Common-pool resource management and the Prisoner's Dilemma: how the potlatch changes the game

Nicola Laaser, Department of Natural Resource Sciences, McGill University, Montreal

July 2020

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Master of Science (M. Sc.) Renewable Resources

Abstract / Résume

Common-pool resources often become depleted because they are rival goods and exclusion of users is difficult. Collective action systems are historically effective solutions to this problem that use agent heterogeneity and complex social structures to motivate sustainable extraction and generate abundance in the community. However, most economic analyses of the depletion problem and its solutions are based on individualistic choice models which assume that agents are homogenous, self-interested utility maximisers who make decisions independently of other agents. Such models cannot process social features or unique agent characteristics and thus treat collectives as single decision-making units, preventing the mechanisms within them from being explored and understood. Methodologies such as agent-based modelling can overcome these limitations. Drawing inspiration from the Indigenous potlatch tradition, an agent-based model was built to simulate a heterogenous community interacting with a common-pool resource and engaging in periodic post-extraction resource reciprocity. An analysis of the time-averaged per capita payoffs experienced by different types of agents allowed us to identify certain mechanisms and examine how they shift resource-based incentives at the individual level. This shows that agent-based modelling can improve our understanding of how collective solutions guide individual-level decision-making in order to avoid depletion and generate abundance.

Les ressources communes sont souvent épuisées parce qu'elles sont des biens compétitives et l'exclusion des usagers est difficile. Les systèmes d'action collective sont des solutions historiquement efficaces à ce problème qui utilisent l'hétérogénéité des agents et les structures sociales complexes pour motiver l'extraction durable et générer l'abondance dans la communauté. Cependant, la plupart des analyses économiques du problème déficitaire et de ses solutions sont basées sur des modèles de choix individualistes qui supposent que les agents sont des optimiseurs homogènes et d'intérêt personnel qui prennent des décisions indépendamment des autres agents. De tels modèles ne peuvent pas traiter des caractéristiques sociales ou d'agent uniques et traitent ainsi les collectifs comme des unités de décision uniques, empêchant ainsi l'exploration et la compréhension des mécanismes en leur sein. Des méthodologies telles que la modélisation basée sur les agents peuvent surmonter ces limitations. S'inspirant de la tradition autochtone du potlatch, un modèle basé sur les agents a été élaboré pour simuler une communauté hétérogène interagissant avec une ressource commune et s'engageant dans une réciprocité périodique des ressources après l'extraction. Une analyse des gains moyens par habitant dans le temps subis par différents types d'agents nous a permis d'identifier certains mécanismes et d'examiner comment ils modifient les incitations basées sur les ressources au niveau individuel. Cela montre que la modélisation basée sur les agents peut améliorer notre compréhension de la façon dont les solutions collectives guident la prise de décision au niveau individuel afin d'éviter l'épuisement et de générer l'abondance.

Table of Contents

List of Tables and Figures

Acknowledgements

I would like to sincerely thank Dr. Kosoy for his supervision of this project. His much-valued advice, from the initial conception of this master's research project, to his continued guidance and encouragement throughout the design and execution phases of this research, as well as his assistance in editing this thesis, have played a significant role in the success of the whole endeavour. I would also like to thank the BEHAVE Lab of the University of Milan for their guidance in the early stages of the construction of the agent-based model described in this thesis. Finally, I would like to extend my gratitude to my fellow students and colleagues in the EcoEco lab at McGill for their support throughout the last two years. This research was supported by the Social Sciences and Humanities Research Council of Canada.

1. INTRODUCTION

Common-pool resources (CPRs) – such as fisheries, timber, wildlife / biodiversity, and the atmosphere – are any renewable resource that can support multiple users per source, can be classified as rival goods (i.e. that consumption by one user reduces the amount available for another user), and that have some spatial or temporal characteristic that allows for easy access to the resource (Ostrom, 2012; Sumaila, 2001). These characteristics can often facilitate over-extraction and eventual depletion of CPRs, leading to a phenomenon referred to by Garrett Hardin as the 'Tragedy of the Commons' (Hardin, 1968), and by Elinor Ostrom as a 'common-pool resource problem' (Ostrom, 2012).

Typically, more neoclassical economic solutions are applied to cases of CPR depletion, such as private property allocation, government-imposed quota systems or other centralised regulation systems. However, in many cases, and particularly when the resource in question is mobile or exists over large spatial ranges, these types of management are ineffective and/or inefficient (Bakker, 2007; Brockington, 2002; Brockington and Homewood, 2001; Cooper, 1999; Heynen and Robbins, 2005; Kokorsch and Benediktsson, 2018; Robbins, 2001; Rutten, 1992; Sumaila, 2001; Taylor and Mackenzie, 1992).

Following Ostrom's breakthrough work on the management of CPRs (1990), the root cause of this maladministration arises from the fact that the regulating body responsible for implementing the management system is *external* to the socio-natural community in question, and so suffers from incomplete knowledge and prohibitive enforcement, monitoring and information costs. Effective and feasible management of CPRs therefore remains a critical challenge for centralised governments across the world (Ostrom, 2012).

Yet in our mainstream academic fields, most analyses of CPR depletion, solutions and policies are based on individualised behavioural models such as the Prisoner's Dilemma (Bowles and Gintis, 1993; Gowdy and Polimeni, 2005; Kluver et al., 2014). The Prisoner's Dilemma is a non-cooperative game theory model that tests under which conditions rational decision-makers can end up competing instead of cooperating with one another (Dutta, 1999; Leyton-Brown and Shoham, 2008).

These models are problematic because they lack the ability to address the *heterogeneity* of the individual behaviours that actually make up the collective choice. Hence the model treats a usually diverse group of individuals as a single decision-making unit, a homogenous 'black box' of singular agency. Additionally, these models limit the motivations behind decision-making to the realm of 'rationality'. This means that the agents in these models (collective or otherwise) are assumed to be driven exclusively by self-interest and a drive for utility maximisation, concepts which are largely understood through the lens of Darwin's 'survival of the fittest'(Bowles and Gintis, 1993; Dutta, 1999; Gowdy and Polimeni, 2005; Kluver et al., 2014; Leyton-Brown and Shoham, 2008; Maynard Smith, 1982). Any behaviours *not* fitting this narrow definition are simply labelled as 'irrational', giving little to no consideration to behaviours that appear to be non-maximising for the individual – such as cooperation. (Bowles and Gintis, 1993; Gilbert et al., 2012; Margulis, 1998).

