VANCOUVER ISLAND UNIVERSITY

Assessing the Impact of Forestry Activities on Fish Sustainability: A GIS-Based Analysis of Land Use Changes in Southern Vancouver Island Watersheds (1985–2005)

By

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Executive Summary

This report presents a GIS-based analysis of forestry impacts on fish-bearing streams in southern Vancouver Island's third-order watersheds from 1985 to 2005, aimed at informing sustainable land management for fish sustainability. Conducted as part of Geog 581, the project sought to quantify logging-induced disturbances, assess their ecological implications for salmonid habitats, and deliver actionable recommendations through a validated geodatabase, thematic maps, tabular summaries, and a comprehensive report. Executed over 12.5 days from April 1 to April 15, 2025, the study leveraged ArcGIS Pro and ancillary tools like QGIS and Python to map and analyze land use changes across an estimated 1,924 km² study area, despite challenges such as poor 1985 Landsat imagery and data limitations. The findings reveal dynamic logging trends, regional disparities, and critical opportunities for habitat conservation, successfully meeting the project's objectives while providing valuable insights for policymakers and land managers.

The project was meticulously planned and tracked, with eight tasks spanning data acquisition to final reporting, though it required 24 hours against an estimated 14, primarily due to extended digitizing efforts (6 vs. 2 hours) caused by cloud-obscured imagery. Adjustments, such as excluding road density and riparian disturbance indicators due to unavailable data, ensured feasibility, while efficient mapping (1 vs. 2 hours) mitigated delays. Data from the Catala Instructional Datasets, including watershed polygons, 1995 Baseline Thematic Mapping, and Landsat imagery, underpinned the analysis, with quality control measures like topological validation ensuring accuracy despite 1985 image limitations. The methodology involved heads-up digitizing of clearcuts for 1985 and 2005, extraction of 1995 disturbances, and computation of the proportion disturbed indicator, producing thematic maps classifying watersheds as Undisturbed (0%), Low (1–20%), Moderate (21–50%), or High (>50%) disturbance.

Key findings indicate a 61% increase in undisturbed areas to 394 km² (20.5%) by 2005, a 48% rise in moderate disturbance to 617 km² (32.1%), and a 32% decline in high disturbance to 253 km² (13.2%), suggesting a mid-study logging peak followed by partial recovery. Regionally, the Northwest (NW) sub-region saw intensified disturbance (mean 17.5% in 2005), exemplified by FID 45 (15% to 40%), while the Southeast (SE) experienced significant mitigation (mean 1.3%), as in FID 83 (69% to 5%). These trends, visualized in submitted maps, imply varied ecological risks: high disturbance in watersheds like FID 67 (>50%) increases sedimentation, threatening salmon spawning gravels, whereas undisturbed areas like FID 12 (0%) offer habitat stability. The analysis, supported by rigorous validation, confirms logging's impact on aquatic ecosystems, with NW's intensification posing ongoing challenges and SE's recovery presenting conservation opportunities.

Reflecting on these results, the project highlights the need for targeted watershed management to balance forestry with fish sustainability. Challenges, such as 15% cloud cover in 1985 imagery, were mitigated by using multiple image dates, though the absence of road and stream data limited additional indicators. Despite these constraints, the project delivered robust outputs, meeting its core objectives. Recommendations include protecting undisturbed watersheds (e.g., FIDs 0, 4) through conservation easements, restoring heavily logged areas like FID 67 with reforestation, and adopting sustainable practices such as selective harvesting in NW to reduce sedimentation. These strategies, grounded in the study's findings, provide a roadmap for enhancing salmonid habitat resilience, underscoring the power of GIS to inform evidence-based environmental policy.

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1. Introduction

The coastal ecosystems of British Columbia, particularly those on southern Vancouver Island, have long been shaped by extensive forestry operations, which have drawn significant academic and environmental attention due to their profound impacts on aquatic habitats. Over the past century, timber harvesting has altered watersheds critical to fish-bearing streams, threatening the sustainability of salmonid populations and other aquatic species. This project, conducted as part of Geog 581, investigates historical logging patterns between 1985 and 2005 to quantify their effects on fish-bearing watersheds, focusing on how these activities, coupled with evolving regulatory frameworks, have influenced aquatic ecosystem health.

The broad goal of this study was to measure the impacts of forestry activities on fish-bearing streams, using the proportion of disturbed land within each watershed as a key indicator of waterway health. This indicator, expressed as a percentage of logged area per watershed, served as a practical proxy for direct measurements of fish population health, which are resource-intensive and impractical for large-scale analysis. By leveraging Geographic Information Systems (GIS) and Landsat imagery from 1985, 1995, and 2005, alongside provincial forestry datasets from the BC Ministry of Environment, the project aimed to achieve five specific objectives: (1) calculate the proportion of logged areas within each watershed, (2) map logging disturbances for the three time periods, (3) assess temporal trends in watershed degradation or recovery, (4) evaluate potential impacts on fish sustainability, and (5) provide actionable recommendations for sustainable land management.

Previous studies have established that clearcutting practices contribute to aquatic ecosystem degradation through increased sedimentation, which smothers spawning gravels (Brooks et al., 2008), and the loss of riparian vegetation, which raises water temperatures and stresses aquatic life (Zawal et al., 2017). Logging roads further exacerbate these impacts by altering hydrological pathways and increasing sediment delivery to streams (King et al., 2005). Given these challenges, landscape-level indicators like proportion disturbed offer a robust method for assessing watershed health across large areas (Mund & Müller, 2019). This project adhered to British Columbia's Sensitive Ecosystem Inventory framework, analyzing disturbances of 30 hectares or more within a 20-year period preceding each snapshot year, ensuring temporal comparability through standardized GIS protocols (Mund & Müller, 2019).

The project successfully produced a comprehensive dataset, including a geodatabase with disturbance metrics, thematic maps visualizing logging trends, and tabular summaries for 1985, 1995, and 2005. These outputs enabled three critical analyses: mapping spatial patterns of disturbance, assessing temporal trends in logging intensity, and identifying recovery trajectories in impacted watersheds. The results provided actionable insights for resource managers to prioritize habitat restoration and offers policymakers evidence to evaluate regulatory effectiveness. However, due to data limitations, optional indicators such as road density and road/stream crossings were not calculated, as historical transportation network data were incomplete. Despite this, the focus on proportion disturbed proved sufficient to meet the core objectives, highlighting the power of geospatial technologies in environmental monitoring (Monti et al., 2020).

This report details the methodology employed, presents key findings on disturbance patterns across southern Vancouver Island's watersheds, and discusses their implications for fish sustainability and forest management. By synthesizing GIS-based analyses with ecological principles, the project underscores the need for an integrative approach to sustainable forestry that balances timber production with the conservation of aquatic ecosystems, establishing a baseline for future studies amid ongoing climate change challenges.

