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RESEARCH ARTICLE

How Old-Growth Forest Conservation Policies Support Caribou Recovery in British Columbia

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ABSTRACT

This research examines the critical policy intersection between old-growth forest preservation and caribou conservation strategies in British Columbia. Caribou depend heavily on old-growth forests for lichen, their primary food source. In response, British Columbia has implemented policies aimed at protecting old-growth ecosystems, thereby indirectly safeguarding caribou habitats. While alternative methods such as predator control (e.g., wolf reduction) and maternal penning provide short-term conservation gains, long-term caribou recovery requires substantial protection of old-growth forests. However, expanding conservation efforts entails significant opportunity costs, particularly the loss of logging revenues that remain vital to the provincial economy. To explore these dynamics, this study applies a simple extinction model to evaluate the impact of different forest management scenarios on caribou population trajectories. Through a comprehensive review and critical analysis of current forest preservation policies, the study identifies key gaps and proposes strategic enhancements to strengthen conservation efforts. The findings emphasize that preserving old-growth forests not only supports caribou survival but also enhances British Columbia's ecosystem services and long-term ecological resilience.

Keywords: caribou population, policy review, old-growth forest, British Columbia, economics of conservation

Introduction

British Columbia (BC) encompasses a total land area of 95 million hectares, of which approximately 64% is forested (Government of British Columbia, 2016). Among these forested lands, about 11.1 million hectares—or roughly 20%—are classified as old-growth forests (Ministry of Forests, 2024). Old-growth forests are critical habitats for woodland caribou, a species increasingly threatened by human disturbances, such as forestry operations and pipeline expansions (Cichowski et al., 2022).

Forest harvesting and linear fragmentation disrupt caribou habitats in several ways. First, logging destroys key food sources, particularly lichens, which are vital for caribou survival (Cichowski et al., 2022). Second, reduced forest density creates open landscapes that make caribou more vulnerable to predation (James & Stuart-Smith, 2000). Additional disturbances, including noise pollution and the increase of linear features like roads and pipelines, further intensify risks to caribou populations (Maher et al., 2020; Maltman et al., 2024).

Several recovery strategies have been proposed to mitigate these impacts and support caribou conservation. Key interventions include minimizing habitat alteration, enhancing nutrition through maternal penning, and reducing predator populations such as wolves and moose (Maher et al., 2020). Johnson et al. (2019) demonstrate through their caribou-moose-wolf model that wolf population control is the most cost-effective short-term strategy for recovering the Chinchaga herd in British Columbia. However, for populations like the Charlevoix herd in Quebec, maternal penning proves more effective, highlighting the importance of tailoring conservation strategies to local demographic and ecological conditions.

Although predator-prey dynamics have often been emphasized, Ehlers et al. (2016) argue that in areas of low population density, such as those affected by extensive logging, direct encounters between caribou and wolves are relatively rare. Short-term interventions like wolf culling have shown success, but they are not sustainable in the long term (McNay et al., 2022). A more enduring solution lies in conserving old-growth forests, which provide both abundant lichen resources and the dense forest cover necessary for caribou to evade predators.

To address habitat loss, southern British Columbia has implemented sustainable forest management practices, particularly in second-growth forests (Stevenson, 1990). Strategies such as partial harvesting are designed to minimize impacts on wildlife habitat. Moreover, because caribou prefer high-elevation forests that offer refuge from predators, selective logging and careful forestry planning are critical for maintaining viable habitats (Newsome et al., 2016).

Provincial policy further mandates collaboration between wildlife experts and foresters during forestry planning processes (Government of British Columbia, 2025). This collaboration seeks to establish clear boundaries for caribou habitat reserves and create buffer zones that enhance habitat quality. Innovative planning tools, such as Cumulative Risk or Bow-tie Risk Assessment frameworks, also offer promising approaches to monitoring habitat dynamics and guiding conservation policy decisions (Winder et al., 2020, Hervieux et al., 2020).

Conserving old-growth forests offers additional benefits beyond caribou protection, particularly for Indigenous communities. Programs such as the First Nations Caribou Recovery Implementation Fund and the Caribou Recovery Program provide financial support, offering alternatives to the economic reliance on old-growth logging (Watt, 2024). These initiatives facilitate Indigenous-led conservation projects that integrate traditional ecological knowledge with scientific research, leading to more holistic and culturally grounded recovery strategies (Kutz & Tomaselli, 2019).

This research aims to evaluate current caribou conservation policies in British Columbia and assess their effectiveness in practice. Relying primarily on secondary sources from government publications and peer-reviewed studies, this project seeks to develop a balanced understanding of existing approaches and identify opportunities for improvement. In the next section, a theoretical model will be introduced to illustrate the relationship between caribou populations and old-growth forest conservation, providing a foundation for analyzing large-scale conservation outcomes.

The Dynamics of the Caribou Population in Old-Growth Forests

Taylor and Weder (2024) developed a simple yet powerful model to illustrate the economics of extinction. In this section, we apply their framework to analyze the survival dynamics of caribou populations in British Columbia's old-growth forests. As outlined in the introduction, caribou are increasingly threatened by a combination of wolf predation, habitat degradation from human activities, and direct harvesting through hunting. Effective management and conservation require a clear understanding of how these factors interact and cumulatively affect caribou population trajectories.

To illustrate let $C(t)$ represent the caribou population at time t. The population dynamics can be captured by a modified logistic growth function:

$$\frac{dC(t)}{dt} = gC(t)\left(1 - \frac{C(t)}{K(L)}\right)\left(\frac{C(t) - M}{M}\right) - H\big(C(t)\big) \qquad \text{(I)}$$

where:

g is the constant growth rate of the caribou population, reflecting natural reproductive capabilities.

$K(L)$ represents the natural carrying capacity of the caribou in the presence of logging L where increases in logging reduce the carrying capacity K, $\frac{dK}{dL} < 0$.

M represents the minimum number of caribou below which it becomes extinct.

$H\big(C(t)\big) = cC(t)$ represents the hunting of caribou assumed to be a linear function of the number of caribou, where c is a constant rate.

Also note that the following condition holds: $0 < M < K(L)$.

Let $v(t) = \frac{M}{K(L)}$ as the fraction of the carrying capacity below which extinction occurs, even without active harvesting.