However, cooperative behaviour has been observed historically and experimentally to be the backbone of not only successful collective action systems (Edney and Harper, 1978; Hackett et al., 1994; Isaac and Walker, 1988; McKean, 1992; Orbell et al., 1988; Ostrom, 1990, 2012; Ostrom et al., 1994; Siy, 2011; Wade, 1988) but of human existence in general. Several authors argue that human beings are not isolated individuals, but *symbiotic* creatures that are wholly dependent on cooperative living with one another and other species for survival; that the whole dear notion of one's own Self – marvelous, old free-willed, free-enterprising, autonomous, independent, isolated island of a Self – is a myth" (Gilbert et al., 2012, 334) (Dubos, 1976; Ereshefsky and Pedroso, 2015; Gilbert et al., 2012; Hird, 2010; Margulis, 1998; Ryan, 2002)

Understanding that humans are naturally symbiotic and prone to cooperation allows the narrative of evolution, progress and survival to shift from 'selection by individual fitness' towards group selection. This allows concepts of collective agency, group identity, and social capital to be brought into the analysis of individual behaviour in collective contexts, and provides a new perspective on behavioural paradoxes such as the Prisoner's Dilemma (Gilbert et al., 2012; Margulis, 1998; Okasha, 2006; Sober and Wilson, 1998; Trosper, 2009).

Agent-based modelling is a methodology that allows such a shift. Agent-based models (ABMs) are computer-based models that are specifically used to simulate groups of dynamic, heterogenous agents, and how their interactions with one another and with an equally dynamic and heterogenous environment affect the system as a whole (Bonabeau, 2002). These characteristics allow us to open up that homogenous 'black box' of the collective and examine the diverse structures and incentives within that drive the individual-level decision making that occurs within the constraints of the collective. It further allows us to dispense of the assumption that all actors are rational maximisers driven by self-interest, as agent behaviors in ABMs are determined by programmed rules that can represent any number and type of behavioural drivers that the programmer wishes to include (Banos et al., 2015; Bonabeau, 2002).

Reciprocity is one of the behaviours often observed in collectives that generates the level of cooperation required for them to prosper in their environments (Guzmán et al., 2020; Hulme and Murphree, 2001; Johnsen, 2009; Nelson and Schneider, 2018; Nelson, 2010; Ostrom, 1990; Ostrom et al., 1994; Trosper, 2009). In Indigenous communities on the Northwest Coast of North America, reciprocity is succinctly expressed in a periodic feasting ceremony known as the potlatch. At a potlatch, a clan seeking validation for a change to one of their member's social status must distribute gifts and food to the guests in attendance to prove that the individual is worthy of adopting the desired rank (Beynon et al., 2000; Miller, 1997; Morrison and Wilson, 2004; Ringel, 1979; Trosper, 2009). In redistributing extracted resources this way, the potlatch has been shown to create incentives for the sustainable extraction of CPRs by rewarding collectivism and cooperation instead of self-interested utility maximisation (Miller, 1997; Ringel, 1979; Trosper, 2009).

The research described in this paper therefore takes inspiration from the potlatch to build an agent-based model of a community of heterogenous individuals that interacts with a CPR and uses a reciprocal system to generate cooperative behaviour (defined as the decision to extract at sustainable levels). The goal of this effort is to use the model's output to understand how the structures and mechanisms within the collective system motivate cooperative behaviour at the level of the individual as well as the collective.

To achieve this goal, the following research objectives are addressed:

1) Identify and understand the incentive mechanisms that enforce the potlatch and facilitate resource flows between individuals and collectives.
2) Develop an agent-based model of a collective that extracts from a common-pool resource and engages in the post-extraction resource reciprocity found in the potlatch.
3) Using the model output:
    a. Re-create the game theory interpretation of the potlatch at the level of the clan.
    b. Examine how the potlatch impacts resource-based incentives at the level of the individual under different conditions.

This thesis in divided into six sections. The Introduction in section 1 explains certain epistemological and methodological issues that exist in the context of CPR analysis and collective action solutions and explains why the potlatch was chosen as the inspiration for our ABM design.

Section 2 provides a review of existing literature on common-pool resource management and the game theoretic approach to analysing CPR problems and solutions. This is followed by a review of various socio-cultural structures of the Northwest Coast First Nations as they are related to the potlatch. The section then concludes with an overview of the identified potlatch mechanisms that are included in the model.

Section 3 details how the agents, environment and potlatch processes were designed to operate in the ABM. It also describes the scenarios that were programmed into the model to create different combinations of clan-level and individual-level behaviours. The final part of section 3 outlines the experiments that were set up to generate resource-based incentive data under the different scenarios and other conditions.

The results of these experiments are presented in section 4. First, a subset of the clan-level results is presented as a set of game theory matrices. Thereafter, the bulk of the section focuses on the results produced at the individual level, describing and comparing patterns seen in both CPR stock levels and per capita payoffs under the different behavioural scenarios.

Section 5 provides summaries of the main findings of the model and a review of the assumptions applied in its design, as well as a brief overview of the initial methodological issues discussed in sections 1 and 2 and how this research has addressed them. And finally, section 6 provides the conclusion to this thesis.

2. LITERATURE REVIEW

2.1 Prisoner's Dilemma and solutions

The Prisoner's Dilemma is a game theoretic model used to test under which conditions groups of individuals end up competing instead of cooperating with one another, resulting in a final outcome that is non-optimal for the players involved. Common-pool resource problems are often explored using this theory.

First, this section will describe the single-iteration version of the game and how the Prisoner's Dilemma paradox arises from it. Then, experimental results from an iterated version of the game will be examined, showing how the paradox, under certain circumstances, can be avoided. Finally, this section will present a brief outline of some of the more problematic assumptions of individual behaviour and decision-making that are crucial to achieving the paradoxical outcome of the game.