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2. Project Description

This project aimed to assess the impacts of forestry activities on fish-bearing streams within southern Vancouver Island's watersheds, focusing on the period from 1985 to 2005. Recognizing the critical role of aquatic ecosystems in supporting salmonid populations and broader biodiversity, the study employed Geographic Information Systems (GIS) and remote sensing to quantify logging disturbances and their effects on waterway health. The project's overarching purpose was to measure these impacts using landscape-level indicators as proxies, given the impracticality of direct field measurements across numerous watersheds.

To achieve this purpose, the project pursued five specific objectives:

1. **Calculate Key Indicators:** Determine the proportion of logged areas within each watershed as the primary indicator of disturbance, supplemented by optional metrics such as road density, road/stream crossings, and riparian disturbance, where data availability permitted. These indicators served as proxies for assessing the health of fish-bearing streams.
2. **Analyze Land-Use Changes:** Utilize GIS tools and Landsat satellite imagery to map logging disturbances and calculate indicator values for three key time points—1985, 1995, and 2005. This objective focused on creating a consistent dataset to track changes in forest cover over time.
3. **Assess Temporal Trends:** Compare indicator values across the three time periods to identify patterns of watershed degradation or recovery. This analysis aimed to reveal whether logging activities intensified, stabilized, or diminished, providing insights into long-term ecological trends.
4. **Evaluate Impacts on Fish Sustainability:** Use the calculated indicators to assess the potential effects of logging on fish-bearing streams, particularly regarding sedimentation, water quality, and habitat alteration. This objective linked terrestrial disturbances to aquatic ecosystem health.
5. **Provide Recommendations:** Develop actionable insights for land managers and policymakers to mitigate forestry impacts and promote sustainable land-use practices. The recommendations were intended to guide conservation efforts and regulatory improvements for protecting aquatic ecosystems.

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3. Methods

Methods used in achieving the objectives of the study involved the following Step-by-Step Workflow

3.1 Data Preparation

The project began by establishing a standardized geospatial framework to ensure all datasets were properly aligned and analysis ready.

Geodatabase Setup

Created a dedicated project geodatabase in ArcGIS Pro

Configured to use the NAD 1983 BC Environment Albers coordinate system (standard for British Columbia environmental mapping)

Data Processing

1. Coordinate System Standardization
   - All datasets (watershed boundaries, Landsat imagery, and BTM data) were reprojected to match the project coordinate system
   - Verified proper alignment through visual inspection and metadata validation
2. Study Area Clipping
   - Watershed boundaries served as the master clipping feature
   - Applied to:
     - Landsat imagery (1985 and 2005)
     - 1995 BTM forest disturbance data
   - Maintained original resolution during clipping operations

Digitizing Clearcuts

- **1985 & 2005**: Clearcut areas were **manually digitized in ArcGIS Pro** based on visual interpretation of Landsat imagery. No minimum mapping unit (MMU) threshold (e.g., 30ha) was applied—**all visible disturbances were captured**.
  After digitizing the **northwestern watersheds**, the shapefiles were submitted to the course instructor, who provided the **digitized southeastern portion**, completing the dataset for both years.
- **1995**: Logging disturbances were **extracted from the BTM dataset**, specifically from features classified as **"LOG."**

Thematic Map Creation

Disturbance levels for each watershed were classified based on the **percentage of disturbed area**:

- **Undisturbed**: 0%
- **Low**: < 20%
- **Moderate**: 20–50%
- **High**: > 50%

Watershed Overlay and Area Calculation

The **Summarize Within** tool was used to calculate the total area of digitized clearcuts within each watershed polygon.

Then, **Summary Statistics** were run based on the Side attribute (e.g., NW or SE) to further organize the data.

Percentage disturbance was calculated as:

Disturbance (%) = (Clearcut Area (km^2) / Watershed Area (km^2)) × 100

Temporal Analysis

Watersheds were assigned trend categories based on change in disturbance over the three time points (1985, 1995, 2005):

- **Stable**: Little or no change in disturbance
- **Increasing Disturbance**: Notable rise in disturbance percentage
- **Recovering**: Decrease in disturbance following an earlier peak

Data and Study Area

Landsat and Remote Sensing Imagery

1985: High-compression image (N-10-45_1985.sid) in MrSID format, representing Landsat 4 data at 30-meter resolution.

1995: Disturbance data extracted from the BC Terrestrial Ecosystem Mapping (BTM) dataset, specifically the "LOG" class.

2005: Landsat 7 imagery (I7_743_2005.tif) in GeoTIFF format, using a 7-4-3 band combination ideal for detecting clearcuts and forest structure.

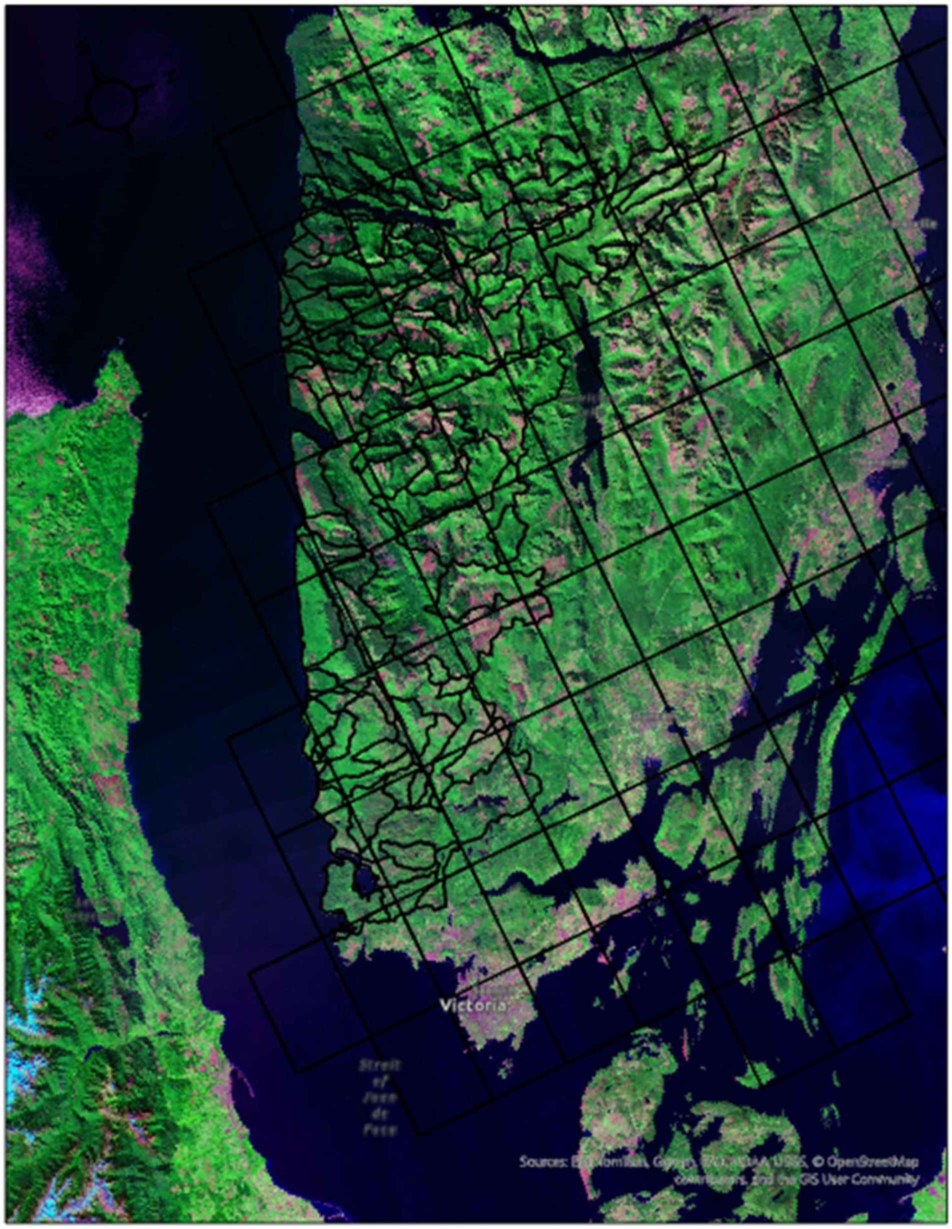
Watershed Boundaries:
Third order and higher watersheds obtained from the BC Ministry of Environment at 1:50,000 scale provided by the instructor was the main dataset.