In the caribou model, the vulnerability parameter $v(t) = \frac{M}{K(L)}$ summarizes how fragile the population is by comparing the minimum viable population M to the carrying capacity $K(L)$ under logging pressure. A higher v means that caribou require a larger share of their potential habitat capacity to avoid slipping below the threshold, so the "safe zone" between collapse and carrying capacity becomes narrower. Ecologically, this makes the population much less resilient: the peak of biological growth falls, the unstable threshold shifts upward, and the buffer against hunting or predation shrinks. Because logging reduces $K(L)$ while M remains relatively fixed, habitat loss automatically increases v, raising extinction risk even if hunting effort is unchanged. In this way, v operates as a combined indicator of how both ecological requirements and habitat degradation interact to determine the likelihood of collapse.

This model captures several critical ecological dynamics. In the absence of logging, predation, and hunting, the caribou population would naturally converge with K, the undisturbed carrying capacity, through logistic growth. However, logging reduces $K(L)$, diminishing available habitat and increasing predator encounters, thereby accelerating population decline toward extinction thresholds. The harvesting function $H\big(C(t)\big)$ captures mortality from both traditional subsistence hunting and natural predation. The harvest function is increasing linearly as the caribou population increases.

Figure 1 depicts a theoretical model of caribou population dynamics under harvesting and no logging, incorporating logistic growth with a threshold, M, and a linear harvest function. The green curve represents population growth $G(C(t))$, and the red line represents harvest losses $H(C) = cC(t)$. The intersections of these functions define five key equilibria. The point $C = 0$ represents extinction and is a conditionally stable equilibrium: if the population begins below the C_L threshold, it will decline toward zero. At $C_L = 500$, net growth is zero, but the equilibrium is unstable; small downward shifts lead to extinction, while upward shifts trigger recovery. The upper interior equilibrium at $C_H = 2{,}600$ is the only stable equilibrium; if populations reach this level, they will persist unless strongly disturbed (See Appendix III). Finally, the carrying capacity at $K = 3{,}000$ is unstable under harvest pressure; growth ceases while harvesting continues, leading to a net decline. Altogether, the model defines a bistable system in which long-term survival depends on maintaining populations above critical thresholds to avoid collapse. A summary is provided next:

- $\boldsymbol{C_L}$ **is an unstable equilibrium:** any small decrease below C_L triggers a collapse toward extinction.
- $\boldsymbol{C_H}$ **is a stable equilibrium:** deviations from C_H are self-correcting, guiding the population back to C_H.
- The range between C_L and C_H represents sustainable population levels where growth exceeds harvest pressure.

In the absence of human activities, extinction risks persist due to natural predation or extreme environmental events. If $C(t)$ falls below M, even without human interference, extinction follows. However, if the caribou population remains above C_L, natural predator-prey dynamics allow the population to stabilize around C_H.

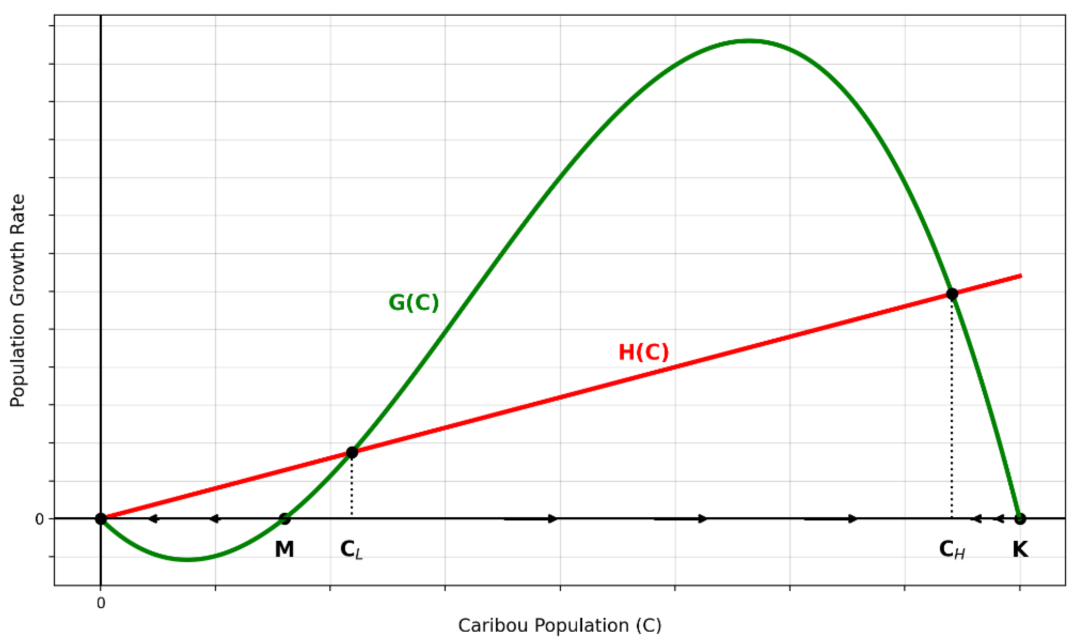

Figure 1: *Illustration of the caribou in Itcha-Ilgachuz with the minimum viable threshold population of caribou at 100 herds, a carrying capacity of 3,000, a growth rate of 0.3, a harvest slope of 1, and no logging results in an approximate lower unstable equilibrium* (C_L) *of 500 caribou and a* C_H *of 2600. See [Appendix I](#) for the derivations. The other equilibrium is the extinction of the caribou if the herd falls below 100. Logging impact is absent in the above figure. [Image Description](#)*

Predation exerts downward pressure on growth rates, often forcing caribou to migrate toward higher-elevation, denser forests that offer better refuge and food resources. Without logging or excessive hunting, these movements help maintain a stable ecosystem balance.

Impact of Logging on Population Equilibria

Logging has a huge impact on the caribou due to the creation of open space and increased success rate of predators. Logging reduces the carrying capacity and the viability of the caribou population. At the carrying capacity of $K = 3{,}000$, the model shows a lower unstable threshold and an upper stable equilibrium, allowing for potential recovery if populations remain above the critical level of C_L. However, by the time K declines below $K = 1{,}537$ (See Appendix IV), the model crosses a tipping point: the growth function G(C) lies entirely below the harvest function H(C). In this regime, caribou populations are certain of extinction regardless of initial size (Figure 2, bottom right).

