	8.0	2	0
19	14.7	2	0
20	10.9	2	6
21	1.8	1	0
22	1.0	1	84
23	5.4	1	78
24	9.2	2	0
25	18.4	2	3
26	22.7	2	0
27	21.5	2	0
28	23.9	2	0
29	26.9	2	0
30	28.5	2	0
31	31.8	2	0
32	35.4	2	0
33	32.8	2	0
34	31.7	2	0

Note. A disturbed area is categorised with the number 1 and an undisturbed area is categorised with the number 2.

Appendix C

Table C1

Coordinates of Each Individual Iris pseudacorus *Plant Marked for Use in Mapping*

Name	Latitude	Longitude
1	-123.5571463	48.98196590
2	-123.5571684	48.98191769
3	-123.5571426	48.98193932
4	-123.5571685	48.98193706
5	-123.5571781	48.98190367
6	-123.5571813	48.98191636
7	-123.5571677	48.98189983
8	-123.5572235	48.98189336
9	-123.5571924	48.98189840
10	-123.5571714	48.98189837
11	-123.5571651	48.98189387
12	-123.5571724	48.98193221
13	-123.5571461	48.98193087
14	-123.5571549	48.98195755
15	-123.5571401	48.98196139
16	-123.5571382	48.98192846
17	-123.5571451	48.98194283
18	-123.5571537	48.98194274
19	-123.5571520	48.98193860
20	-123.5573184	48.98185029
21	-123.5573149	48.98184130
22	-123.5573300	48.98185027
23	-123.5573395	48.98184143
24	-123.5573230	48.98183652
25	-123.5573371	48.98182920
26	-123.5573539	48.98184095
27	-123.5573269	48.98182094
28	-123.5573504	48.98183196
29	-123.5573601	48.98182232
30	-123.5573380	48.98182254
31	-123.5573232	48.98181277

32	-123.5573476	48.98181713
33	-123.5573343	48.98181436
34	-123.5573174	48.98180684
35	-123.5573311	48.98180456
36	-123.5572986	48.98179734
37	-123.5572922	48.98179303
38	-123.5573052	48.98180084
39	-123.5572991	48.98179572
40	-123.5573000	48.98178906
41	-123.5573156	48.98180063
42	-123.5572863	48.98178369
43	-123.5572982	48.98178286
44	-123.5572802	48.98177857
45	-123.5573136	48.98179101
46	-123.5573234	48.98179666
47	-123.5573457	48.98179563
48	-123.5573244	48.98178577
49	-123.5573365	48.98178836
50	-123.5572832	48.98176966
51	-123.5573133	48.98177653
52	-123.5573014	48.98176549
53	-123.5573409	48.98177117
54	-123.5573209	48.98176149
55	-123.5572709	48.98174836
56	-123.5572614	48.98174190
57	-123.5572680	48.98173775
58	-123.5572772	48.98173737
59	-123.5572992	48.98174903
60	-123.5572622	48.98173183
61	-123.5573100	48.98175143
62	-123.5572612	48.98173084
63	-123.5572724	48.98173244
64	-123.5573067	48.98174586
65	-123.5573166	48.98175493
66	-123.5573276	48.98176076
67	-123.5572652	48.98173056
68	-123.5572784	48.98172990
69	-123.5573114	48.98174738

70	-123.5572554	48.98171726
71	-123.5572660	48.98172048
72	-123.5572803	48.98172423
73	-123.5572929	48.98172520
74	-123.5573069	48.98173741
75	-123.5573265	48.98172918
76	-123.5573385	48.98174364
77	-123.5573390	48.98173437
78	-123.5573370	48.98172475
79	-123.5573221	48.98171920
80	-123.5573337	48.98171918
81	-123.5573443	48.98173005
82	-123.5573273	48.98171120
83	-123.5573405	48.98172162
84	-123.5573180	48.98170596
85	-123.5573306	48.98171564
86	-123.5573364	48.98171883
87	-123.5573519	48.98174396
88	-123.5573198	48.98170084
89	-123.5573312	48.98170076
90	-123.5573401	48.98171389
91	-123.5573406	48.98170600
92	-123.5573262	48.98168914
93	-123.5573325	48.98169490
94	-123.5573398	48.98170214
95	-123.5573210	48.98168486
96	-123.5573368	48.98169036
97	-123.5573440	48.98169448
98	-123.5573118	48.98167434
99	-123.5573311	48.98167404
100	-123.5573050	48.98166709
101	-123.5573003	48.98165524
102	-123.5573121	48.98166013
103	-123.5573272	48.98166319
104	-123.5573239	48.98165665
105	-123.5573371	48.98166938
106	-123.5573419	48.98168376
107	-123.5573395	48.98165894