2.1.1 The Prisoner's Dilemma: justifying competition as the natural human condition

The original version of the Prisoner's Dilemma, formulated by Merrill Flood and Melvin Dresher, and formalised by Albert Tucker in 1951, describes a situation in which two prisoners, locked in separate interrogation rooms, are each presented with two choices: to confess (defect) or to not confess (cooperate). There are two possible payoffs associated with each available decision, as the payoffs are dependent on the *combined* choice of both prisoners (Gale et al., 1951; Trosper, 2009).

The prisoners are not allowed to communicate and come to a collective decision. Furthermore, it is assumed that both prisoners are fully rational, self-interested and want to optimise their own utility – the economic measure of well-being, happiness or pleasure gained (or lost) in an exchange or decision process. Logically, therefore, they will make the decision that is best for themselves, regardless of what the other player chooses to do. Finally, both players must make their decision simultaneously, so neither of them knows what option the other has chosen. There is only one chance to make a decision, or one turn, and no opportunity to punish or reward either player for their decision. In short, the only incentives at work are the payoffs presented to the prisoners in this moment (Gale et al., 1951; Trosper, 2009). The payoff matrix for this game can be seen in Table 1.

		Prisoner 2	
		Cooperate (not confess)	Defect (confess)
Prisoner 1	Cooperate (not confess)	3/3	0/5
	Defect (confess)	5/0	1/1

Table 1 Tucker's Prisoner's Dilemma from (Gale et al., 1951)

If we follow all of the neoclassical (and notably Darwinian) assumptions of rationality and self-interest listed above, both players will choose to defect because it is the most profitable option regardless of whether their opponent cooperates (payoff = 5 instead of 3) or defects (payoff = 1 instead of 0) (Leyton-Brown and Shoham, 2008). Thus mutual defection is the Nash Equilibrium[1] of the Prisoner's Dilemma.

The paradox of the Prisoner's Dilemma is that the Nash equilibrium of this game is also the only *non-Pareto-optimal* outcome[2]. In the single-iteration Prisoner's Dilemma, mutual cooperation Pareto-dominates mutual defection, despite mutual defection being the Nash Equilibrium of the game. However, if the players were choosing as a collective unit, the outcome would be mutual cooperation, which is Pareto optimal. This has been understood as a mismatch between individual and social rationality, in that mutual defection is the outcome arrived at due to both players' individual rationality, whereas mutual cooperation would be the outcome as a result of social rationality (Axelrod, 1980a).

It can be argued, however, that this 'mismatch' is actually a consequence of the fact that individual rationality is defined as being driven by self-interested utility maximisation in most economic choice models. Section 2.1.4 will discuss some of the problems with this definition, particularly those that are relevant to situations involving groups of individuals engaged in decision-making and social agreements.

[1] The Nash Equilibrium is the outcome arrived at when all players adopt the strategy that maximizes their expected individual payoffs, given the strategies and payoffs available to themselves and their opponent (Leyton-Brown and Shoham, 2008).

[2] An outcome is Pareto-optimal if it is not Pareto-dominated by another outcome. Pareto-domination occurs when an alternative outcome exists that is a) at least as good for each player, and b) strictly preferred by at least one player (Leyton-Brown and Shoham, 2008).

2.1.2 Evolution of cooperation in the repeated Prisoner's Dilemma

One of the most well-known solutions to the Prisoner's Dilemma was proposed and experimentally tested by Axelrod in the 1980s. This solution does not remove the paradox by changing the payoffs of the original game; rather, it illustrates what happens when real agents play an iterated game against the same opponent. These repeated interactions amongst a fixed set of players showed that, under certain conditions, mutual cooperation could *evolve* over time as a result of two features: the ability to learn from previous turns, and having future turns and payoffs to consider (Axelrod, 1980a, 1980b).

The first element, learning from the past, erodes agent anonymity over time and provides a new predictive power to players. Over time they can better understand how their opponent tends to play – how often they tend to defect or cooperate, how they tend to react to their opponent's behaviour, and how these change over time (Axelrod, 1980a, 1980b).

The second element, the existence of a future, changes the players' calculations of their expected payoff. The probabilities involved can now take into account what has been learned about the opponent's strategy, and can be used to determine a strategy that will maximise the player's own *long-term* payoffs, instead of immediate payoffs (Axelrod, 1980a, 1980b).

Recall that mutual cooperation only evolves in the iterated game under certain conditions. These conditions are a specific set of three player characteristics, or traits. That is, both players have to be *nice*, *provocable* and *forgiving*. If one of these traits are missing in even one of the two players' strategies, the probability that mutual defection evolves instead of mutual cooperation increases greatly (Axelrod, 1980a, 1980b; Farrell and Ware, 1989).

Axelrod's 1980 experiments recruited a set of real players, requiring them to develop strategies (in the form of algorithms) that they thought would earn them the highest payoff in the long run given the same payoffs as originally presented by Tucker (see Table 1).

The first experiment was fixed at 200 iterations; this generated a number of strategies containing end-game plays in which cooperation would fade away towards the end of the game in an attempt to maximise immediate payoffs. The second experiment prevented this by randomising the number of iterations per game; however, despite this alteration, the main findings regarding successful strategies were very similar in both experiments (Axelrod, 1980a, 1980b).

At the start of the game, players were essentially anonymous as they had no knowledge of their opponent's strategy. The ability to learn had to therefore be built into the player's algorithms. Some, such as the 'tit-for-tat' strategy (TFT), did this with a very simple eye-for-an-eye reaction that mirrored an opponent's previous play. This effectively punished defection, but also rewarded a shift back to cooperation with cooperation. Other strategies contained more complex reactions that adjusted the frequencies of cooperation and defection in response to their opponent's cumulative plays at each step of the game (Axelrod, 1980a, 1980b).

Consideration for the future was also programmed for in different ways. Some strategies were geared towards motivating opponents to mutually cooperate (again, such as TFT), having recognised this as the best compromise in the long run. Others tried to exploit an anticipated tendency to cooperate by setting a relatively high rate of defection, sometimes with the flexibility to adjust for punishment frequencies (Axelrod, 1980a, 1980b).