Hence, introducing logging into the model alters the system's dynamics by the vulnerability parameter $v(t) = \frac{M}{K(L)}$ for the caribou. As logging progresses and available habitat shrinks, K declines from its initial value of 3,000 according to a degradation rate linked to cumulative logging effort. This reduction of carrying capacity causes the population growth curve $G(C)$ to shift leftward, reducing the maximum sustainable population size. As a result, $\boldsymbol{C_L}$, the lower unstable equilibrium, and C_H, the upper stable equilibrium, begin to converge (Figure 2). If logging continues unchecked, these equilibria eventually merge and vanish, eliminating the system's capacity to stabilize at any positive population level. Beyond this tipping point, no population size above extinction can be sustained, and collapse becomes inevitable regardless of initial conditions. Thus, logging-induced habitat loss not only reduces the long-term ecological potential of the environment but also erodes the caribou population's resilience to harvesting and other pressures. One of the assumptions is that the hunting function remains unchanged, which is most likely not true since hunters can more easily detect their prey. Hence, increased logging leads to a higher hunting rate, which could drive extinction even faster than shown in the illustration.

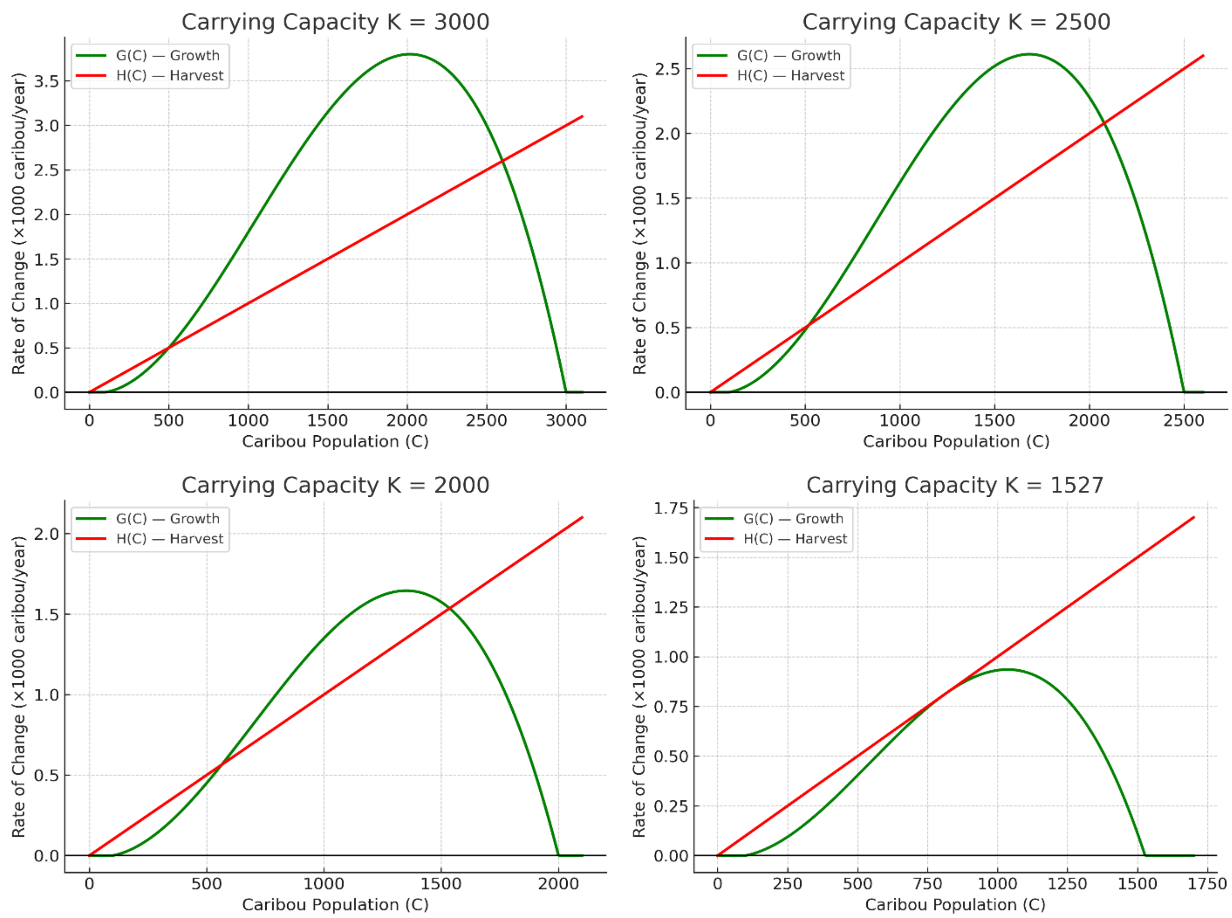

Figure 2: *Simulated caribou population dynamics under varying carrying capacities K, with growth G(C) and harvest H(C) functions. At K = 1,527, the two interior equilibria* C_L *and* C_H *merge, and a tipping point occurs around 814 herds (See* *Appendix II* *and IV). Below this threshold, no positive equilibrium exists, and the population collapses to extinction.* *Image Description*

In the next section, evidence from the Cariboo region of BC is shown. First, regions showing consistent population declines over time are identified. Then, micro-level analyses of specific study blocks are conducted by applying the model to predict future population trends under both regulated and unregulated harvesting scenarios. This approach aims to evaluate the model's practical utility and inform conservation policy decisions.

Evidence from the Caribou Region

While caribou populations are distributed across eight regions of British Columbia, this study focuses on the Cariboo region, which historically supports some of the province's highest caribou numbers. The Cariboo region is home to five distinct herds: Barkerville, Wells Gray North, Itcha-Ilgachuz, Rainbows, and Charlotte Alplands (Figure 3). These subpopulations are managed separately but may involve overlapping survey counts (Government of British Columbia, 2025).

Figure 3: *Cariboo region in BC (Credit: Government of British Columbia, n.d.)* *Image Description*
This map was created using ArcGIS® software by Esri.

Population data were retrieved from the *Wildlife Species Inventory Survey Summary* (Government of British Columbia, n.d.). Although the dataset includes multiple species such as elk, sheep, moose, and goats, only caribou data were extracted for this analysis. To ensure data credibility, only records with the "best parameter" designation were included, as this classification indicates the highest survey reliability according to the Government of British Columbia (n.d.).

To further refine data quality, the dataset was filtered based on survey methodology. Priority was given to methods with higher accuracy, including:

- Expert Knowledge
- Model Correction
- Model/Correction using Joint Hypergeometric Estimator
- Model/Correction using Lincoln-Peterson Estimator

- Model/Correction combined with Expert Knowledge
- Observed Total Count (used only when no better methods were available)

According to Conns et al. (2017), model-based corrections and expert knowledge approaches are more credible than raw total counts. Nonetheless, limitations remain as inconsistent survey coverage across years resulted in missing data points for some subpopulations. To aid visualization and analysis, caribou population counts were transformed using natural logarithms.

