**Natural Resource Use in Clayoquot and Barkley Sounds**

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## Introduction

Clayoquot and Barkley Sounds (Appendix Figure 1) are two ocean inlets along the west coast of Vancouver Island in British Columbia. These two inlets are estuarine systems with input from both cold, salty ocean waters and from fresh waters that transit across the land, often entering the stream network before entering the larger waterbodies of the sounds. Thus any large-scale change people make to the area landscape is often noticed in the quality and quantity of water entering the sounds.

Clayoquot Sound encompasses over 2,600 square kilometers between Esowista Peninsula and Hesquiaht Peninsula. It is home to a wealth of natural resources, including the largest intact watershed on Vancouver Island, old growth forests, salmon spawning habitat, and 29 rare plant species (Ministry of Forests, Lands and Natural Resource Operations 2011). Barkley Sound is an area of about 800 square kilometers just south of Clayoquot Sound. Barkley Sound forms the entrance to Alberni Inlet.

In 1993, after the land use and development protests of the 1980s, the government of British Columbia developed a more restrictive land use policy in Clayoquot Sound (Ministry of Forests, Lands and Natural Resource Operations 2011) This new policy severely limits logging in Clayoquot Sound as well as calling for the designation of Clayoquot Sound as a United Nations Educational Scientific and Cultural Organization (UNESCO) Biosphere Reserve. Clayoquot Sound received its Biosphere Reserve status in January 2000 (Clayoquot Biosphere Trust 2011).

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Because of the Biosphere Reserve status and attempts to limit logging, Clayoquot Sound is considered by many to be a more pristine system than Barkley Sound, which has not garnered support for its fragile ecosystem despite hosting Barkley Sound hosts the third largest population center on Vancouver Island, the almost 25,500 people who call Port Alberni home (Statistics Canada 2011). The truth is that both Clayoquot and Barkley Sound feel the effects of natural resource use.

The use of natural resources within the watersheds has been shown to affect native shellfish, aquatic insects, and fish distribution within the watershed (Cooper 1987; Osborn *et al* 1993). Point and nonpoint source pollutants from mining activities are also likely to severely impact aquatic fauna (Diamond *et al* 2002). Much of these impacts come from both logging and mining – both of which send an increase of water and sediments from watersheds into local streams (Carpenter *et al* 1998; Rabalais *et al* 2001; Forsyth *et al* 2006). Increased nutrient loads, carried into the water with the increased sediment load, have been shown to contribute to phytoplankton production which, when they die and decompose, leads to hypoxic or anoxic conditions in the waterbody (Boesch *et al* 2001). This nutrient enrichment is considered by many to be the leading cause of degraded water quality in coastal waters (Howarth 2004; Bricker *et al* 2007).

Both shellfish and finfish aquaculture interests also have an impact to the surrounding waters. Shellfish aquaculture is considered by some to improve area waters by taking excess nutrients, in the form of phytoplankton, from the water

column (Gren *et al* 2009). However this improvement comes at a cost. Shellfish feces contribute to the sediment nutrient loading – this impact of "self-pollutants" on the environment cannot be neglected (Yuan *et al* 2010). Likwise, finfish farming can add significant nutrient loading from feed waste and fish excretion (Wu 1995). Most of this nutrient loading accumulates in the bottom sediments and significantly impacts are confined to within 1 kilometer of the farm (Wu 1995). This nutrient loading can lead to the degradation of marine sediments and benthic areas of hypoxic or anoxic conditions, the result of eutrophication (Yuan *et al* 2010).

## Objectives

To quantify the quality of the water and sediments in Clayoquot and Barkley Sounds, oceanographer, Dr. Cheryl Greengrove, has been collecting both water and sediment samples in the sounds since 2006. Among the water qualities tested are dissolved oxygen concentrations, nutrient loads, and phytoplankton concentrations. The sediments cores are analyzed for their particle size and total organic content. The following analysis is an attempt to explain, however rudimentary, how humans are changing the watersheds around Clayoquot and Barkley Sounds and how those changes might impact the water and sediment quality of the sounds.

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## Analysis Planning

Originally, three categories of data were to be included in the analysis. These included foundational data, human impact data, and additional data sources. The foundational data were to include geopolitical boundaries, bathymetry, topography, populated places, roads, and oceanographic data collection. The human impact data were to include data for population, impervious surfaces, logging tenures, saw mills, freshwater and marine aquaculture facilities, mining interests, marinas, dams, sewage outfall, and the location of agricultural lands. Locations of additional environmental data such as mooring buoys, lighthouses, airports, and weather stations were also to be added to the dataset.