As mentioned previously, some strategies were more successful than others in motivating and/or maintaining mutual cooperation for the majority of each iterated game. All of these successful strategies displayed the same set of three characteristics which were mentioned above (Axelrod, 1980a, 1980b). Firstly, they were all '*nice'* by not defecting on the first round, '*provocable'* by being quick to punish their opponent's defection, and '*forgiving'* by being willing to cooperate soon after the punishment had been dealt[3] (Axelrod, 1980a, 1980b).

The effectiveness of these three traits can be illustrated using five consecutive turns in a game where one player uses the TFT strategy. According to its niceness, TFT will start with cooperation; assuming the opponent is also nice, it will start the game similarly. Let us say that in the second turn however, the opponent defects. Given TFT's immediate reaction to defection (provocable), the chain of action profiles might resemble the following[4]: (C,C), (C,D), (D,D), (D,C), (C,C). After a few more turns, and possibly even a few more tries at defecting, immediate retaliation and quick forgiveness teaches the opponent that, in the long-term, they can only

---

[3] Note that a variant of the TFT strategy that only punished two successive defections would have been more successful against a wider range of strategies. The risk of an instant eye-for-an-eye approach to punishment is that it can trigger retaliation and prevent mutual cooperation from evolving against certain strategies.

[4] Where an action profile is written here as (action of player 1, action of player 2), and the resultant payoffs are written as [payoff to player 1 , payoff to player 2].

maximise their payoff by cooperating. This can be explained purely in terms of the average expected payoffs from this set of plays compared to the average expected payoff from five turns of mutual cooperation:

(C,C), (C,D), (D,D), (D,C), (C,C)

[3,3], [0,5], [1,1], [5,0], [3,3] → average payoff = [2.4, 2.4]

(C,C), (C,C), (C,C), (C,C), (C,C)

[3,3], [3,3], [3,3], [3,3], [3,3] → average payoff = [3,3]

Mutual cooperation is strictly dominant *in the long run* over the choice to defect and be punished intermittently, and obviously also the choice to mutually defect for five turns (with an average payoff of 1 for both players). Thus mutual cooperation evolves in the long-term (Axelrod, 1980a, 1980b).

If we change the characteristics of the players, however, this result changes. For instance, replace 'nice' players with players that both defect on the first turn, are quick to punish the opponent's defection, but very slow to forgive them. The result, in the long run, is a string of mutual defections. Even if one player is 'nice', but quick to provoke and mistrusting thereafter, the end-result is often the same: long-term mutual defection (Axelrod, 1980a, 1980b).

Strategies that started the game with defection almost always triggered near-immediate long-term defection due to the punishment reactions built into the majority of strategies. Strategies that ignored punishments, i.e. that did not learn from the past, tended to trigger a high frequency of punishment defections, particularly from opponents that cumulatively adjusted how forgiving they were. Exploitative strategies would also trigger ruts of mutual defection for at least a large portion of the game due to punishment responses (Axelrod, 1980a, 1980b).

In short, there were multiple combinations of traits that led to a significant portion of the iterated game deteriorating towards mutual defection in both versions of the experiment (Axelrod, 1980a, 1980b). Long-term cooperation in this context is therefore strongly dependent on a specific combination of the personalities and/or behaviour of the agents involved, instead of being guaranteed regardless of them. This diminishes the robustness of this solution.

What can be gleaned from Axelrod's experiments, however, is that many of the successful players programmed some form of *reciprocity* into their strategies. Even if there are no alterations to the prisoner's dilemma payoffs and players are prevented from communicating, having a future to care about and a past to learn from is sufficient for players with certain characteristics to view reciprocity as "an extremely successful operating rule [even] for an individualistic pragmatist." (Axelrod, 1980a, 18).

On the other hand, if agents *are* allowed to communicate, there is a much larger likelihood of cooperative behaviour occurring in a collective, even if the individuals involved have diverse and sometimes conflicting personalities (Ostrom et al., 1994).

Recall that one of the major assumptions in the Prisoner's Dilemma is that agents cannot communicate with one another and thus cannot make agreements prior to choosing an action in the game. This assumption stems from the view that only an external agent can enforce the types of agreements that could be made in such situations – agreements which Thomas Hobbes referred to as "covenants of mutual trust" (Hobbes, [1651] 1960, 87). These verbal agreements are thought to be easily reneged on unless there exists "the terror of some punishment [that is] greater than the benefit they expect by the breach of their covenant" (Hobbes, [1651] 1960, 94).

The persistence of this view has led to a consensus in non-cooperative game theory that communication and verbal agreements are unlikely to impact individual behaviour, as they cannot be relied upon if agents perceive a high cost in maintaining the agreement in the future (Nash, 1951; Ostrom et al., 1994). Yet there are results from field settings and experiments that show that this is not the case (Bornstein and Rapoport, 1988; Dawes et al., 1977; Edney and Harper, 1978; Hackett et al., 1994; Isaac and Walker, 1988; Orbell et al., 1988).

In the context of CPR problems specifically, Ostrom et al. (1994) show that a group of CPR appropriators can endogenously design and enforce cooperative strategies if they are allowed to communicate – even when communication is costly. They additionally showed that communication is a robust mechanism in the face of agent or group heterogeneity (in terms of appropriation capacity), as well as incomplete / asymmetric information (Ostrom et al., 1994).

However, communication must be supported by certain parallel mechanisms and structures for cooperation to be maintained effectively. Creating an "institution for communication" (Ostrom et al., 1994, 167), for instance, ensures that communication is repeated periodically and allows the collective to deal with enforcement in a structured and agreed-upon way, prolonging the lifespan of agreements (Ostrom et al., 1994). The use of sanctions or punishments are also often found to be effective parallel mechanisms, particularly in situations where only a few non-cooperative individuals could trigger a CPR problem (Ostrom et al., 1994).

So, with the careful building of parallel institutions and enforcement mechanisms, communication becomes a cornerstone of cooperative behaviour and relationships within the collective systems (Ostrom et al., 1994). We will see later how important this is in the case of the First Nations of the Northwest Coast, and how communication and its parallel mechanisms bolster the enforcement of post-extraction resource reciprocity (see sections 2.3 and 2.4).