Figure 4 depicts notable population changes over time across the five herds.

- Prior to 2008, most herds, except Rainbow, showed relatively stable or increasing trends.
- Post-2010, sharp declines were evident in nearly all herds, with the Itcha-Ilgachuz herd experiencing the steepest decline—losing nearly 90% of its population within a decade.
- While signs of short-term recovery appeared before 2010, the year 2010 stands out as a critical turning point, warranting further investigation.

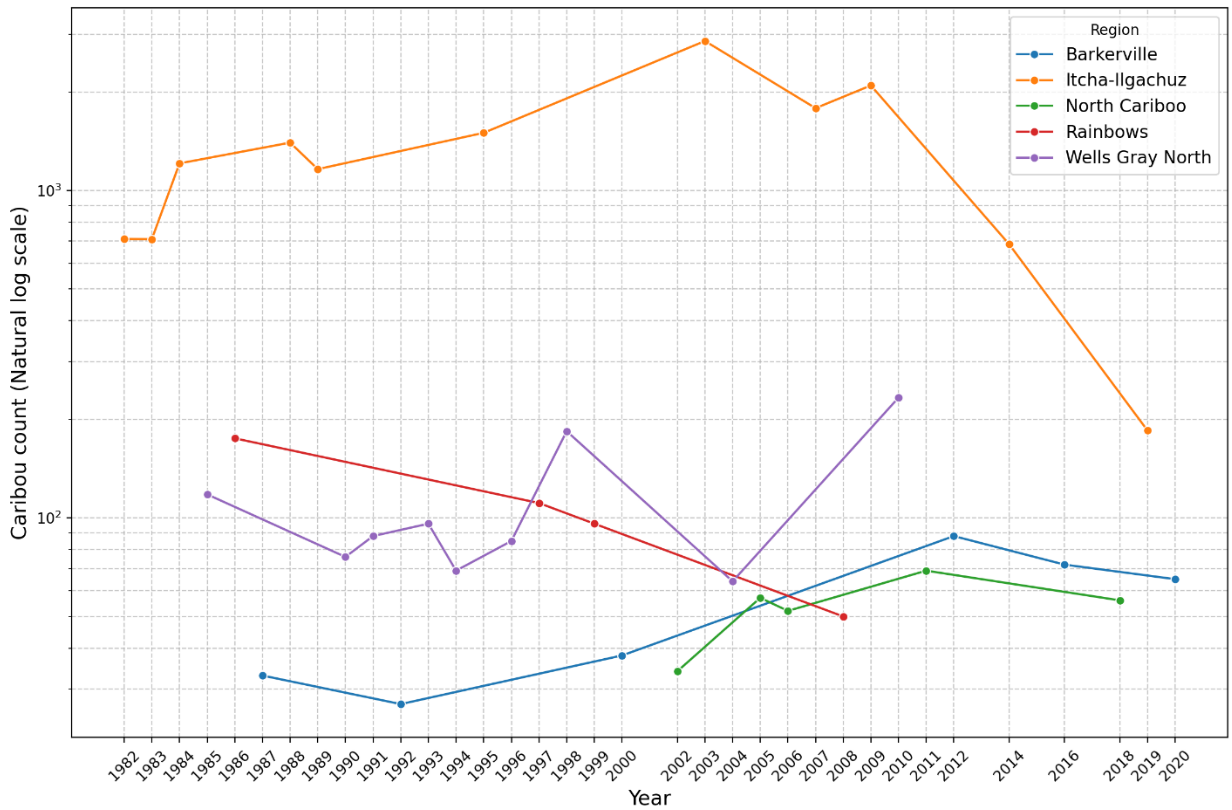

Figure 4: *Caribou in the Cariboo region of BC.* *Image Description*

Given the dramatic decline of the Itcha-Ilgachuz herd, this subpopulation serves as the primary case study for applying the extinction model outlined previously. Simulations will explore whether observed population trends align with theoretical predictions under different management regimes, including regulated and unregulated harvesting.

Further insights are drawn from a controlled field experiment conducted by Waterhouse and Armleder (2005) in the Itcha-Ilgachuz Provincial Park. Five blocks, each spanning 60 to 80 hectares, were designated as treatment and control groups.

- **Treatment blocks** underwent partial harvesting in 1996.
- **Control blocks** remained unharvested.

Baseline conditions were established in 1995 when the park was created. Subsequent surveys in 1998, 2000, and 2004 assessed lichen abundance, the primary winter food source for caribou. The results were stark:

- Partial harvesting reduced lichen cover in treatment areas by 45–56% relative to control areas.
- After eight years, only a modest recovery (~10%) in lichen abundance was observed.

These findings highlight the long-term ecological impacts of forest harvesting, even under selective logging practices. They highlight the critical importance of preserving old-growth forests to maintain essential habitat conditions for caribou survival, particularly in vulnerable herds like the Itcha-Ilgachuz.

Building upon the historical analysis of the Itcha-Ilgachuz herd, this section applies the extinction model introduced earlier to simulate potential future population trajectories and recommend conservation actions.

Historically, the Itcha-Ilgachuz caribou population exhibited robust growth, rising from approximately 711 individuals in the 1980s to a peak of 2,861 in 2004. However, from 2006 onward, the herd began a continuous and dramatic decline, falling to just 185 individuals by 2019. Although there was a minor recovery in 2009, the population ultimately plummeted by over 90% within a decade.

One major factor contributing to this decline was the mountain pine beetle outbreak. According to the Government of British Columbia (2009), red-stage infestations—where trees are fatally attacked—affected 358,000 hectares in 2008 and 199,730 hectares in 2009, with the Itcha-Ilgachuz region suffering particularly severe losses. While direct causal research is limited, the importance of forest health to caribou survival is well-established; caribou depend heavily on lichen that grows on mature trees (Fortin et al., 2017). Extensive tree mortality likely disrupted critical food sources and exacerbated population pressures.

Applying the extinction model (Equation 1) from Taylor and Weder (2024), Figure 5 presents three simulated scenarios based on varying levels of old-growth forest protection:

- **High Regulation (green line):** Development deferrals and strict no-logging policies allow for rapid recovery. The herd surpasses a recovery target of 400 individuals within 10 years and approaches historical population levels within 35 years.
- **Moderate Regulation (yellow line):** Partial harvesting and limited logging delay recovery significantly. It would take more than 35 years to surpass the recovery threshold, and the herd would remain vulnerable for decades.
- **No Regulation (red line):** Continued, unrestricted old-growth logging results in inevitable extinction by 2035.