During the planning and data-gathering process, it quickly became apparent that the full, originally planned analysis would be unmanageable in the given time frame. It was decided to narrow the scope of the analysis and concentrate only on natural resource use – the logging of forests, freshwater and marine aquaculture, and coal and mineral mining. Once the data was gathered, it could be determined which watersheds within Clayoquot and Barkley sounds were the most changed by natural resource use.

## Data Sources

The data used in this analysis were obtained from the following sources:

DataBC - DataBC was the source for the aquaculture tenures, coastline data and named places data used in this project. All aquaculture data, including shellfish tenures, freshwater hatcheries and fisheries, and marine fisheries tenures, were provided by DataBC in conjuncture with Coastal Resource Information Management Systems (CRIMS).

GeoBase - Canadian Digital Elevation Data were downloaded from GeoBase. The original author was Base Mapping and Geomatic Services - British Columbia Government - Victoria. The Canadian Digital Elevation Data files provided elevation data, relative to mean sea level, which were used to create the watershed polygons and the hillshade raster used to visualize the data. The data use the North American Datum 1983 coordinate system and had a resolution of 1:50,000.

Global Forest Watch Canada - The intact forest land and mineral claims data were provided by Global Forest Watch Canada. Intact forest land data was chosen over logging tenures because it considers all land use that affects the forests, not just commercial logging interests.

## Methodology

Before spatial manipulation of the data could occur, a geoprocessing extent was created by converting a coastline polyline shapefile into a coastline polygon shapefile. This coastline polygon was used as the geoprocessing extent for all the processes involved in creating watersheds. This file, along with all others used in this spatial analysis, was projected using the BC Albers projection and stored within

a feature class in a geodatabase. The BC Albers projection was chosen over UTM projection because while both projections preserve area, only BC Albers covered the full spatial extent of this analysis (Province of British Columbia 1996). Clayquot and Barkley Sounds span UTM zones 9 and 10.

Creation of Watersheds - Thirty-eight individual Canadian digital elevation data (CDED) files were downloaded from GeoBC and added to ArcMap. In order to create a single, workable raster file, these CDED files were mosaicked into a single "master" raster file. Once the "master" raster file was created, it was filled to ensure the proper delineation of the streams, the flow direction tool was used to determine how water would flow across the topography of the land. The flow direction raster was then used to determine areas of flow accumulation. Areas with a flow accumulation greater than 500 cells were designated as streams within the watershed. Pour points were manually created where each of the highest stream outflows intersected with larger waterbody of the sound. These pour points, along with the flow direction raster, were then used as the basis for watershed creation. These watersheds, once converted from a raster file to a polygon shapefile, would serve as the basis for normalizing the data comparing natural resource use in Clayoquot and Barkley Sounds.

Intact Forest Land - The area within each watershed considered to be intact forest land was determined using a third party program, Geospatial Modeling Environment. This program facilitated the summing the area of multiple polygons within a single zonal polygon. These data were then normalized to determine the

percent of each watershed area still covered by intact forest land. This percent was then subtracted from 100 to determine the percent of the watershed without intact forest land.

Shellfish and Marine Finfish Influences - In order to determine which oceanographic data collection points were most impacted by area shellfish tenures and marine finfish tenures, a .5 km buffer was drawn around each data collection point. A spatial location join was then performed to determine the number of tenures within a .5 km radius of each research station where oceanographic data are collected.

Freshwater Aquaculture - Because the freshwater finfish data file contained point data only, a spatial join was performed to determine the number of freshwater finfish interests within each watershed.

Coal Mining Tenures - It was determined that there was no coal mining taking place in any of the watersheds of interest. This data was not included in any further processing.

Mineral Mining Tenures - The percent of each watershed's area that is covered by mining tenures was determined using a third party program, Geospatial Modeling Environment. This program facilitated the summing the area of multiple polygons within a single zonal polygon. This data was then normalized to determine the percent of each watershed leased for mineral mining.

Calculating Total Natural Resource Use – Because some of the natural resource use takes place in the water and other natural resource use takes place on

the land, a water-based raster and land-based raster were created to show which areas were most impacted by natural resource use. In order to create these rasters, the statistical significance was calculated for each use in each watershed or research station. Using map algebra, these z-scores were then added to determine the watersheds and research stations that were most impacted by natural resource use.

## Results

Watersheds – There are a total of 3,324 watersheds in Clayoquot and Barkley Sounds. Of these watersheds, only 906 are the result of a stream network draining into the larger waterbody. Water from the remaining 2,418 watersheds empties into the receiving waterbody directly, without first entering a stream network.