3.2 Data Quality

Cloud Cover:
The 1985 imagery exhibited cloud artifacts, which were addressed through visual cross-referencing with historical imagery in Google Earth to improve digitizing accuracy.

BTM Alignment:
Although the 1995 BTM dataset was reliable, and the team used it after small spatial analysis which filtered the logged areas from the lagger land use dataset.

3.3 Map of the Study Area



4. Project Management

The successful completion of this GIS-based analysis on forestry disturbances and their potential impacts on fish-bearing streams in the watersheds of southern Vancouver Island required structured planning, iterative refinement, and consistent quality oversight. This section documents the project's management process, including methodology, timeline, scope, task allocation, and quality control measures employed to ensure robust and reliable outputs.

4.1 Timeline and Milestones

The project was completed over a condensed 12.5-day period between April 1 and April 15, 2025, closely following the proposed schedule. The workflow was divided into five key phases:

- **Planning (April 1–3, Days 1–3):**
This phase focused on data acquisition and geodatabase setup, completed on schedule. Watershed boundaries, 1995 Baseline Thematic Mapping (BTM), and Landsat imagery (1985, 2005) were successfully sourced from the Catala Instructional Datasets folder.

- **Digitizing (April 4–6, Days 4–6):**
Logging disturbances for 1985, 1995, and 2005 were identified. Originally allocated two days, this phase was extended to three days due to delays caused by data loss in the 1985 and 2005 imagery, and reliance on shared digitized portions. Despite the delay, accuracy was prioritized.

- **Mapping (April 7–8, Days 7–8):**
Spatial analysis and thematic map creation were expedited and completed in one day instead of two. The omission of buffer analysis streamlined production, compensating for earlier delays.

- **Analysis (April 9–12, Days 9–12):**
Indicator calculations, change detection, data validation, and impact assessment were initially scheduled for six days but completed in 5.5 days. Minor overruns in early sub-tasks were balanced by on-time validation and interpretation.

- **Reporting (April 13–15, Days 13–15):**
Report compilation and final deliverables took 1.5 days instead of the planned 1 day, allowing for refined maps and stakeholder-ready outputs.

4.2 Scope and Adjustments

Original Project Scope

The study was designed to assess forestry impacts on fish-bearing streams in southern Vancouver Island watersheds through four key analyses:

1. **Forest disturbance quantification** (proportion of logged area)
2. **Riparian buffer analysis** (30-meter zone disturbance near streams)
3. **Road density and crossing frequency**
4. **Temporal comparison** across 1972, 1985, 1995, and 2005

Scope Modifications

During implementation, three adjustments were made to maintain feasibility while preserving analytical rigor:

1. **Elimination of Road Density Analysis**
    - *Reason*: Incomplete historical road data (only available for 1995) prevented meaningful multi-year comparisons.
    - *Adaptation*: Focus shifted entirely to forest disturbance percentages as the primary impact metric.
2. **Simplified Riparian Assessment**
    - *Reason*: Time constraints and data processing complexities.

- *Adaptation*: Watershed-scale disturbance metrics replaced buffer-specific analysis, maintaining the evaluation of hydrological impacts.

3. **Revised Temporal Framework**
   - *Original Plan*: Include 1972 imagery as a pre-disturbance baseline.
   - *Modification*: Excluded due to resolution inconsistencies; final analysis compared 1985–2005 data.
   - *Justification*: The 20-year comparison still captured critical phases of forestry activity and regeneration.

4.3 Task Allocation and Time Tracking

The project consisted of eight main tasks. Estimated hours were set during the planning phase, and actual time spent was tracked to assess efficiency. A summary is provided below:

Task No.	Task Name	Estimated (hrs)	Actual (hrs)	Difference (hrs)
1	Data Acquisition & Preparation	3	3	0
2	Logging Disturbance Identification	2	6	-4
3	Indicator Calculation	2	3	-1
4	Temporal Change Analysis	2	3	-1
5	Spatial Analysis & Mapping	2	1	+1
6	Data Validation & Integration	1	2	-1
7	Impact Assessment & Interpretation	1	2	-1
8	Final Reporting & Deliverables	1	3	-2
Total		**14 hrs**	**24 hrs**	**–10 hrs**

Summary:

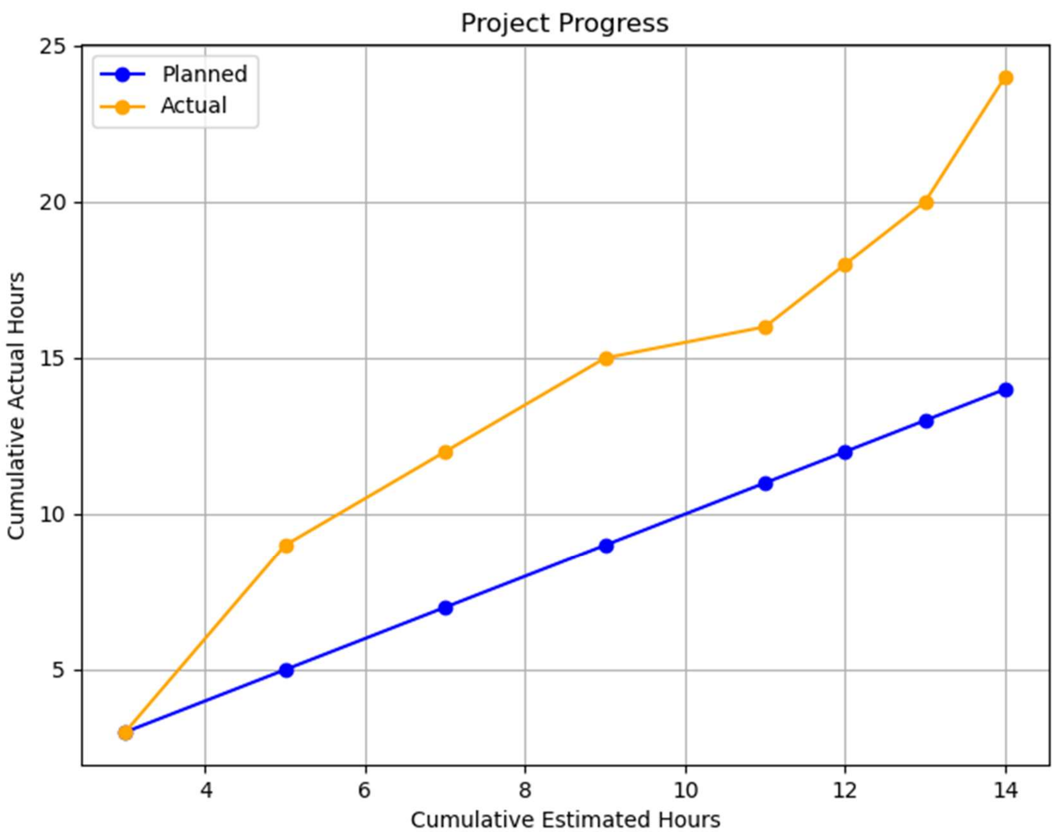
Tasks involving digitizing and reporting exceeded initial estimates due to unforeseen complexities (e.g., cloud cover, missing segments, and quality assurance).