2.1.3 Modelling choice with *Homo economicus*

In the original Prisoner's Dilemma model there exist a number of assumptions about individual behaviour and the information that players have at their disposal during the game. It is important to understand these assumptions and how they impact the decision-making process, even in this simple two-choice, two-player game, as they are crucial to the existence of its paradoxical outcome (Axelrod, 1980a, 1980b; Bowles and Gintis, 1993).

The concept of the self-interested, rational man was first described by Adam Smith in *The Theory of Moral Sentiments,* first published in 1759 (Smith, 1759). This persona made choices in the market by calculating the marginal rates of substitution between two goods and/or services (Smith and Haakonssen, 2002). The neoclassical remodeling of Smith's character, however, turned it into an optimiser of *all* things, from how much effort to put into productivity, to how honest to be in trade, to whether or not to default on a loan. This new *Homo economicus* was "uncompromisingly thorough in pursuing objectives [and] less benign" (Bowles and Gintis, 1993, 84) than its conceptual ancestor (Kluver et al., 2014).

An even further truncation of Smith's characterisation is the more recent Walrasian model of *Homo economicus*. Whilst the original neoclassical model maintained the realistic assumption that exchanges carried non-zero enforcement and information costs, the Walrasian model assigns a zero cost to them. The intent was to further simplify choice models and the model of competitive equilibrium; however, this also reduced the consistency and descriptive power of such models (Bowles and Gintis, 1993; Coase, 1960; Gowdy and Polimeni, 2005).

What is now represented is no longer an individual agent making strategic choices involving complex and dynamic individual and social influences whilst having incomplete knowledge of the possible outcome of their choice. Instead, we see an artificially reduced, purely selfish optimiser of utility, that as a result of the further assumption of complete information (hence zero information costs), knows exactly the structure of the game they are playing, all of the choices available to themselves and their opponents, and the exact payoffs associated with these choices. Add to that the artificial certainty that their opponent is equally rational and well-informed, and they can, in theory, rationally choose their optimal alternative. It is this version of *Homo economicus* that is most commonly assumed to represent the players in the Prisoner's Dilemma (Axelrod, 1980a; Bowles and Gintis, 1993; Kluver et al., 2014).

Firstly, it is important to understand that information and enforcement (of agreements, social norms, or laws) are, in reality, *not zero-cost*. Whether the costs are borne exogenously or endogenously to the exchange, they will always influence the completeness of information, the efficacy of enforcement and the expected gains and/or losses of choosing to cooperate or defect (Alchian and Demsetz, 1972; Bowles and Gintis, 1993; Coase, 1960; McCloskey, 1998).

To further complicate matters, these costs are influenced by dynamic complexities arising from power and information asymmetries, uncertainty, risk aversion and long-term commitments, trust and social contracts, preferences, values and circumstances. These factors are not only influenced by the socio-cultural environments in which the agents exist, but also change over time due to external pressures and the agents themselves (Bowles and Gintis, 1993; Gowdy and Polimeni, 2005).

A second assumption that is important is that of agent anonymity. Anonymity was assumed in later individualistic models of choice, primarily for the sake of simplifying and homogenising analyses of incentive mechanisms. However, this assumption forces choice models to ignore many of the driving forces that act on individual decision making as a result of the reality that the individual exists *within*, and is strongly influenced by, their sociocultural and natural environments. Social norms and values, such as truth-telling, non-aggression, or simply helping one another, are the basis of many solutions to coordination problems[5] (Bowles and Gintis, 1993; Kluver et al., 2014; Sen, 1977).

---

[5] Coordination problems occur when a group of agents are unable to make the correct set of individual choices in order to achieve a desired social outcome.

However, if individuals are anonymous, they cannot recognise one another, they cannot learn how other individuals tend to act or what their values are, and they cannot form relationships and repeatedly interact. As a result, social norms and values cannot take shape over time, and cannot act to provide solutions to these coordination problems. One can see the importance of this even in Axelrod's iterated games: learning who your opponent is, what they tend towards in the game, and adapting your own strategy to this is the foundation of mutual cooperation evolving. Even in such a simplified form, social norms and values have a clear and real impact on how agents make decisions and play the game (Axelrod, 1980a; Bowles and Gintis, 1993; Gowdy and Polimeni, 2005; Sen, 1977).

Within the building and maintaining of community values, the building of trust between players over time is worth special mention. In cases where enforcement costs are very high otherwise, trust is an important factor in the evolution and maintenance of cooperation, particularly in reciprocity, and has been shown experimentally to have a very significant impact on the outcome of Prisoner's Dilemma-type games (Bowles and Gintis, 1993; Gowdy and Polimeni, 2005; Guzmán et al., 2020).

2.2 Existing Variations on Common-Pool Resource Management

Certain natural resources have a specific set of characteristics that define them as a common good, or a common-pool resource (Ostrom, 2012). Firstly, the resource is categorised as a **rival good**, in that consumption by one user will leave less available for others. Secondly, the resource is **very easily accessible** due to the size, temporal / spatial distribution, or some other property of the resource – and therefore exclusion of potential users is very difficult. As a result, CPRs are prone to depletion without some form of management, creating what is known as a CPR problem (Ostrom, 2012; Sumaila, 2001; Trosper, 2009).

The management of CPRs by most centralised governments has been inefficient and ineffective due to the external nature of the institutions tasked with managing the resource. An evidence-based alternative to external management is the decentralised management system formalised by Elinor Ostrom and her colleagues (Ostrom, 1990, 2012), of which the governance systems of the Northwest Coast First Nations are a key example (Johnsen, 2009; Ostrom, 2012; Ostrom et al., 1994; Trosper, 2009).

The CPR problem and Hardin's Tragedy of the Commons will be briefly explained in the next section, followed by a more detailed examination of current solutions to the problem, including Ostrom's concept of decentralised management. Finally, an existing game theoretic interpretation of the potlatch as a solution to the Prisoner's Dilemma will be explored.