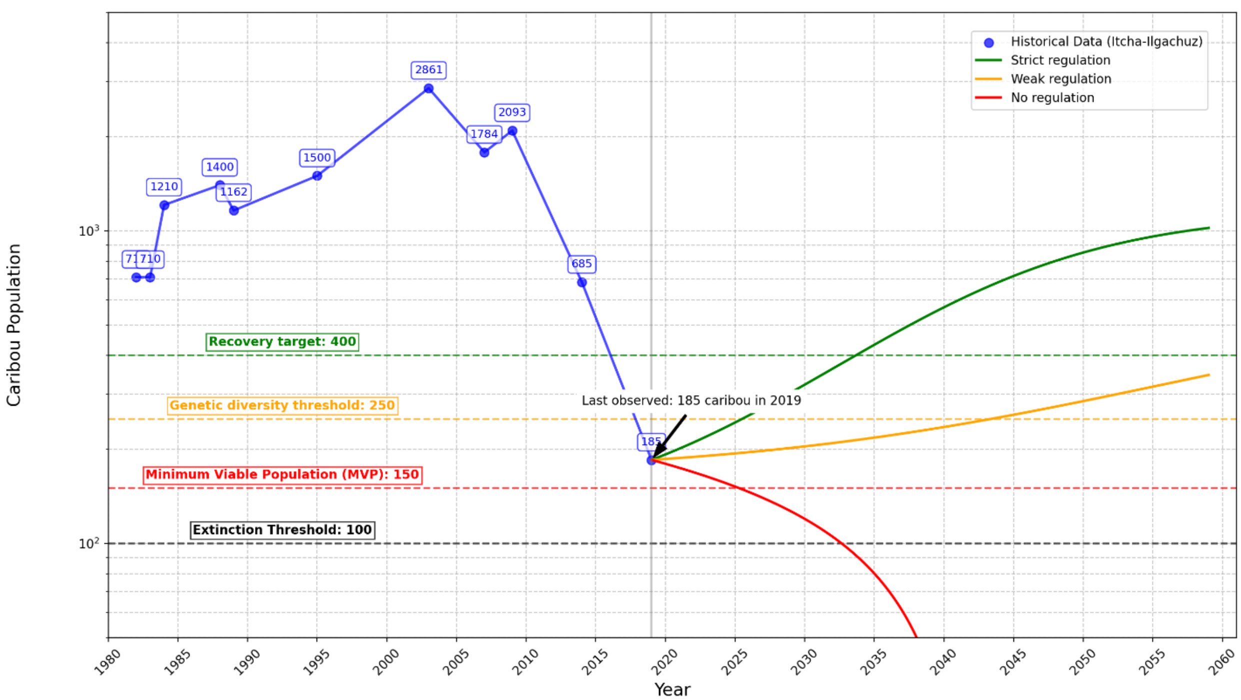

Figure 5: Itcha-Ilgachuz population at risk. *Image Description*

These projections emphasize the acute sensitivity of caribou populations to human activities such as logging and hunting, as well as to indirect ecological effects like predator dynamics. The simulations reinforce the urgent need for proactive and stringent conservation measures.

Moreover, the three scenarios are benchmarked against key biological thresholds: passing the recovery target level (Environment Canada, 2014), maintaining genetic diversity (Frankham et al., 2014), ensuring a minimum viable population size (Shaffer, 1981; Traill et al., 2007), and avoiding extinction (Lande, 1988). Only the high-regulation scenario meets all of these criteria.

The only viable policy path for recovering the Itcha-Ilgachuz herd is to impose strict protection of old-growth forests, thereby minimizing human interference. The next section will explore available regulatory frameworks and conservation policy options to implement this strategy.

Old-Growth Forest Conservation Policies

Development Deferral Strategies

Recognizing the critical relationship between old-growth forests and caribou habitat, forest development deferral has emerged as a mainstream conservation strategy (Parks Canada, 2023; Gorley & Merkel, 2020; Government of British Columbia, 2025). Development deferral involves postponing commercial logging activities in designated areas, subject to future reassessment (Government of British Columbia, 2025).

The Government of British Columbia (2025) identifies three primary types of development deferrals:

- **Voluntary deferrals:** Negotiated agreements between Indigenous nations and the logging industry to conserve selected areas.
- **Regulation-based deferrals**: Enforced through provisions in Part 13 of the *Forest Act*.
- **Directed deferrals:** Conservation orders issued directly by the provincial government to BC Timber Sales.

Applying the extinction model (Equation 1), development deferrals effectively increase the carrying capacity $K(L)$for caribou populations by eliminating logging pressures. For example, in Upper Seymour Provincial Park, 2,640 hectares (Cox, 2022) of a total 10,672 hectares (BC Parks, n.d.) are protected under regulation-based deferrals, while an additional 3,070 hectares are safeguarded through voluntary agreements.

However, as Cox (2022) highlights, these deferrals are closely tied to caribou population status. If the herds were to disappear, protected areas could revert to commercial logging eligibility, demonstrating the mutually reinforcing relationship between caribou conservation and old-growth forest protection.

Parks Canada (2023) further underscores the ecological consequences of logging, noting that post-harvest landscapes create open spaces that increase predator access to prey such as caribou (James & Stuart-Smith, 2000). In the absence of human disturbance (i.e., $H(C) = 0$), natural predator-prey dynamics stabilize. To restore disturbed habitats, reforestation efforts and forestry road deactivation are critical (Central Chilcotin Rehabilitation Ltd., 2025). Reversing the effects of industrial seismic lines and replanting access roads can restrict predator movement and help reestablish natural forest density.

Together, proactive development deferral and habitat restoration provide the foundation for effective caribou conservation through integrated forest landscape planning.

Indigenous-Led Conservation Initiatives

Indigenous-led conservation projects have played a transformative role in safeguarding old-growth forests (Government of British Columbia, 2024). A landmark example is the creation and expansion of Twin Sisters (Klinse-Za) Provincial Park, led collaboratively by the West Moberly and Saulteau First Nations in partnership with the Government of Canada.

The park's size expanded by nearly 1,000%, from 2,700 hectares in 2020 to approximately 200,000 hectares by 2024 (Cruickshank & Wood, 2024). This dramatic growth aims to conserve critical ecosystems for at-risk species, including caribou, grizzly bears, and bull trout.