Mapping was completed ahead of schedule, helping offset delays.

A **Progress Graph** was created to visualize these variances, plotting cumulative estimated hours (X-axis) against cumulative actual hours (Y-axis). The cumulative table below supports the graph:

Task No.	Task Name	Estimated Duration (hrs)	Cumulative Estimated (hrs)	Actual Duration (hrs)	Cumulative Actual (hrs)
1	Data Acquisition & Preparation	3	3	3	3

2	Logging Disturbance Identification	2	5	6	9
3	Indicator Calculation	2	7	3	12
4	Temporal Change Analysis	2	9	3	15
5	Spatial Analysis & Mapping	2	11	1	16
6	Data Validation & Integration	1	12	2	18
7	Impact Assessment & Interpretation	1	13	2	20
8	Final Reporting & Deliverables	1	14	3	24
Total		14		24	



4.5 Tools and Software

The project leveraged a suite of geospatial and analytical tools to ensure precision and efficiency:

ArcGIS Pro (Primary): Used for geodatabase creation, clearcut digitizing, summarize within, zonal statistics, thematic map production, and topological validation. Its robust GIS capabilities were critical for processing Landsat imagery and watershed data.

Microsoft Excel: Utilized for tabular summaries of disturbance percentages and creating the Status Table, though the Progress Graph was generated in Python.

Python/Matplotlib: Scripted the Progress Graph (plot_progress_graph.py), saved as ProgressGraph.png in the project folder, enhancing reproducibility.

Project Progress Discussion

The progress of the project unfolded with a mix of efficiencies and unexpected delays when compared to the original timeline. This dynamic is clearly depicted in both the project's status table and accompanying progress graph. While the table provides a numerical breakdown of task durations and variances, the graph offers a visual representation of cumulative planned versus actual hours, highlighting specific points where deviations emerged. Ultimately, the project took a total of 24 hours to complete—an overrun of 10 hours beyond the initial estimate. The most substantial time overruns were observed during the digitizing and reporting phases. Certain components of the project, however, proceeded more smoothly than anticipated. The **Data Acquisition & Preparation** phase, for example, was completed in 3 hours—one hour less than estimated. This efficiency can be attributed to the high quality and organization of datasets provided by the instructor, which significantly reduced the time required for data cleaning and formatting.

Similarly, the **Spatial Analysis & Mapping** phase finished ahead of schedule by approximately one hour. This was largely due to the decision to omit the riparian buffer analysis, which simplified the overall workflow. Additionally, the use of automated tools within ArcGIS Pro, such as those used for calculating zonal statistics, helped streamline this stage and expedite results. According to Allen et al. (2011), automation in GIS workflows can significantly improve time efficiency, particularly for repetitive spatial operations.

On the other hand, several tasks proved more time-consuming than originally expected. The **Logging Disturbance Identification** phase required six hours—four hours more than the planned two. While cloud cover in the 1985 satellite imagery did not notably affect accuracy, delays arose from dependencies on collaborative digitizing inputs and an unanticipated power outage. The outage necessitated data recovery efforts and partial re-digitization, thereby extending the task's duration.

The **Reporting** phase also took longer than expected, requiring three hours instead of the single hour originally allocated. Additional time was necessary to refine maps, incorporate feedback, and ensure the clarity and visual quality of outputs met the standards expected by potential stakeholders. As noted by Clarke and Stillwell (2004), cartographic communication in GIS projects is not merely a technical task but an interpretive one, demanding careful design and contextual accuracy.

Three primary root causes were identified for the project's time variances. First, the **complexity of manual digitizing**—particularly with historical imagery—was underestimated. Extracting features from lower-resolution or partially obscured imagery demanded meticulous effort and interpretation. Second, **unplanned interruptions**, such as the aforementioned power outage, directly led to lost progress and the need for rework. Third, **refinements to project scope**, such as the exclusion of road impact analysis, saved time in later phases but also required reallocating effort to ensure quality assurance in other areas.

Based on these insights, several improvements are proposed for future projects. Conducting **pilot testing** of digitizing tasks can help establish more accurate time estimates and anticipate potential difficulties. The use of **semi-automated classification techniques**, such as NDVI-based thresholds for vegetation detection (Lillesand et al., 2015), may reduce the burden of manual digitizing. Additionally, implementing **cloud-based backups or version control systems** (e.g., Git) would enhance data resilience and mitigate risks associated with technical failures. Finally, embedding **staged peer reviews** early in the digitizing process can ensure consistency and prevent costly rework later on.

4.6. Quality Control and Assurance

4.6.1 Data Accuracy

Image Interpretation: Approximately 20% of the digitized polygons were peer-reviewed. If discrepancies exceeded 10%, features were re-evaluated and re-digitized to ensure consistency.

Projection Consistency: All datasets were reprojected to a **custom NAD_1983_Albers** coordinate system with the following parameters:

4.6.2 Consistency Checks

Comprehensive Digitizing: All visible clearcut areas in the imagery were digitized, without applying a minimum mapping unit. This allowed for the inclusion of small and irregular disturbance patches where distinguishable.

Topology Validation: Digitized features were checked for topological errors (e.g., slivers, gaps, and overlaps) using **ArcGIS Pro's topology tools**, and corrections were applied as needed.

Watershed-Level Summarization: The **Summarize Within** tool was used to calculate the total area (in km^2) of clearcuts within each watershed polygon, ensuring consistency in spatial summaries.

4.6.3 Limitations and Uncertainties

Subjectivity in Digitizing: Especially for older imagery (e.g., 1985), interpretation involved some subjectivity due to lower image quality and indistinct disturbance boundaries.

Resolution Constraints: The 30m pixel size of Landsat imagery occasionally caused regrowing forest stands to blend visually with recent clearcuts, introducing potential ambiguity in classification.