Forest Land, Mining Tenures, and Freshwater Aquaculture – In Clayoquot and Barkley Sounds, the loss of intact forest land occurred in easily accessible places near the water (Appendix Figure 2). When the data were normalized, it was found that the watersheds of Barkley Sound had a greater percentage of each watershed impacted by the loss of intact forest land than the watersheds of Clayoquot Sound (Appendix Figure 3).

Like the loss of intact forest land, active mineral mining tenures were concentrated to areas near the water (Appendix Figure 4). When the data were normalized, it was found that the watersheds of both Clayoquot and Barkley Sounds were roughly similar in the percent of each watershed that was leased for mineral mining (Appendix Figure 5).

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Because the only four freshwater aquaculture facilities within the watersheds of Clayoquot and Barkley Sounds were clustered one watershed near Port Alberni, a decision was made to remove this data outlier from the land-based raster analysis. The land-based raster analysis included only impact from the loss of intact forest land and mineral mining tenures. Both the loss of intact forest land and mineral mining were given equal weight when their z-scores were combined to determine the level of impact by natural resource use realized by each watershed (Appendix Figure 6)

When statistically analyzed (Appendix Figure 6), it was found that 2,261 watersheds were considered to have an average impact when considering natural resources use. These are the watersheds where the combined z-scores fell within two standard deviations from the mean combined z-score. Four hundred fifty-eight (458) watersheds are considered to have a low natural resource use impact when compared to the mean. Most of these watersheds are in lands surrounding Clayoquot Sound. Six hundred five (605) watersheds are considered to have a high natural resource use impact when compared to the mean. Most of these watersheds are in lands surrounding Barkley Sound.

Shellfish Aquaculture and Marine Finfish Aquaculture – Shellfish aquaculture interests are active throughout both Clayoquot and Barkley Sounds with 73 separate shellfish aquaculture facilities spread throughout the area. Despite the widespread nature of shellfish aquaculture, only 7 facilities occur within half a

kilometer of an oceanographic research station where water and sediment quality are monitored.

Marine finfish interests have a lesser presence in Clayoquot and Barkley Sounds than does shellfish aquaculture. There are 23 marine finfish farms spread across the sounds, with only one of those facilities occurring within a half a kilometer of an oceanographic research station.

When statistically analyzed, only 5 of the 79 oceanographic research stations were found to be impacted by marine finfish and shellfish aquaculture (Appendix Figure 7). These stations are stations 6, 7, 43, 90, and 91. Of these five stations, station 43 is considered to be the most impacted by marine finfish and shellfish aquaculture, with three shellfish farms and one finfish farm occurring within half a kilometer of the station.

## Discussion

It is not surprising that Clayoquot Sound was found to be less impacted by natural resource use than Barkley Sound. Currently, Clayoquot Sound hosts 16 provincial parks, including Strathcona Provincial Park – the largest undisturbed watershed on Vancouver Island, part of the Pacific Rim National Park Reserve, and two ecological reserves (BC Parks 2002).

Unlike Barkley Sound, Clayoquot Sound has a history of protecting its natural resources. When land use and development began to encroach on environmental interests, protesters were quick to rally to save the area's natural resources. These

protests of the 1980s and early 1990s lead to policies severely limiting logging in Clayoquot Sound. In January 2000, the work began by the protestors of the 80s and 90s resulted in Clayoquot Sound being designated as a UNESCO Biosphere Reserve.

This analysis focused on a handful of natural resources uses that are occurring in the sounds, it is not a complete look at the impact of natural resource use. Future analyses should include the presence of hydroelectric dams to determine what percent of stream systems remains free-flowing. This would be important data to include because dams are known to change flow regimes within the stream system and severely change sediment conditions below the dam (Yuan *et al* 2012; Brandt 2000).

In addition to quantitative data, it would be wise to include participatory GIS data into the analysis. Mendoza and Martins (2006) believe that including such qualitative data serves a four-fold purpose:

- 'It seeks to take explicit account of multiple, conflicting criteria'
- It helps to structure the management problem
- It provides a model that can serve as a focus for discussion
- It offers a process that leads to rational, justifiable, and explainable decisions.

When local stakeholders are included in natural resource management, the community can be positively impacted through better governance, improved dialog, legitimatize local knowledge, and the redistribution of resource access and control (McCall and Minang 2005).