2.2.1 The common-pool resource problem

Based on the characteristics of CPRs, and the individualistic assumptions of human behaviour and exchange explored in the previous section, Hardin detailed his theory known as the 'Tragedy of the Commons'. The essence of this theory is that, due to the finite yet easily accessible nature of the resource, a perception of imminent scarcity evolves in individual users which leads to a mismatch between individual optimisation and social optimisation (Hardin, 1968). The result is that the individual user's optimum yield exceeds the per capita maximum sustainable yield (MSY) of the resource. If all users extract at this individual optimum, the resource would become depleted over time – hence the (1,1) payoff for mutual defection in the original Prisoner's Dilemma (Gale et al., 1951; Sumaila, 2001; Trosper, 2009).

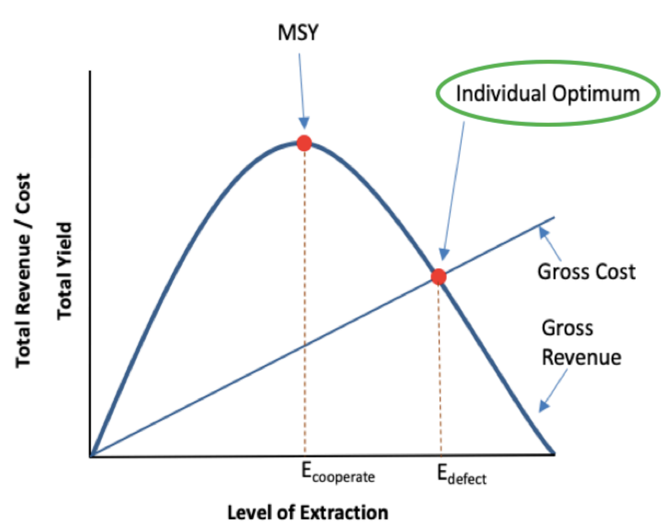

Figure 1 The common-pool resource problem, adapted from Sumaila (2001). ***Shows the relationship between Total Revenue, Cost and Yield as functions of the individual level of extraction.***

Figure 1 shows that without management, individuals will extract at the point at which total cost equals total revenue. This level of extraction typically exceeds the per capita MSY. In terms of the previous discussion on the Prisoner's Dilemma, if the individual user's optimum yield is extracted, the agent has defected. If the agent extracts at or below the MSY per capita, they have cooperated (Sumaila, 2001; Trosper, 2009).

Hardin's argument viewed this phenomenon of depletion through the prevalent economic lens, stating that the impact of one user's optimal extraction – the depletion of available resources for another user – was an *externality* caused by extraction (and high population levels) in the unmanaged commons (Hardin, 1968). Not accounting for this externality artificially lowers the total cost of extraction and therefore raises the individual user's optimal level of extraction, leading to an unsustainable use of the commons .

Hardin briefly discusses a range of solutions in his first article on the Tragedy, all of which involved the "enclosure of the commons" (Hardin, 1968, 1248) to some extent. In the various examples of the commons that he discusses (excluding the atmosphere and air pollution, which is now known to be a problem of open access) he briefly outlines options for enclosure as a form of management. These included allocating the right to use / extract a resource based on wealth, merit or lottery systems, and the division and/or sale of the commons as private property (Hardin, 1968). Hardin does note that all of these options are "objectionable" (1968, 1245), but that they are the only conceivable alternatives outside of restricting the human population's "freedom to breed" (1968, 1248).

The evidence that certain communities were, in fact, able to manage their common goods and pass on the required knowledge to do so over multiple generations *without* needing external regulation was largely ignored. Hardin criticized systems that relied on education in general, stating that "[e]ducation can counteract the natural tendency to do the wrong thing, but the inexorable succession of generations requires that the basis of this knowledge be constantly refreshed. A simple incident … shows how perishable the knowledge is" (Hardin, 1968, 1245).

What Hardin failed to acknowledge in this critique and throughout the article, however, was that his analysis only pertained to common goods *that had no pre-existing communal or otherwise local management system in place* and were therefore actually being treated as open access goods. In such situations, Hardin's Tragedy does indeed occur, and some management system is required (Ciriacy-Wantrup and Bishop, 1975).

For this reason, throughout this thesis the depletion problem in the unmanaged commons will be referred to as the common-pool resource (CPR) problem instead of the tragedy of the commons (Ostrom, 1990, 2012; Trosper, 2009).

2.2.2 Decentralised management

Elinor Ostrom's devotion to solving the CPR problem culminated in the formalisation of a management system that described the return of agency and autonomy to communities that have a longstanding relationship with a particular resource (Ostrom, 1990). This system limits the power of external regulating bodies to the designation of property to communities – property to which the resource, *as a whole*, is constrained and can thus be managed holistically and effectively. These communities are then responsible for developing their own localised sets of rules and monitoring and enforcement mechanisms. This system is successfully practiced in all but name in many parts of the world, proving its viability under multiple circumstances (Andersson et al., 2006; Baker, 2007; Hulme and Murphree, 2001; Nelson, 2010; Ostrom, 2012; Ostrom et al., 1994; Trosper, 2009).

Ostrom's framework was built to acknowledge existing cases of community-based resource management as a viable alternative to the mainstream management regimes for CPRs. These mainstream systems were all forms of external regulation, involving either top-down government control, or the arbitrary division and privatisation of property (Ostrom, 2012).

External regulation systems tend to lack sufficient contextual information to effectively manage a distant resource. By nature of their external origins, they have only a shallow, generalised knowledge of the character of the resource and the incentives perceived by the community and other interested parties. Gathering the necessary knowledge – the same knowledge that communities have gathered over generations of experience – is costly to the point that it can be prohibitive. Additionally, some of this knowledge cannot be gathered by external actors in the first place. Cultural norms, values, perceptions and reactions to problems are all elements that are near-instinctive to the communities in question, and can thus be very difficult to express verbally and translate into regulatory language (Ostrom, 1990, 2012).

Additionally, there is the problem that external regulators are too far removed from the situation and have little personal stake in the decisions made for a resource and its associated community. They are rarely adequately rewarded for creating *successful* management systems, and are instead expected to maintain the interests of the regulating agency, tending to prioritise its welfare and the satisfaction of well-connected interest groups seeking property rights (Ostrom, 1990, 2012).