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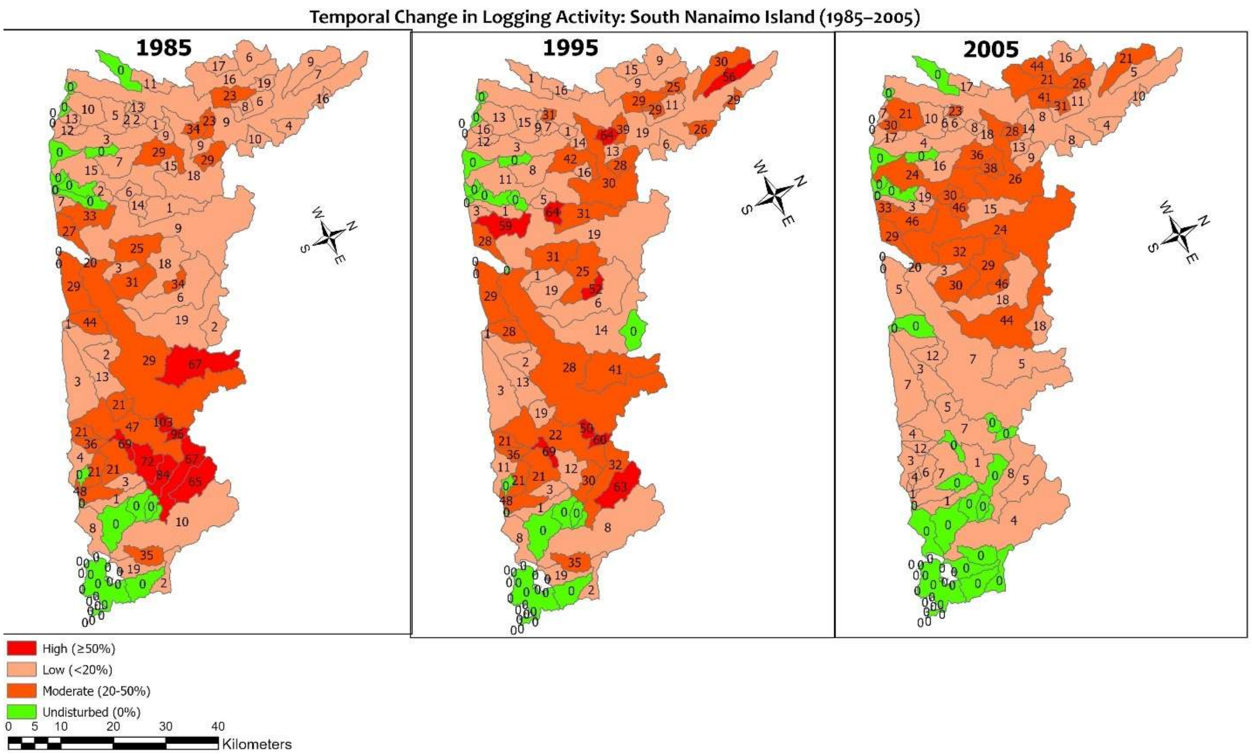
5. Results



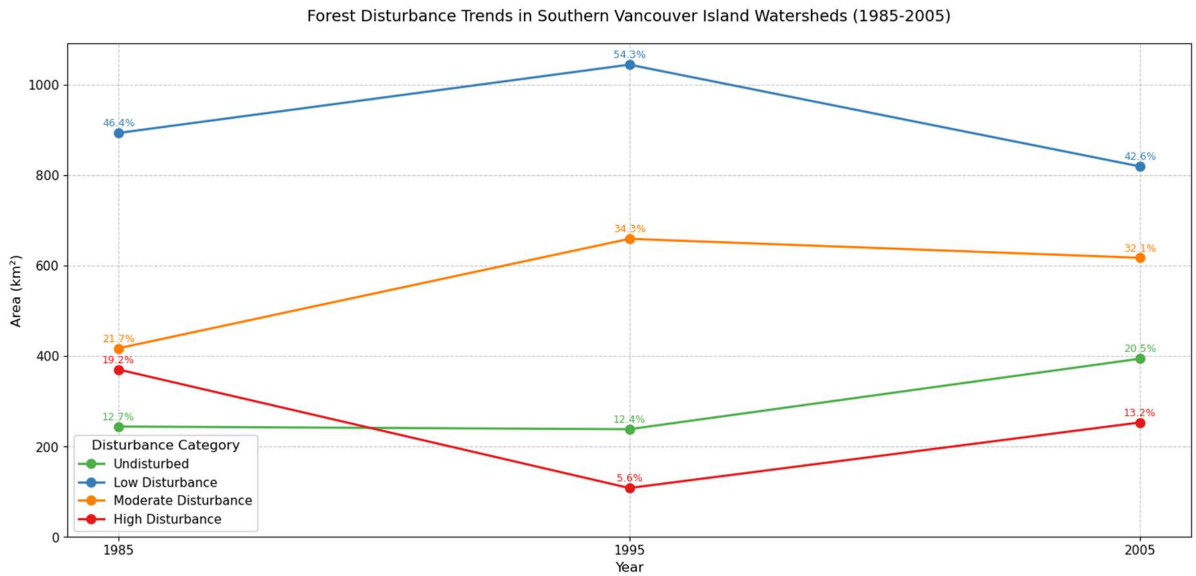
This section delineates the findings of the geospatial analysis conducted to evaluate the impact of forestry activities on fish-bearing streams within southern Vancouver Island's third-order watersheds from 1985 to 2005. The results are derived from a comprehensive examination of logging disturbance trends, regional variations, and their ecological implications for fish sustainability, as captured in the proportion disturbed indicator. These findings are supported by thematic maps and tabular summaries submitted as deliverables, including a geodatabase, disturbance classification maps for 1985, 1995, and 2005, attribute tables, and metadata adhering to FGDC standards. The analysis reveals significant shifts in land use patterns, with implications for watershed management and salmonid habitat conservation.

5.1 Logging Disturbance Trends (1985–2005)

The analysis of logging intensity across the study period, as visualized in the thematic maps for 1985, 1995, and 2005, indicates dynamic changes in disturbance levels across the study area's approximately 1,924 km² of third-order watersheds. The proportion disturbed indicator, defined as the percentage of logged area per watershed, was categorized into four classes: Undisturbed (0%), Low Disturbance (1–20%), Moderate Disturbance (21–50%), and High Disturbance (>50%). The table below summarizes the area and percentage of the total study area for each category, derived from attribute table calculations, alongside observed trends.