Future research in the natural resource use of Clayoquot and Barkley Sounds would be wise to include participatory GIS data including:

- The perceived quality of the watersheds by area residents
- The perceived quality of today's watersheds as compared to local First Nations' historic knowledge
- The perceived effectiveness protests in the 1980s and early 1990s
- The perceived impact the preservation of Clayoquot Sound has had on area residents

## Conclusion

This limited spatial analysis focused on four natural resource uses that affect Clayoquot and Barkley Sounds. It was found that while the majority of natural resource use occurs in proximity of the coastline in both sounds, Clayoquot Sound is less impacted by natural resource use than Barkley Sound. This is in part due to the protests of the 1980s and early 1990s which lead to stricter logging regulations and the designation of Clayoquot Sound as a UNESCO Biosphere Reserve. This analysis should not be considered a complete summation of natural resource use in the sounds. It is prudent that future analyses include participatory GIS data in order to

get a more complete look at the true nature of natural resource use across Clayoquot and Barkley Sounds.

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# Appendix

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Figure 1: Clayoquot and Barkley Sounds are located on the west coast of Vancouver Island, British Columbia, Canada.

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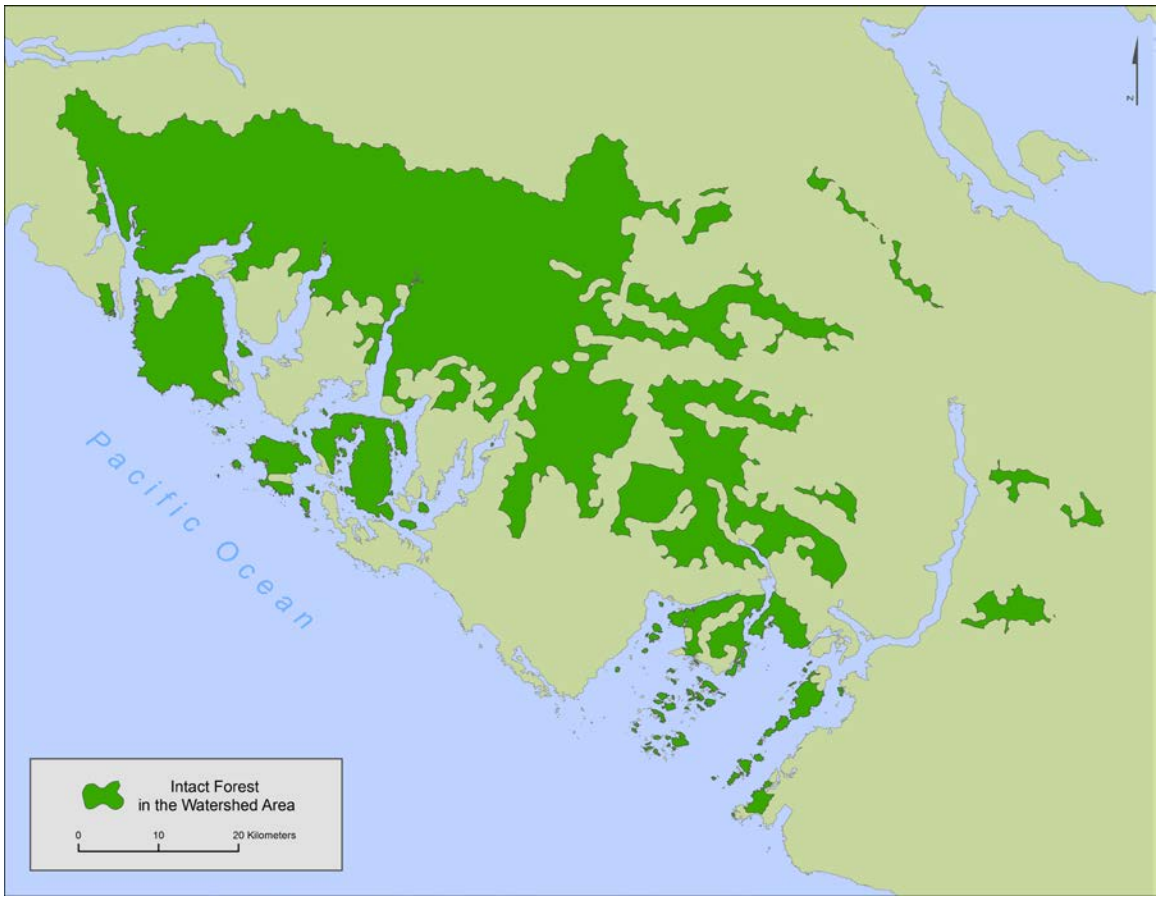


Figure 2: The extent of intact forest land in Clayoquot and Barkley Sounds. Land that has been forested is concentrated near the coastline.