Supporting this initiative, the Government of Canada and British Columbia committed $46 million in financial compensation to forestry stakeholders affected by logging restrictions. To further offset economic impacts, the South Peace Mackenzie Economic Diversification and Stabilization Trust was established, providing an initial $1 million to support local economic diversification (Government of British Columbia, 2022).

Additionally, the Province of British Columbia invested $300 million to launch a new Indigenous-led conservation program (Verde, 2023). This initiative supports the broader goal of protecting 30% of British Columbia’s old-growth forests by 2030.

The funding enhances Indigenous stewardship capacities, empowering First Nations to lead conservation policy development, implement protection measures, and pursue economic alternatives to old-growth logging.

Organizations like the Ancient Forest Alliance (n.d.) have endorsed these measures, emphasizing that financial support not only compensates for foregone logging revenues but also builds Indigenous capacity for conservation planning and governance. Moreover, the Alliance advocates for expanding second-growth commercial forestry to meet wood product demand while minimizing further impacts on remaining old-growth ecosystems.

Collectively, these policy measures illustrate a paradigm shift toward Indigenous leadership, sustainable economic development, and the long-term protection of critical wildlife habitats, including those needed by caribou populations.

Discussion and Concluding Remarks

Effectiveness of Existing Policies

Despite considerable efforts to recover caribou populations, significant challenges remain. Biologist Clayton Lamb, in an interview with Rochefort (2024), noted that predator management strategies have led to only a 60% recovery of South Mountain caribou herds over a decade. Lamb cautions that predator control is unsustainable in the long term, as it disrupts broader ecosystem balances. He advocates for habitat regeneration, although he acknowledges it is a slow and uncertain process (Rochefort, 2024).

Additional critiques highlight inconsistencies in British Columbia’s conservation policies. Lindsay (2024) reports that despite substantial financial commitments to caribou recovery, commercial logging persists within critical caribou habitats. For instance, BC Timber Sales and Pacific Woodtech proposed clear-cutting 620 hectares of old-growth forests within the Seymour River watershed—an area vital for the Columbia North caribou—overlapping old-growth deferral zones initially set aside for conservation.

Similar shortcomings are observed elsewhere. In Ontario, the government has failed to meet agreed-upon standards for forestry management in critical habitats, falling short of species-at-risk commitments (CPAWS Northern Alberta, 2024).

Gorley and Merkel's (2020) review of old-growth conservation in British Columbia further identifies key gaps:

- Inconsistent monitoring of old-growth areas
- Lack of periodic review despite recommendations
- Failure to track conservation outcomes across the broader landscape

Moreover, some areas designated for conservation were poorly chosen, sometimes lacking significant old-growth stands or being prone to wildfires. Resource constraints have limited the government's capacity to address these systemic weaknesses (Gorley & Merkel, 2020).

Overall, the lack of comprehensive monitoring and adaptive management undermines the effectiveness of existing caribou conservation policies, signaling an urgent need for stronger, better-enforced measures.

Insights from the Itcha-Ilgachuz Case Study

The Itcha-Ilgachuz herd provides a microcosm of broader trends. Following a peak population in 2004, the herd suffered a dramatic decline, likely due to logging pressures and the mountain pine beetle outbreak. The critical dependence of caribou on old-growth forest ecosystems, particularly lichen-rich habitats, has been well-documented (Waterhouse & Armleder, 2005). Applying the extinction model developed by Taylor and Weder (2024) reveals clear outcomes under different management scenarios:

- **Strict protection** of old-growth forests could enable the herd to surpass recovery targets within a decade.
- **Minimal or no protection** would likely lead to extinction by 2035.

The model highlights the vital importance of immediate, effective interventions. Moreover, logging not only reduces habitat area but also creates open landscapes that increase predator access, further stressing vulnerable caribou populations. Strategies such as forestry road deactivation and habitat restoration are crucial to mitigating these effects.

Policy Recommendations

To safeguard caribou populations in British Columbia, several strategies emerge from the analysis:

- ***Expand Development Deferral Programs***

  Strengthen the enforcement of voluntary, regulation-based, and directed deferrals. Ensure deferrals are resilient to fluctuations in caribou population status. Without effective intervention, the decline of caribou populations may result in the removal of conservation protection and ultimately lead to the opening of commercial logging. It is recommended that further development deferral programs be expanded to advance caribou habitat conservation and to strengthen enforcement laws under the Forest Act, thereby preventing unauthorized logging activities.

- ***Support Indigenous-Led Conservation***

  Build on successful models such as Twin Sisters Park. Increased funding for Indigenous stewardship programs can foster regionally focused, culturally informed conservation strategies while supporting economic diversification in affected communities. Expanding Indigenous-led conservation initiatives and consulting with Indigenous communities will further Truth and Reconciliation efforts while helping restore people's relationship and connection with the land.

- ***Enhance Monitoring and Adaptive Management***

  Implement periodic, landscape-scale reviews of old-growth conservation effectiveness. Address resource gaps that have historically limited monitoring and enforcement capacities. According to Gorley and Merkel (2020), the lack of formal review and monitoring of old-growth forest areas makes it difficult to assess policy effectiveness. In addition, the implementation of old-growth forest conservation has been criticized for poor site selection, with some protected areas containing few old trees or being at higher risk of wildfire.

- ***Integrate Habitat Restoration with Policy Enforcement***

  Promote forestry road deactivation, seismic line restoration, and reforestation in critical caribou habitats. Logging also impacts predator-prey dynamics, as clear-cutting creates open landscapes that increase predator access to caribou and decrease the caribou's carrying capacity. Implementing forestry road deactivation, habitat restoration, and old-growth forest preservation is essential to mitigate these impacts. Collaboration with local communities can support monitoring efforts and help design regionally focused caribou recovery strategies.

- ***Balance Ecological and Economic Goals***

  Extend financial support to communities transitioning from logging economies and invest in second-growth forestry as a sustainable alternative. By balancing ecological priorities with economic considerations, policymakers can improve caribou survival while promoting rural economic growth and community well-being.

Concluding Reflections

Caribou conservation efforts in British Columbia have combined maternal penning, predator control, and habitat interventions. While some short-term successes have been achieved, long-term sustainability demands a renewed focus on habitat conservation. The Itcha-Ilgachuz case study vividly demonstrates the stark consequences of inaction and the potential for recovery under strong regulation. A holistic strategy must integrate Indigenous leadership, expand habitat protections, enforce logging regulations more rigorously, and balance ecological priorities with economic considerations. By embracing these approaches, policymakers can foster a future where caribou populations survive and thrive, promoting both ecological resilience and community well-being across British Columbia. Immediate, decisive and effective action is essential to reverse the threat of caribou extinction.