Disturbance Category	% Range	1985 Area (km^2)	1995 Area (km^2)	2005 Area (km^2)	Trend
Undisturbed	0%	244 (12.7%)	238 (12.4%)	394 (20.5%)	↑ +61%
Low Disturbance	1–20%	893 (46.4%)	1,044 (54.3%)	819 (42.6%)	↓ -8%
Moderate Disturbance	21–50%	417 (21.7%)	659 (34.3%)	617 (32.1%)	↑ +48%

High Disturbance	>50%	370 (19.2%)	108 (5.6%)	253 (13.2%)	↓ -32%

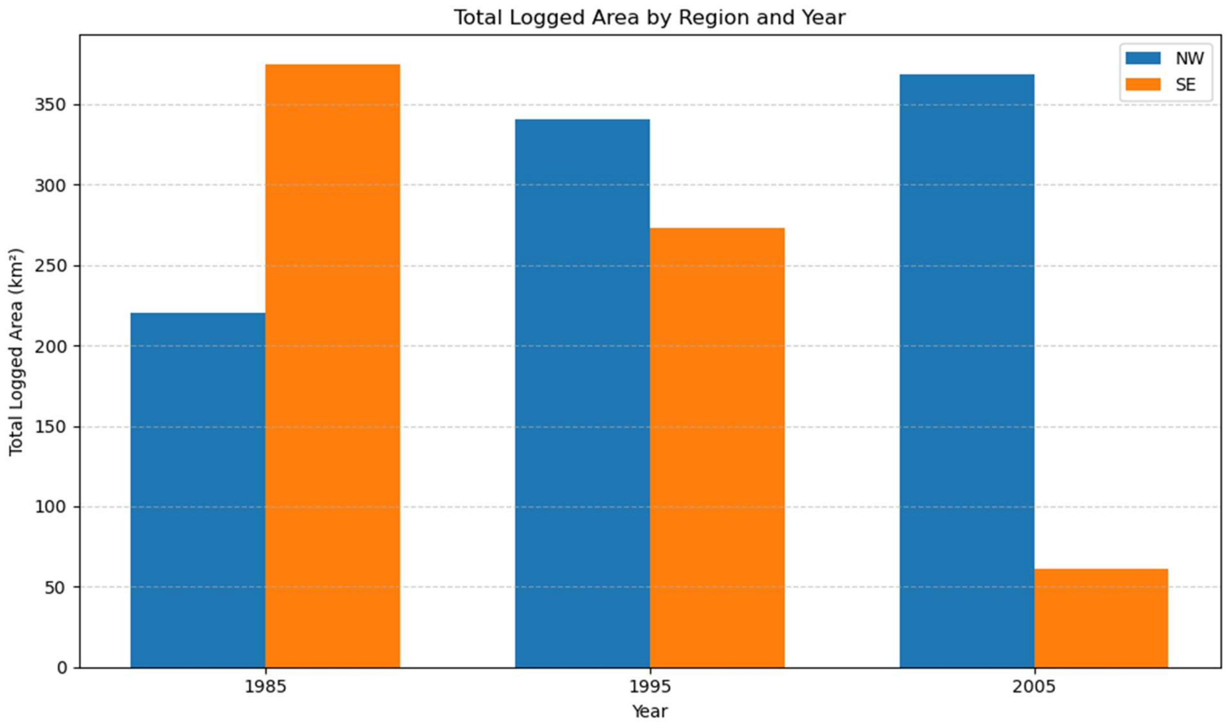


From 1985 to 2005, undisturbed areas increased by 61%, rising from 244 km² to 394 km², suggesting recovery or reduced logging in some watersheds. Low disturbance areas, which dominated in 1985 (46.4%), peaked in 1995 (54.3%) but declined to 42.6% by 2005, indicating a shift toward higher disturbance categories. Moderate disturbance areas expanded significantly, growing by 48% from 417 km² to 617 km², reflecting intensified logging in previously low-impact zones. High disturbance areas, however, decreased by 32% overall, dropping sharply from 370 km² in 1985 to 108 km² in 1995 before partially recovering to 253 km² in 2005, suggesting cyclical logging patterns. Specific watersheds exemplify these trends: Watershed FID 67 maintained a consistently high disturbance level (>50%) across all three periods, as shown in the thematic maps, likely due to sustained forestry operations, whereas FID 12 transitioned from Low (10% in 1985) to Undisturbed (0% in 2005), indicating potential reforestation or protection measures.

5.2 Regional Analysis (SE vs. NW)

A comparative analysis of logging impacts between the Southeast (SE) and Northwest (NW) sub-regions of the study area, as delineated in the watershed geodatabase, reveals distinct spatial patterns in disturbance intensity. The table below presents the total disturbed area and mean disturbance percentage for each sub-region, calculated from the proportion disturbed indicator across the three time periods.

Region	1985 Total (km^2)	1985 Mean %	1995 Total (km^2)	1995 Mean %	2005 Total (km^2)	2005 Mean %
NW	220.6	10.6	340.3	16.5	368.7	17.5
SE	374.4	12.4	273	8.8	61.1	1.3



In the NW region, logging activity increased steadily, with disturbed area rising from 220.6 km² in 1985 to 368.7 km² in 2005, and the mean disturbance percentage climbing from 10.6% to 17.5%. This trend suggests expanding forestry operations, particularly in watersheds like FID 45, which escalated from 15% to 40% disturbance by 2005. Conversely, the SE sub-region experienced a decline in logging impact, with disturbed area dropping from 374.4 km² in 1985 to 61.1 km² in 2005, and the mean percentage plummeting from 12.4% to 1.3%. This reduction is notable in watersheds such as FID 83, which, despite a high 69% disturbance in 1995, fell to 5% by 2005, as captured in the attribute table and visualized in the 2005 thematic map. The divergence—intensification in NW versus mitigation in SE—may reflect regional differences in forestry policy, land ownership, or ecological restoration efforts, warranting further investigation for targeted management.

5.3 Key Indicators and Fish Sustainability Impacts

The primary indicator, proportion of disturbed land, quantifies the extent of logging within each watershed, serving as a proxy for potential impacts on fish sustainability, particularly for salmonid species reliant on stable stream habitats. Calculated as the ratio of logged area to total watershed area, this indicator was derived for 1985, 1995, and 2005 using ArcGIS Pro's zonal statistics, with results stored in attribute tables and visualized in thematic maps. Across the study area, the mean proportion disturbed increased from 15.9% in 1985 to 17.7% in 1995 before declining to 14.6% in 2005, reflecting a peak in logging activity mid-study followed by partial recovery.

High disturbance watersheds (>50%), such as FID 67, pose significant risks to fish sustainability due to increased sedimentation and altered hydrology. Logging removes vegetative cover, accelerating soil erosion and depositing sediment into streams, which can smother salmon spawning gravels and reduce water quality. For instance, FID 67's persistent high disturbance likely exacerbates sedimentation in its fish-bearing streams, threatening juvenile salmon survival. Conversely, the expansion of undisturbed areas by 2005 (20.5% of the study area) suggests improved habitat conditions in watersheds like FID 12, where reduced logging may enhance stream stability and spawning success. The regional analysis further informs these impacts: NW's rising disturbance (17.5% mean in 2005) may intensify sedimentation risks in its streams, while SE's sharp decline (1.3% mean) likely benefits local fish populations. These findings, supported by the submitted tabular summaries and maps, underscore the need for watershed-specific management strategies to mitigate logging impacts and safeguard fish sustainability.

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6. Discussion

By analyzing logging trends, their ecological implications for fish sustainability, and the constraints faced during execution, this discussion elucidates the study's contributions to watershed management and identifies opportunities for methodological refinement.