108	-123.5573123	48.98165683
109	-123.5572996	48.98164587
110	-123.5573093	48.98164699
111	-123.5572849	48.98163620
112	-123.5573384	48.98165034
113	-123.5573110	48.98164062
114	-123.5573182	48.98164964
115	-123.5572917	48.98164092
116	-123.5573000	48.98163673
117	-123.5572886	48.98163107
118	-123.5573206	48.98163920
119	-123.5573312	48.98164385
120	-123.5573251	48.98164199
121	-123.5572743	48.98172072
122	-123.5572793	48.98162917
123	-123.5572931	48.98163494
124	-123.5572808	48.98162595
125	-123.5573425	48.98164232
126	-123.5573327	48.98163954
127	-123.5573382	48.98163888
128	-123.5573290	48.98163586
129	-123.5573208	48.98163537
130	-123.5573094	48.98163545
131	-123.5572875	48.98162650
132	-123.5572985	48.98163344
133	-123.5572933	48.98162964
134	-123.5573010	48.98163096
135	-123.5572967	48.98162177
136	-123.5573059	48.98162997
137	-123.5573013	48.98162624
138	-123.5573167	48.98163162
139	-123.5573107	48.98162389
140	-123.5573206	48.98162648
141	-123.5573088	48.98185122
142	-123.5572964	48.98184375
143	-123.5573122	48.98184274
144	-123.5573029	48.98161780
145	-123.5573283	48.98162359

146	-123.5573138	48.98161788
147	-123.5573250	48.98161737
148	-123.5572949	48.98161450
149	-123.5573195	48.98160707
150	-123.5573020	48.98160766
151	-123.5573292	48.98161065
152	-123.5573075	48.98160244
153	-123.5573246	48.98160798
154	-123.5573156	48.98159771
155	-123.5573237	48.98160287
156	-123.5572258	48.98157490
157	-123.5572329	48.98157310
158	-123.5573097	48.98158867
159	-123.5573266	48.98159476
160	-123.5572970	48.98158394
161	-123.5572948	48.98157257
162	-123.5572326	48.98156937
163	-123.5572355	48.98155673
164	-123.5572878	48.98156255
165	-123.5572583	48.98157342
166	-123.5572490	48.98155353
167	-123.5572966	48.98155242
168	-123.5573085	48.98157447
169	-123.5573055	48.98156456
170	-123.5573248	48.98158613
171	-123.5572046	48.98156311
172	-123.5572143	48.98156056
173	-123.5571895	48.98156435
174	-123.5572197	48.98155523
175	-123.5572300	48.98154952
176	-123.5572494	48.98154864
177	-123.5573261	48.98157215
178	-123.5573103	48.98156649
179	-123.5573081	48.98155935
180	-123.5573144	48.98157000
181	-123.5573231	48.98156645
182	-123.5573184	48.98155953
183	-123.5573055	48.98155053