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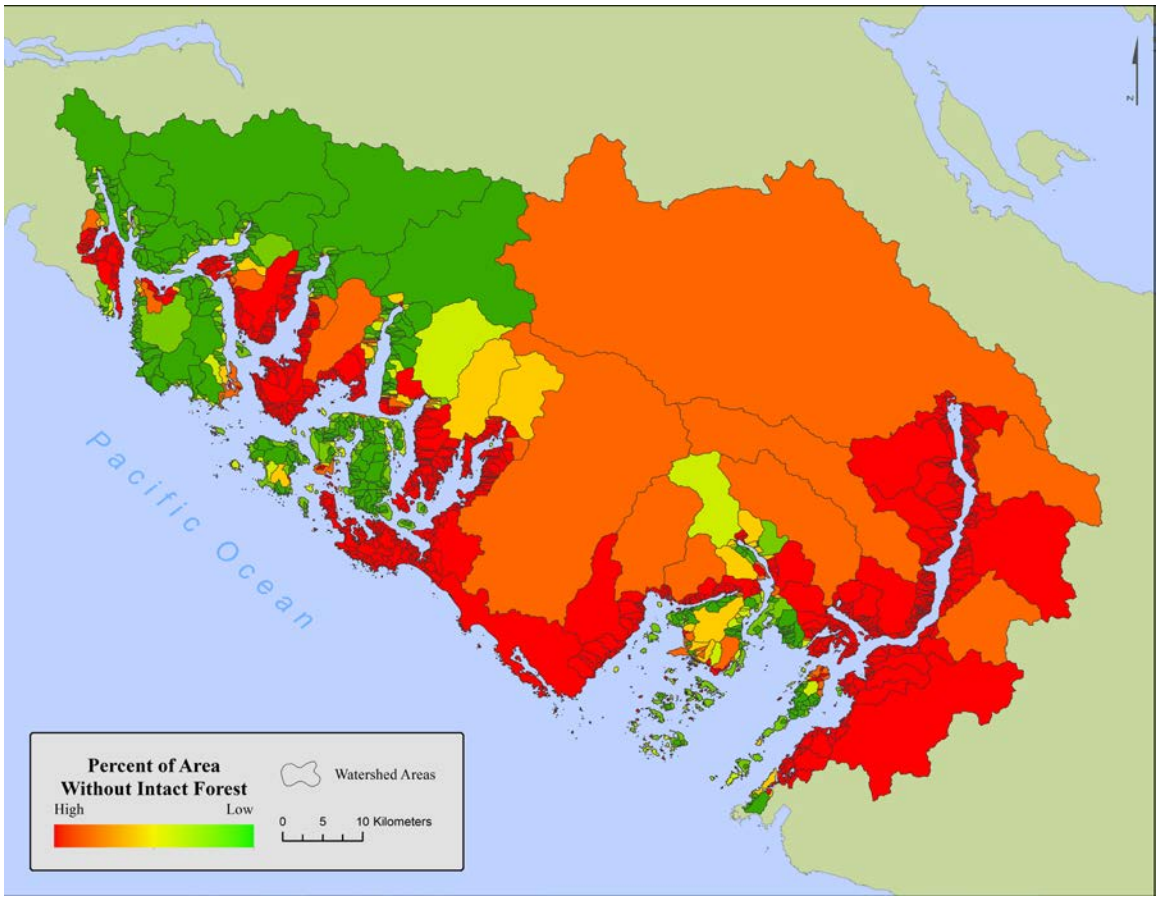


Figure 3: The percent of each watershed without intact forest land. Clayoquot Sound has a greater percent area of intact forest land with logged areas confined near the coastline. Barkley Sound was found to have a greater percent of land that has been logged.