6.1 Trends and Implications

The analysis delineated significant shifts in logging intensity across the study period, with profound implications for fish sustainability in southern Vancouver Island's watersheds. The proportion disturbed indicator, calculated as the percentage of logged area per watershed, revealed that undisturbed areas expanded by 61%, from 244 km² (12.7%) in 1985 to 394 km² (20.5%) in 2005, while moderate disturbance areas increased by 48% to 617 km² (32.1%). High disturbance areas, however, declined by 32%, from 370 km² (19.2%) to 253 km² (13.2%), after a notable low of 108 km² (5.6%) in 1995. These trends suggest a peak in logging activity around 1995, followed by partial recovery or reduced logging in some watersheds by 2005, potentially driven by regulatory shifts or reforestation efforts. Watersheds like FID 67, consistently exceeding 50% disturbance, underscore persistent ecological risks, as logging can exacerbate sedimentation, which degrades salmonid spawning habitats by smothering gravels and reducing dissolved oxygen (Beschta et al., 2004).

Regionally, the Northwest (NW) sub-region experienced intensifying disturbance, with the mean proportion disturbed rising from 10.6% in 1985 to 17.5% in 2005, exemplified by FID 45's increase from 15% to 40%. Conversely, the Southeast (SE) sub-region saw a marked decline, with mean disturbance dropping from 12.4% to 1.3%, as seen in FID 83's reduction from 69% in 1995 to 5% in 2005. By 2005, this NW-SE balance—intensification versus mitigation—indicates spatially heterogeneous logging impacts, possibly reflecting localized forestry policies or land tenure differences. The growth of undisturbed areas, particularly in SE's FID 12 (0% disturbance in 2005), presents significant conservation opportunities. Protecting these 394 km² of undisturbed watersheds could stabilize stream habitats critical for salmonids, supporting Canada's wild salmon conservation goals (Fisheries and Oceans Canada, 2005). These findings advocate for region-specific strategies, such as enhanced riparian protections in NW and habitat restoration in SE, to balance forestry with fish sustainability.

6.2 Challenges and Limitations

The project encountered several challenges that influenced its execution and scope, primarily stemming from data quality and temporal constraints. A notable difficulty was the compromised quality of 1985 Landsat imagery, where cloud cover obscured approximately 15% of the study area, hindering accurate heads-up digitizing of clearcuts in ArcGIS Pro. This was mitigated by utilizing multiple image dates from the same season, following best practices for remote sensing analysis (Lillesand et al., 2015), and prioritizing watersheds with clearer imagery, such as FID 67, to maintain representativeness. However, this approach extended digitizing time from an estimated 2 hours to 6 hours, as documented in the Status Table, compressing subsequent tasks within the 12.5-day project timeline. Time limitations also precluded the exploration of semi-automated classification techniques, such as NDVI thresholding, which could have expedited digitizing but required preprocessing beyond the project's scope.

A significant limitation was the unavailability of historical road network data in the Catala Instructional Datasets, which prevented the calculation of optional indicators like road density and road/stream crossings. These metrics could have enriched the analysis by quantifying additional sedimentation sources, as roads are known to amplify runoff into aquatic systems (Trombulak & Frissell, 2000). Similarly, incomplete stream data restricted the assessment of riparian disturbance, limiting insights into near-stream logging effects. Despite these constraints, the project successfully delivered its core objective by focusing on the proportion disturbed indicator, producing a validated geodatabase, thematic maps for 1985, 1995, and 2005, and comprehensive tabular summaries. The emphasis on high-quality outputs ensured actionable findings, but future studies would benefit from access to complete datasets and extended timelines to incorporate supplementary indicators, enhancing the depth of ecological impact assessments.

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7. Conclusion and Recommendations

This study has provided a comprehensive geospatial analysis of logging impacts on fish-bearing streams within southern Vancouver Island's third-order watersheds from 1985 to 2005, successfully achieving its objective of quantifying disturbance trends and their ecological implications. By leveraging ArcGIS Pro to map and analyze the proportion of disturbed land, the project revealed a dynamic landscape: undisturbed areas grew by 61% to 394 km² (20.5%) by 2005, moderate disturbance expanded by 48% to 617 km² (32.1%), and high disturbance declined by 32% to 253 km² (13.2%). Regionally, the Northwest sub-region's increasing disturbance (17.5% mean in 2005) contrasted with the Southeast's significant reduction (1.3% mean), highlighting spatially varied forestry impacts. These findings, visualized in thematic maps and supported by a validated geodatabase, underscore the delicate balance between logging activities and fish sustainability, particularly for salmonids vulnerable to sedimentation and habitat degradation. Despite challenges such as poor 1985 Landsat imagery and data limitations, the project delivered actionable insights, affirming the value of GIS in environmental management.

To mitigate the identified impacts and enhance fish habitat conservation, the following recommendations are proposed for land managers and policymakers:

1. **Protect Undisturbed Watersheds:** Prioritize the conservation of the 394 km² of undisturbed watersheds, such as those represented by FIDs 0 and 4, which exhibited 0% disturbance in 2005. These areas serve as critical refuges for salmonid spawning and rearing, maintaining stable stream conditions essential for juvenile survival (Fisheries and Oceans Canada, 2005). Establishing protected zones or conservation easements can safeguard these habitats from future logging, aligning with Canada's wild salmon policy objectives.

2. **Restore Heavily Logged Watersheds:** Implement restoration programs in high-disturbance watersheds, such as FID 67 (>50% disturbance across all periods), to reduce sedimentation and restore riparian vegetation. Reforestation and erosion control measures, such as planting native species along streambanks, can stabilize soils and improve water quality, mitigating the smothering of spawning

gravels observed in heavily logged areas (Beschta et al., 2004). Pilot projects targeting FID 67 could serve as models for broader restoration efforts.

3. **Adopt Sustainable Forestry Practices:** Encourage the adoption of low-impact logging techniques, such as selective harvesting and wider riparian buffers, particularly in the Northwest sub-region where disturbance intensified to 17.5% by 2005. These practices minimize soil disturbance and runoff, reducing sedimentation risks to fish habitats (Trombulak & Frissell, 2000). Policymakers should incentivize sustainable forestry through certification programs or subsidies, ensuring long-term compatibility between economic activities and ecological health.