184	-123.5571162	48.98154561
185	-123.5571094	48.98157063
186	-123.5571052	48.98159783
187	-123.5570905	48.98162772
188	-123.5570847	48.98165149
189	-123.5570731	48.98167918
190	-123.5570425	48.98162433
191	-123.5570451	48.98165924
192	-123.5570251	48.98169804
193	-123.5570547	48.98162240
194	-123.5570660	48.98159903
195	-123.5570613	48.98163037
196	-123.5570507	48.98166580
197	-123.5570344	48.98169823
198	-123.5570828	48.98159784
199	-123.5571100	48.98153119
200	-123.5571162	48.98152080
201	-123.5571086	48.98150822
202	-123.5571187	48.98150503
203	-123.5571143	48.98149718
204	-123.5571198	48.98149475
205	-123.5570916	48.98153294
206	-123.5570927	48.98156958
207	-123.5570884	48.98155565
208	-123.5570835	48.98159310
209	-123.5570953	48.98159514
210	-123.5571085	48.98156374
211	-123.5570637	48.98164881
212	-123.5570756	48.98162838
213	-123.5571040	48.98158937
214	-123.5570882	48.98162047
215	-123.5570659	48.98162184
216	-123.5570836	48.98153188
217	-123.5570611	48.98167393
218	-123.5570288	48.98168855
219	-123.5570410	48.98169902
220	-123.5570533	48.98169797
221	-123.5570927	48.98158638

222	-123.5570947	48.98155833
223	-123.5570653	48.98161494
224	-123.5570730	48.98158658
225	-123.5570957	48.98154963
226	-123.5571011	48.98149350
227	-123.5569685	48.98176447
228	-123.5569659	48.98175854
229	-123.5569757	48.98176106
230	-123.5569519	48.98176137
231	-123.5569529	48.98175461
232	-123.5569452	48.98177626
233	-123.5569593	48.98175278
234	-123.5569719	48.98175600
235	-123.5569499	48.98177985
236	-123.5569612	48.98177796
237	-123.5569319	48.98176628
238	-123.5569381	48.98176021
239	-123.5569414	48.98175225
240	-123.5569516	48.98175080
241	-123.5569448	48.98179490
242	-123.5569639	48.98178224
243	-123.5569583	48.98179713
244	-123.5569298	48.98177830
245	-123.5569259	48.98176237
246	-123.5569377	48.98175015
247	-123.5569326	48.98179359
248	-123.5572183	48.98189535
249	-123.5571646	48.98192342
250	-123.5571641	48.98198320
251	-123.5572093	48.98204152
252	-123.5572198	48.98210561
253	-123.5572217	48.98218050
254	-123.5572171	48.98225482
255	-123.5571357	48.98228878
256	-123.5571066	48.98241330
257	-123.5569464	48.98242413
258	-123.5568970	48.98184437
259	-123.5568688	48.98189667

260	-123.5568547	48.98189541
261	-123.5568469	48.98191645
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263	-123.5568561	48.98192156
264	-123.5568271	48.98192890
265	-123.5568274	48.98191397
266	-123.5568287	48.98194030
267	-123.5567981	48.98198707
268	-123.5568055	48.98198264
269	-123.5567891	48.98198413
270	-123.5567954	48.98197944
271	-123.5567983	48.98199683
272	-123.5567738	48.98200626
273	-123.5572011	48.98190185
274	-123.5571679	48.98192611
275	-123.5571484	48.98194497
276	-123.5571444	48.98195088
277	-123.5571381	48.98194716
278	-123.5571533	48.98192974
279	-123.5571458	48.98192773
280	-123.5571578	48.98194459
281	-123.5571637	48.98195881
282	-123.5571679	48.98197494
283	-123.5572094	48.98211700
284	-123.5572060	48.98214378
285	-123.5572260	48.98217083
286	-123.5572167	48.98216449
287	-123.5572077	48.98218865
288	-123.5572137	48.98220419
289	-123.5572198	48.98215440
290	-123.5572195	48.98214555
291	-123.5572205	48.98213629
292	-123.5572321	48.98216804
293	-123.5572243	48.98220008
294	-123.5571965	48.98220042
295	-123.5571904	48.98219797
296	-123.5571935	48.98219206
297	-123.5571853	48.98218962

298	-123.5571739	48.98219247
299	-123.5571793	48.98218722
300	-123.5572193	48.98212608
301	-123.5572283	48.98211508
302	-123.5572058	48.98225158
303	-123.5572043	48.98226069
304	-123.5571998	48.98225282
305	-123.5571990	48.98224443
306	-123.5571900	48.98225467
307	-123.5571461	48.98227809
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