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Image Descriptions

Figure 1 Image Description: A graph illustrates caribou population growth dynamics using two functions: G(C) and H(C). The x-axis represents caribou population size (C), and the y-axis represents population growth rate. The (G(C)) curve rises, peaks, and then declines, showing natural growth patterns with density dependence. The (H(C)) line is linear and increasing, representing external pressures (e.g., harvesting or mortality). The two curves intersect at two points: a lower equilibrium point (C_L) and a higher equilibrium point (C_H). At very small population sizes (below M), growth is negative and populations trend toward extinction. At populations above

C_L but below C_H, caribou can persist and grow until they stabilize near C_H. The carrying capacity is marked as K. The arrows along the axis show direction of population change depending on starting population size.

[Back to Figure 1]

Figure 2 Image Description: This figure compares four scenarios of caribou population dynamics.

- **Top Left panel (Original System):** The G(C) curve shows natural caribou growth with density dependence, peaking and then declining. The H(C) line represents external pressures. The two curves intersect at two equilibrium points: a lower unstable threshold (C_L) and a higher stable equilibrium (C_H). Populations starting above C_L move toward persistence at CH, while populations below C_L decline toward extinction. C_L = 500 and C_H = 2,500
- **Top Right panel (K = 2,500):** The G(C) curve shifts left to a carrying capacity K=2,500 from 3,000 herds due to increased logging activity. In this case C_L = 521 and C_H = 2,079.
- **Bottom Right panel (K = 2,000):** The G(C) carrying capacity has dropped to 2000 herds to due increased logging. There are still two positive intersections, now closer together. C_L is farther right, and C_H is much lower than in the previous panels, indicating fragility: only populations starting well above $\mathbf{C_L}$ persist. In this case C_L = 564 and C_H has dropped to 1,536 herds.
- **Bottom Right panel (K = 1,527):** The two crossings have merged into one tipping point. There's no safe level anymore, only a single, knife-edge point where gains and losses exactly balance. Any herd that isn't exactly at that point will drift downward, and even small shocks push the population toward extinction. To recover, you'd need to raise K (restore/protect habitat) and/or lower removals, so the system moves back to the "two-crossings" case.

  [Back to Figure 2]

Figure 3 Image Description: A map of part of British Columbia showing designated caribou ranges and regions.

- Rainbows and Itcha-Ilgachuz herds are highlighted within the Charlotte Alplands and Cariboo region (labeled as "5 - Cariboo").

- Additional caribou ranges are also identified, including Barkerville, Wells Gray North, Wells Gray South, Columbia North, Columbia South, Groundhog, Frisby-Boulder, and Central Rockies.

The map shows how these ranges are geographically grouped, with western herds (Rainbows and Itcha-Ilgachuz) highlighted separately from central and eastern ranges such as Wells Gray and Columbia. Boundary lines indicate regional divisions, while highlighted overlays identify specific herd ranges.

[Back to Figure 3]

Figure 4 Image Description: A line graph tracking caribou population trends across five regions of British Columbia between the early 1980s and 2019, shown on a natural log scale.

- The Itcha-Ilgachuz herd had the largest population, peaking in the early 2000s at over 2,500 animals before declining steeply to below 200 by 2019.
- The Barkerville and North Cariboo herds remained small, fluctuating between about 30 and 100 animals.
- The Rainbows herd steadily declined from about 200 in the mid-1980s to under 50 by 2008.
- Wells Gray North showed variable growth, rising from about 100 in the 1980s to around 200 by 2011.

Overall, most herds declined, with the sharpest losses seen in the Itcha-Ilgachuz and Rainbows populations.

[Back to Figure 4]

Figure 5 Image Description: A line graph shows the population trends of the Itcha-Ilgachuz caribou herd from the early 1980s to 2019, with projections under different regulation scenarios extending to 2060.

- Historical data indicate a peak of nearly 2,900 caribou around 2003, followed by a sharp decline to 185 caribou by 2019.
- Four thresholds are marked:
  - recovery target (400),
  - genetic diversity threshold (250),
  - minimum viable population (150), and

  - extinction threshold (100).
- Projections from 2019 show three possible futures:
  - strict regulation, where the population recovers above the 400 target;
  - weak regulation, where numbers rise slowly but remain below 400;
  - no regulation, where the herd declines below 100 and reaches extinction before 2040.

[Back to Figure 5]

Author

Trang Phan is an Economics major at Thompson Rivers University with a strong academic focus on applied econometrics, environmental economics, and natural resource management. His research explores how economic tools and data-driven analysis can be leveraged to address real-world challenges, particularly those affecting environmental sustainability and rural community development. Currently, Trang serves as a Socioeconomist for the Adams Lake Indian Band, where he conducts economic research on cumulative environmental effects and contributes to policy analysis in forestry development.

Trang has also demonstrated leadership through various roles, including Conference Coordinator for the TRU Economics Students' Association and Financial Manager for the TRUSU Dance Club. Looking ahead, Trang plans to pursue graduate studies in environmental economics and indigenous studies, aiming to deepen his quantitative expertise and advance evidence-based research and policy evaluation.