Furthermore, external regulators are prone to creating systems according to the central government's values and social norms, so incentive mechanisms are likely to be weaker than if they had been aligned with the values and norms of the community being regulated. Dependence on external regulation also reduces the community's sense of responsibility, or duty, that they would otherwise feel in upholding rules created from their own values. Hence there is less incentive to participate in enforcement or monitoring, leaving far more opportunities for non-cooperative behaviour to go unnoticed and unpunished. Additionally, a community that loses autonomy to external agencies for a long time tends to lose its accumulated knowledge of the land and is inhibited from gaining new knowledge. New generations do not learn how to manage their resources in their time and given their circumstances, a problem which only grows over time (Ostrom, 2012; Ringel, 1979; Steltzer, 1984).

The above problems with external regulation are very obvious in systems that utilise centrally imposed control, such as quotas or taxes. Private property systems, however, also suffer from them when the central agency divides and assigns the land. But the primary issue with private property systems is that the division of land is typically arbitrary, following none of the resource's natural stock and flow patterns in space or time. This creates sustainability problems when extraction in one property disproportionately affects stock in another. If the impacts of resource use are not experienced in the same property that they originated from, private property systems are not a good solution to common-pool resource problems (Bakker, 2007; Brockington, 2002; Brockington and Homewood, 2001; Cooper, 1999; Heynen and Robbins, 2005; Kokorsch and Benediktsson, 2018; Ostrom, 2012; Robbins, 2001; Rutten, 1992; Sumaila, 2001; Taylor and Mackenzie, 1992).

Communities that have a long-standing history with the land they exist on have the advantage that they have evolved *with* the land. Over time that spans generations, they have had the opportunity to learn how to best manage and share the resources with other human and non-human communities in a way that is sustainable. Thus in most cases they are acutely aware of the nature of the CPR problem and are the most qualified group of actors to find stable and effective methods of defining and enforcing CPR boundaries and the rules of extraction (Ostrom, 2012).

Of course, it is important to note that decentralised management is not a blanket solution. Ostrom stresses the importance of avoiding the "Panacea problem" (Ostrom, 2012, 15) when approaching CPR problems, and acknowledging exceptions to the framework when they exist.

Certain cultural contexts and/or physical characteristics of a common-pool resource may render such systems non-viable; in such cases, private property or state regulation may indeed be the more feasible options (Ostrom, 2012).

In light of this, Ostrom detailed a set of principles that describe the requirements for decentralised management to be viable and effective. Each principle, based on evidence from existing CPR management systems, is "an essential element or condition that helps to account for the success of these institutions in sustaining the CPRs and gaining the compliance of generation after generation of appropriators to the rules in use" (Ostrom, 1990). These principles were originally published in 1990 in *Governing the Commons: The evolution of institutions for collection action* (Ostrom, 1990), and have since been revised. The following summary is drawn from the version found in Ostrom's later book, *Future of the commons: beyond market failure and government regulation* (2012).

1. *Clearly defined resource boundaries*: community management of a resource requires that those who are not part of the community can be excluded from accessing the resource. Without clear boundaries, the limits to exclusion cannot be defined.
2. *Well-defined rules within the community*: this is necessary in efficiently and effectively preventing individual members from exploiting the CPR.
3. *Rules that are locally adapted to each community*: resources are uniquely dynamic in space and time, as are the communities that manage them; thus, the rules governing a community's interaction with said resources should be appropriately contextualised.
4. *Strong monitoring and enforcement mechanisms*: it is very important when managing CPRs to account for the existing incentive to defect. A community's rule system should therefore reward cooperation and/or punish defection, and do so in ways that are meaningful to members of the community. Even in communities that are stable and have social cohesion, it is highly unlikely that *all* members of the community are adequately motivated to cooperate by reputation and status alone (Ostrom, 2012, 27). Some members may need to be materially rewarded or punished in order to cooperate, and a successful management system must account for this heterogeneity.
5. *Clear, well-established procedures for resolving disputes*: "well-developed and transparent court systems" (Ostrom, 2012, 28) enhance a community's motivation to cooperate, as they ensure that the majority of members are aware of defectors and the

consequences of their behaviour. Note that a "court" can be replaced by any public arena in which defectors are held accountable for their actions by the managing body of the community.

6. *Inclusion of immediate stakeholders in development and enforcement of rules*: the collective building of a rule system by the same people who will be affected by it ensures that a more transparent, rigorous and holistic enforcement mechanism is created. It also makes the process of adapting the system over time more efficient.
7. *Local rule systems and rights are respected by external and/or overseeing government bodies*: decentralised management is not a stand-alone regime and can technically be overridden by higher levels of governance. It is thus essential that such governance supports the community, their property rights and their autonomy, and that they do not overrule the community's management to give external interested parties access to the land.

Private property, according to Ostrom, can be an acceptable alternative when it is possible to clearly define boundaries in space, or when the community in contact with it is mobile and/or culturally heterogeneous. Here, a private property system will prevent the likely tensions and delays that could arise when a highly heterogeneous group tries to create rule systems and enforcement mechanisms. In such cases, objective mediation by external enforcement agencies and dispute resolution systems is more effective – provided that the private property rights and boundaries are adequately defined (Ostrom, 2012).

Conversely, government or central control would be more effective when there are no clear resource boundaries, and users are once again highly mobile and/or culturally diverse. In particular, the lack of clear resource boundaries makes the transaction costs of creating a decentralised management solution prohibitive to the process, as identifying defectors in such situations is a very time-consuming, difficult and costly procedure (Ostrom, 2012).

In short, decentralised management does not work well when there is no social consensus on the rules and their enforcement methods, when those who defect are not identifiable, and when the consequences of their defection are not localised to the community. However, the majority of CPRs do have clearly defined boundaries and do range over a community that shares similar social norms and values. In these cases, *decentralised management remains the better alternative* (Ostrom, 2012).