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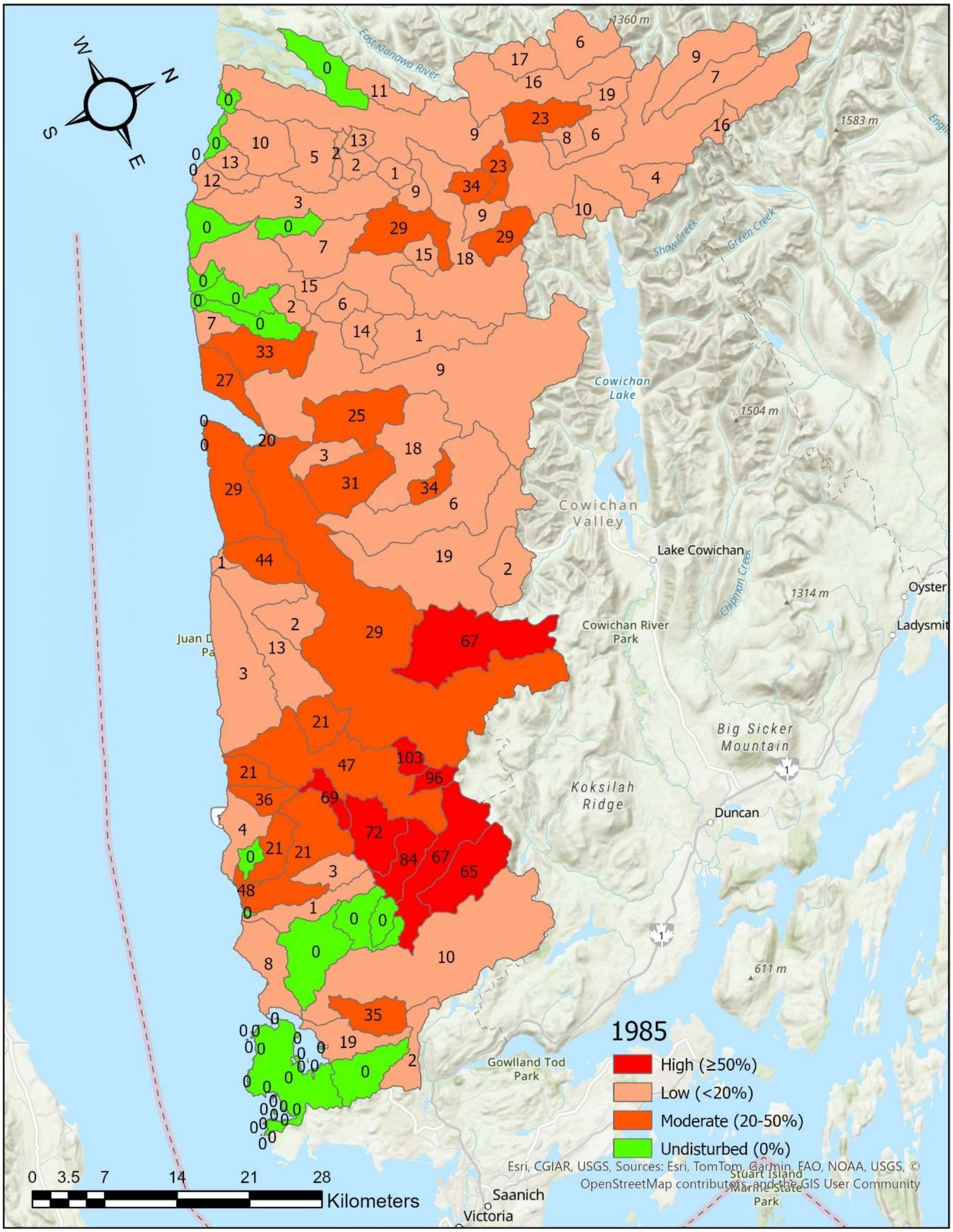
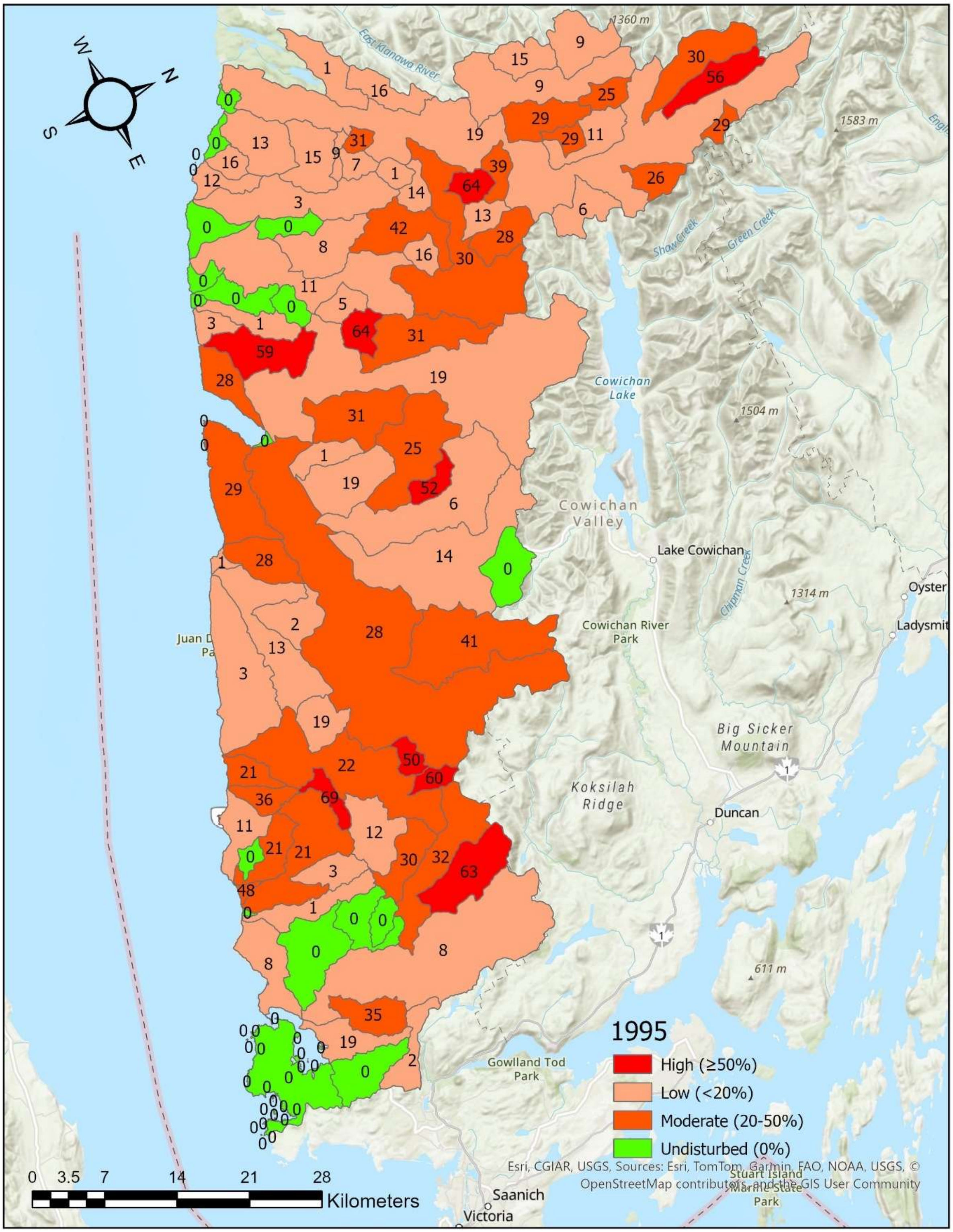
8. Appendices

Appendix A: Sample Thematic Maps

1985 Thematic map



1995 Thematic map



2005 Thematic map