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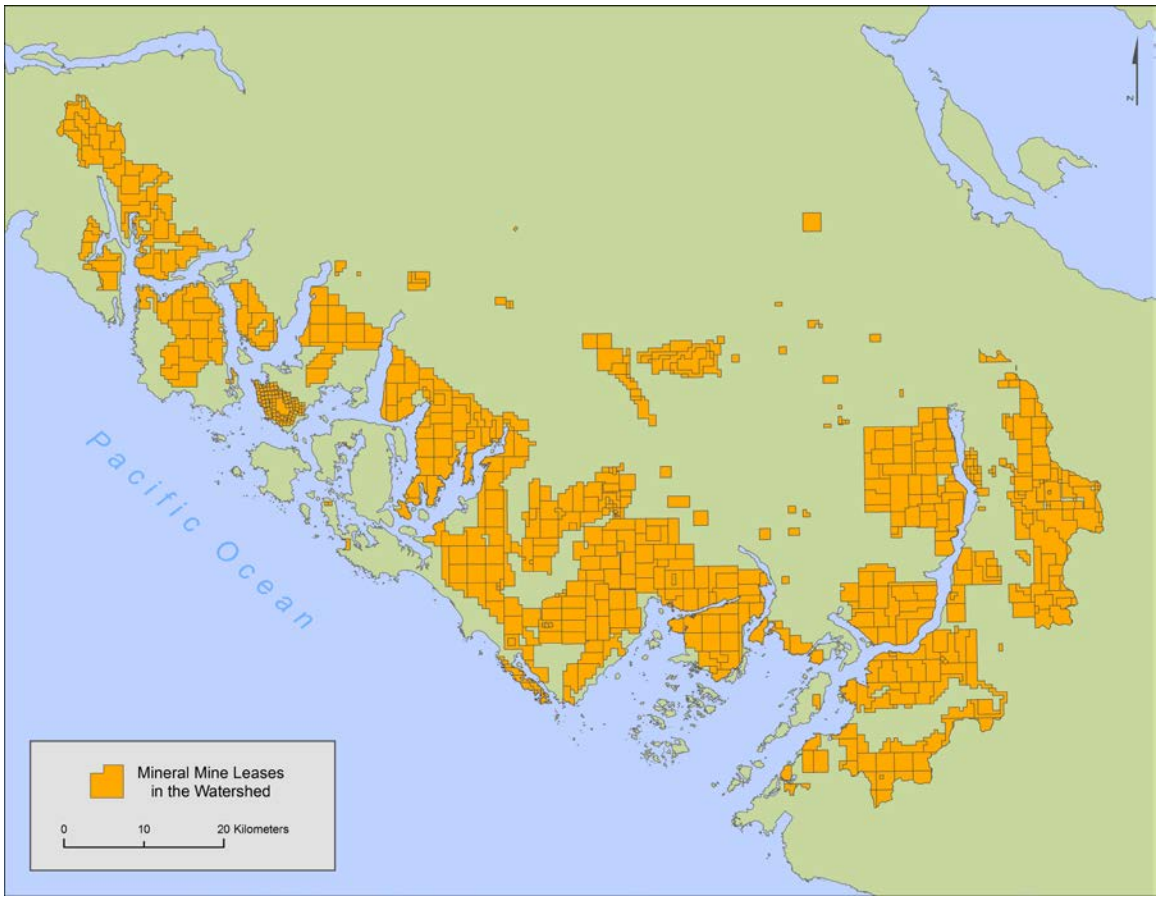


Figure 4: Mineral mining leases in Clayoquot and Barkley Sounds. Mining leases are generally confined to coastal areas.

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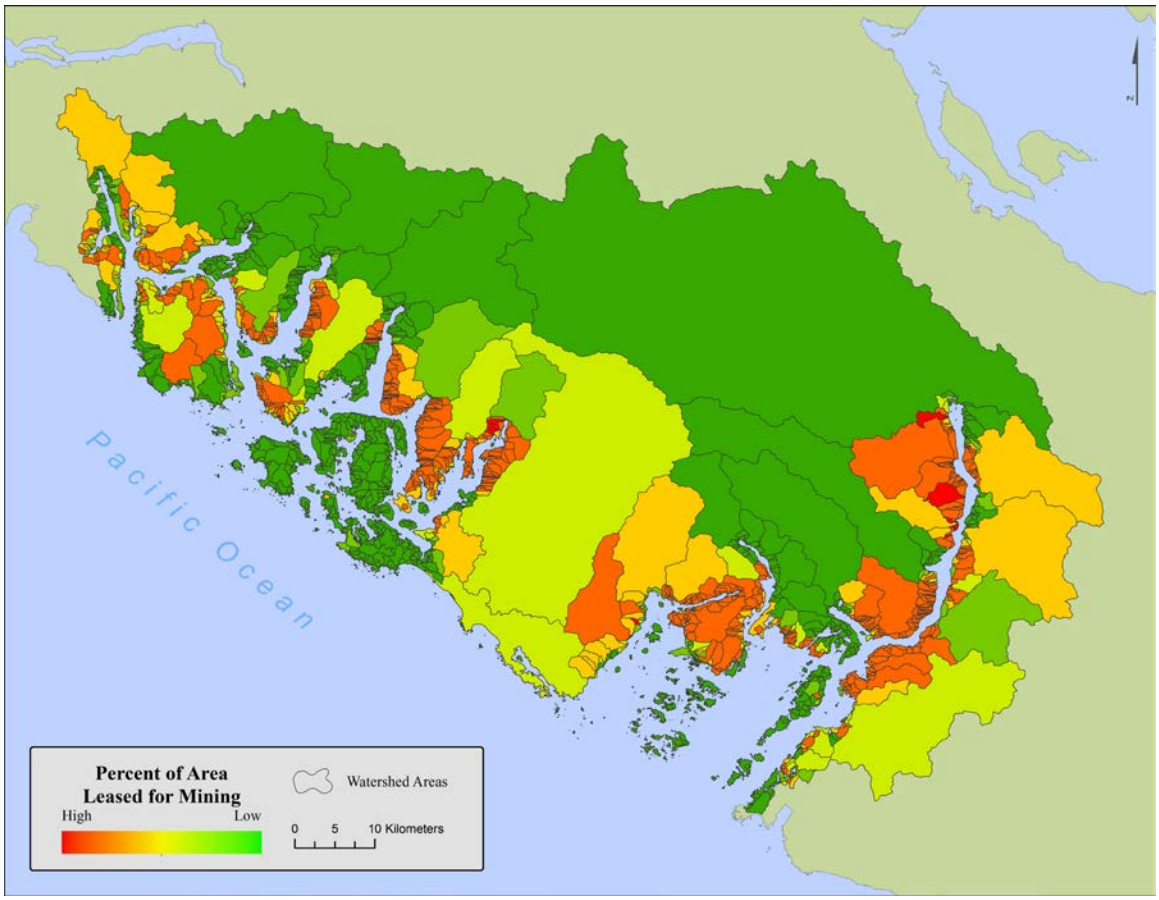