Appendices

Appendix I

Python Program for Figure 1

```
import numpy as np
import matplotlib.pyplot as plt
from scipy.optimize import fsolve
```

```
# Parameters
M_val = 100.0
K_val = 3000.0
r_val = 0.3
h_slope = 1.0

# Domain
C = np.linspace(0, K_val, 4000)

# Functions
def G(C):
    return r_val * C * (1 - C / K_val) * (C / M_val - 1)

def H(C):
    return h_slope * C

# Intersection function

def intersection(x):
    return G(x) - H(x)

# Roots for reference
C_L = float(fsolve(intersection, 500.0))
C_H = float(fsolve(intersection, 2600.0))

# Curves
G_vals = G(C)
H_vals = H(C)
maxG = float(np.max(G_vals))

# Figure
plt.figure(figsize=(12, 7))
plt.grid(True, color='black', linestyle='-', linewidth=0.5, alpha=0.2)
plt.plot(C, G_vals, color='green', linewidth=3)
```

```
plt.plot(C, H_vals, color='red', linewidth=3)

# Axes lines
plt.axhline(0, color='k', linewidth=1.5)
plt.axvline(0, color='k', linewidth=1.5)

# Set y-limits to include requested y coordinate if needed
lower_extra = -round(maxG * 0.1, 1)
upper_limit = max(maxG * 1.05, 2281 * 1.05)
plt.ylim(lower_extra, upper_limit)

# Labels
plt.xlabel('Caribou Population (C)')
plt.ylabel('Population Growth Rate')

# Place G(C) at exact coordinates
x_gc = 1000
y_gc = 2281
plt.text(x_gc, y_gc, 'G(C)', color='green', fontsize=14, fontweight='bold')

# H(C) label
x_h = K_val * 0.55
y_h = H(x_h) + maxG * 0.05
plt.text(x_h, y_h, 'H(C)', color='red', fontsize=14, fontweight='bold')

# X-axis labels positioned in the gap
label_y = lower_extra * 0.4
plt.scatter([M_val, K_val, 0], [0, 0, 0], color='black', s=50)
plt.text(M_val, label_y, 'M', ha='center', va='top', fontsize=14, fontweight='bold')
plt.text(K_val, label_y, 'K', ha='center', va='top', fontsize=14, fontweight='bold')
plt.text(C_L, label_y, 'C$_{L}$', ha='center', va='top', fontsize=14, fontweight='bold')
plt.text(C_H, label_y, 'C$_{H}$', ha='center', va='top', fontsize=14, fontweight='bold')

# Dotted lines and points
plt.scatter([C_L], [G(C_L)], color='black', s=50)
```

```
plt.scatter([C_H], [G(C_H)], color='black', s=50)
plt.plot([C_L, C_L], [G(C_L), 0], color='black', linestyle='dotted', linewidth=1.5)
plt.plot([C_H, C_H], [G(C_H), 0], color='black', linestyle='dotted', linewidth=1.5)

# Direction arrows using sign of G-H
ax = plt.gca()
narrow_props = dict(arrowstyle='->', color='black', lw=2)
regions = [0, C_L, C_H, K_val]
for a, b in zip(regions[:-1], regions[1:]):
    x_test = a + 0.3*(b-a)
    val = intersection(x_test)
    num_arrows = 3
    seg = np.linspace(a + 0.1*(b-a), b - 0.1*(b-a), num_arrows)
    arrow_len = (b - a) / 15.0
    for sx in seg:
        if val > 0:
            ax.annotate('', xy=(sx + arrow_len, 0), xytext=(sx, 0), arrowprops=arrow_props)
        else:
            ax.annotate('', xy=(sx - arrow_len, 0), xytext=(sx, 0), arrowprops=arrow_props)

# Clean bottom-most tick label if present
yt = ax.get_yticks()
yt_new = [t for t in yt if not (t == lower_extra)]
ax.set_yticks(yt_new)

# Ticks
ax.xaxis.set_major_locator(plt.MultipleLocator(500))
ax.yaxis.set_major_locator(plt.MultipleLocator(maxG/10.0))

plt.tight_layout()
plt.show()
```

Appendix II

Python Program for Figure 2

```
import numpy as np
import matplotlib.pyplot as plt

# Parameters
r = 0.3       # intrinsic growth rate
M = 100       # minimum threshold
h = 1.0       # harvest slope
phi = 1.0     # linear harvest function

# Population range
C_dict = {
    3000: np.linspace(0, 3100, 500),
    2500: np.linspace(0, 2600, 500),
    2000: np.linspace(0, 2100, 500),
    1537: np.linspace(0, 1700, 500)
}

# Growth function with minimum threshold effect
def G(C, r, K, M):
    return np.maximum(0, r * C * (1 - C / K) * (C / M - 1))  # prevent values below 0

# Harvest function
def H(C, h, phi):
    return h * C**phi

# Carrying capacities
K_vals = [3000, 2500, 2000, 1537]

# Plotting
```

```
fig, axes = plt.subplots(2, 2, figsize=(12, 8))
axes = axes.flatten()

for i, K in enumerate(K_vals):
    C = C_dict[K]
    G_vals = G(C, r, K, M)
    H_vals = H(C, h, phi)

    axes[i].plot(C, G_vals / 1000, label='G(C) — Growth', color='green')
    axes[i].plot(C, H_vals / 1000, label='H(C) — Harvest', color='red')
    axes[i].axhline(0, color='black', linewidth=0.5)
    axes[i].set_title(f'Carrying Capacity K = {K}')
    axes[i].set_xlabel('Caribou Population (C)')
    axes[i].set_ylabel('Rate of Change (×1000 caribou/year)')
    axes[i].legend()
    axes[i].grid(True)

plt.tight_layout()
plt.show()
```

Appendix III

Equilibrium Values Without Logging

MODEL PARAMETERS:

M = 100: Minimum viable population

K(L) = K = 3000: Carrying capacity without logging

g = 0.3: Intrinsic growth rate

c = 1.0: Harvest rate

The time path of the caribou over time is given by [1] in the manuscript:

$$\frac{dC(t)}{dt} = gC(t)\left(1 - \frac{C(t)}{K(L)}\right)\left(\frac{C(t) - M}{M}\right) - H\big(C(t)\big)$$

Equilibrium requires $\frac{dC(t)}{dt} = 0$ and given the above parameters we have

$$0.3C^*\left(1 - \frac{C^*}{3{,}000}\right)\left(\frac{C^* - 100}{100}\right) - C^* = \ 0$$

Where C^* is the stationary equilibrium. Factoring out C^*yields:

$$C^*\left[0.3\left(1 - \frac{C^*}{3{,}000}\right)\left(\frac{C^* - 100}{100}\right) - 1\right] = \ 0$$

Hence 1 equilibrium is extinction $C^* = 0$ and occurs if $C(t) < 100$.

The other two equilibria are found by solving the following quadratic equation

$$\left[0.3\left(1 - \frac{C^*}{3{,}000}\right)\left(\frac{C^* - 100}{100}\right) - 1\right] = \ 0$$

After simple manipulations we get the following quadratic equation:

$$C^{*2} - 3100C^* + 1{,}300{,}000 = 0$$

Solving yields $C_L^* = 500$ and $C_H^* = 2{,}600$

In general, the quadratic equation is:

$$C^{*2} - (K + M)C^* + \left(1 + \frac{c}{r}\right)KM = 0$$

Appendix IV

Equilibrium Values With Logging

Table A1: *With Logging Equilibrium Values*

Carrying Capacity (K)	Lower Equilibrium (CL)	Upper Equilibrium (CH)
3000	500	2600
2500	521	2079
2000	564	1536
1800	600	1300
1700	629	1171
1600	679	1021
1550	730	920
1527	804	823
1526.785	814	814