Figure 5: The percent of each area that has been leased for mining. The percent of each watershed leased for mining is roughly equal across Clayoquot and Barkley Sounds.

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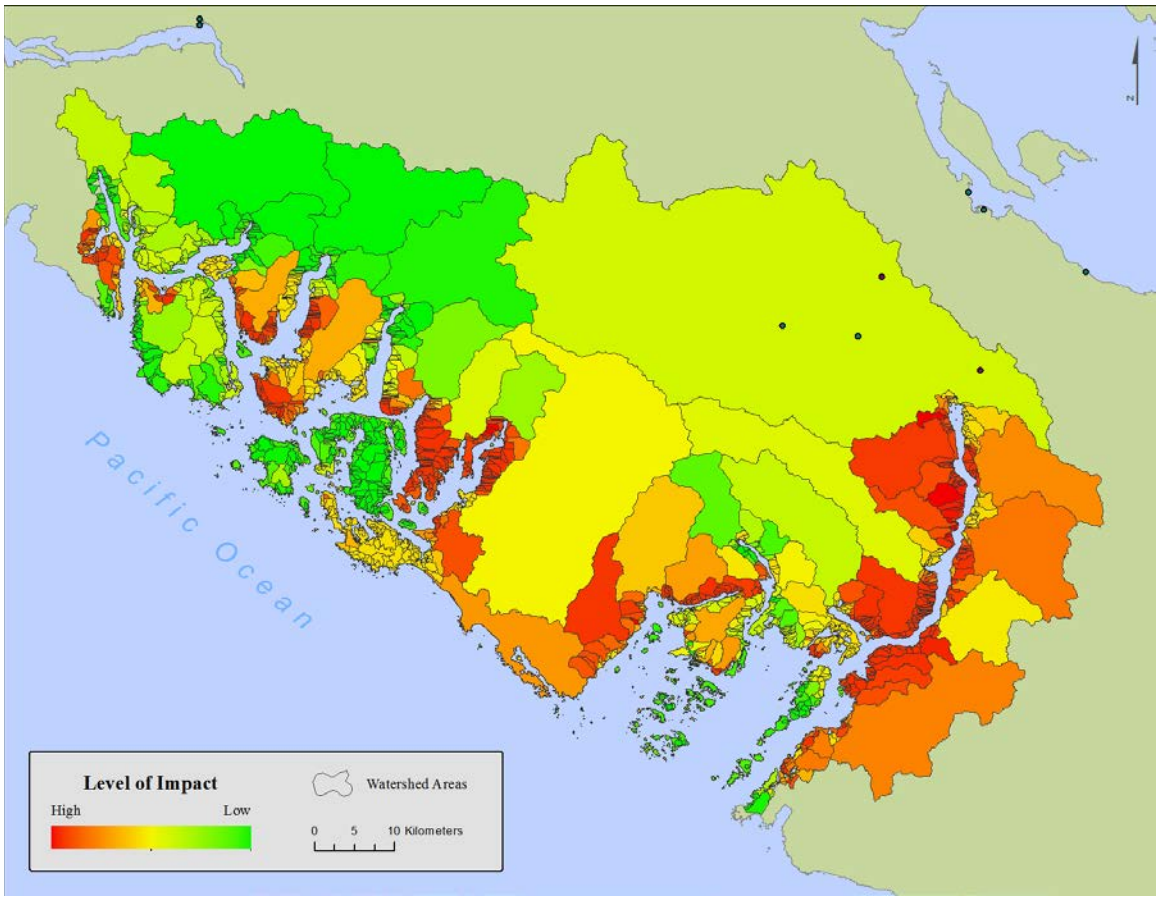


Figure 6: When the watersheds were statistically analyzed to compare the average level of impact by logging and mining, it was found that Barkley Sound was more impacted than Clayoquot Sound. Because freshwater aquaculture impacts were considered an outlier during the analysis, the four freshwater aquaculture facilities are shown as point features on the map.

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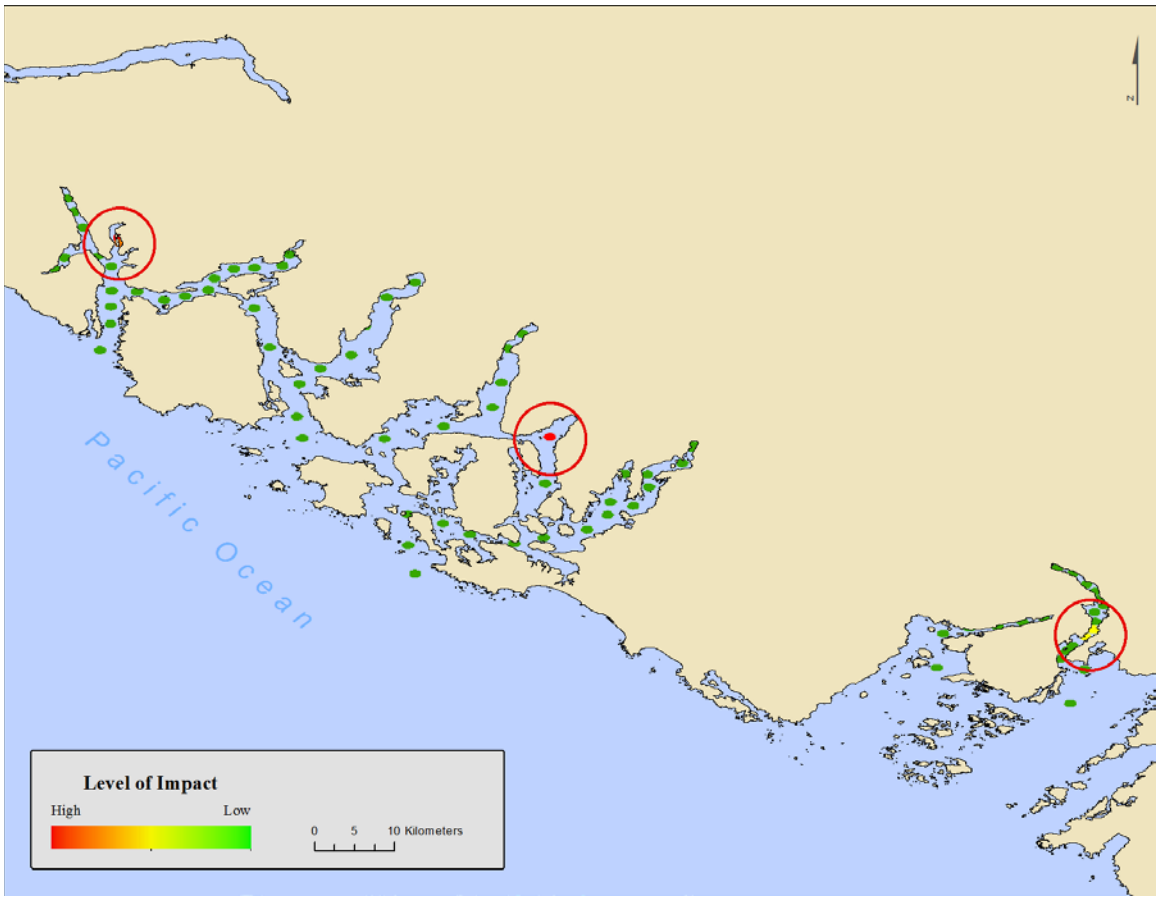


Figure 7: When statistically compared, it was found that only five of the oceanographic research locations were affected by either shellfish aquaculture or marine finfish farms. Of the five affected, station 43 (center) was found to be most impacted with three shellfish and one finfish facilities within half a kilometer of the station.