2.2.3 Resource sharing and social status: a modification of incentives

The Indigenous peoples of the Northwest Coast of North America practice a community-based traditional ceremony known as the potlatch. This ceremony forms not only part of their cosmologies, but also serves as a mechanism to enforce the chiefs' collective resource management systems, thus ensuring mutual cooperation in game theory terms. A very brief summary of the ceremony will be given in this section to aid understanding of the game theoretic analysis conducted by Ronald Trosper (2009); a more nuanced and detailed description of the potlatch, its associated cultural and social norms, and some of the changes that these have undergone as a result of colonisation will be explored further in section 2.3.

The First Nations of the Northwest Coast divide their land amongst the head Titleholders of each of the houses in a village. The head Titleholders are in return responsible for sustainably managing access to, and level and nature of, resource extraction occurring on that piece of land. Incorrect management, as determined by fellow Titleholders and chiefs of the community, would lead to a set of penalties, including in severe cases the removal of the land from the Titleholder's care (Trosper, 2009).

The potlatch ceremony, beyond its cosmological role in communing with the ancestors and animal spirits of the village, was a critical mechanism in the enforcement of the Nation's laws, including those that governed resource management, both within and across networks of communities. A potlatch would occur primarily at the naming of new Titleholders after the passing of their predecessors, or at any stage in a (potential) Titleholder's life when their title or status would significantly change. The intent was to prove to the community, via appropriate gifting to those invited to witness the ceremony, that the new Titleholder had been correctly trained and was able to satisfactorily manage the land that they would now be responsible for (Trosper, 2009).

Gifts were given according to the rank of their receiver – the higher their status within the community, or the section of it gathered at the feast, the more valuable their gift would be and the sooner they would receive it in the ceremony. Gift-giving and gift-accepting were two of the major opportunities that individuals had to signal their approval (or disapproval) of a Titleholder's management in the period of time between the last potlatch they attended and this – in other words, opportunities to identify and punish a defector. Hosts could signal disapproval of their guest by not gifting in the right order, and/or the right amount. In turn, guests could signal disapproval of the host by refusing to accept the gift offered to them (Trosper, 2009).

As all houses essentially take turns hosting potlatches, and therefore take turns gifting and receiving, the potlatch can be interpreted as a form of reciprocity via enforced resource sharing. Ronald Trosper provides two representations of how this mechanism modifies the payoffs in the Prisoner's Dilemma, summarising the effects of multiple potlatches in one game and solving the paradox (Trosper, 2009).

The first modification is the symmetric generosity rule, whereby players share exactly half of their resource yield with the other player, regardless of whether or not they cooperated or defected with the rules of extraction. This modification is shown in Table 2:

Prisoner's Dilemma – extraction phase (Player 1 rows, Player 2 columns)

	C	D
C	10 / 10	4 / 12
D	12 / 4	5 / 5

→

Symmetric Generosity – potlatch phase (Player 1 rows, Player 2 columns)

	C	D
C	10 / 10	8 / 8
D	8 / 8	5 / 5

Table 2 Symmetric generosity modification of the Prisoner's Dilemma, from Trosper (2009). ***'C' represents the choice to cooperate; 'D' represents the choice to defect.***

This representation of the reciprocity found in the potlatch effectively eliminates the incentive to defect for both players. Defectors no longer reap the full benefits of cheating, as they are forced to share half of those added benefits after extraction has taken place anyway. Additionally, because of a lesser, though still positive depletion problem that occurs when one of the players extracts above the MSY, the total yield in a (C,D) outcome is less than that of the (C,C) outcome. And so, the new Nash Equilibrium is now also the strictly dominant strategy for both players in the game, ensuring that they will consistently choose to mutually cooperate. If this game were played iteratively, mutual cooperation would evolve instantaneously and be maintained for as long as the game was played. The dilemma, or paradox, is no more (Trosper, 2009).

Side payments are the second of Trosper's interpretations of the reciprocal gifting that occurs over the course of multiple potlatches. Trosper argues that this is a more realistic representation of the mechanics of the potlatch, as it takes into account heterogeneous skill levels, extent of ownership, power (social status) and other such asymmetries that dictate how much each individual or house receives at a potlatch – and how much each house is expected to distribute when hosting a potlatch. Each player essentially must offer, or promise, a high enough payment to the other player to motivate them to cooperate. Typically, there would be some risk involved here, as the incentive operates *a priori,* and there is opportunity to renege on the deal once extraction is completed. Effective governance is a requirement for this type of reciprocity to work in the absence of fully honest players. However, effective governance is also required to ensure that all players share half of their yield in the symmetric generosity modification, and do not lie about how much they did, in fact, extract. This is to say that the need for effective governance does not put either modification at a disadvantage compared to the other (Trosper, 2009). How side payments could modify the Prisoner's Dilemma is shown in Table 3:

Prisoner's Dilemma – extraction phase

Player 1 \ Player 2	C	D
C	6 / 7	0 / 11
D	9 / 0	3 / 4

→

Side payments – potlatch phase

Player 1 \ Player 2	C	D
C	5 / 8	4 / 7
D	4 / 5	3 / 4

Table 3 Side payments modification of the Prisoner's Dilemma; from Trosper (2009). *'C' represents the choice to cooperate; 'D' represents the choice to defect.*

Remember that this representation already accounts for differing levels of extractive ability and/or quality of land in the extraction phase of the game, where the paradox still exists. The player with the lower ability is shown here to offer more to the player with higher ability in order to redistribute payoffs sufficiently for mutual cooperation to occur (Trosper, 2009).

A key feature of this interpretation is that payments are received for cooperating regardless of which strategy the other player chooses. If both cooperate, both make and receive payments; if both defect, no payments are made or received. The important change to the game once again occurs in (C,D) situations: if one player defects when the other cooperates, the defector will have to make the expected payment, *and receive nothing* as punishment. This ensures the shift of incentive towards mutual cooperation, solving the dilemma (Trosper, 2009).

2.3 The potlatch: norms, traditions and variations

In the following section the potlatch will be summarised from the descriptions and interpretations given by various Indigenous and non-Indigenous scholars, focusing on elements that facilitate the enforcement of sustainable resource use. Additionally, a section will be dedicated to outlining the changes that the potlatch underwent as a result of European colonisation and the later outlawing of the ceremony. Finally, the incentive and enforcement mechanisms that can be expressed in the agent-based model will be defined and detailed.

It is important to acknowledge here that neither myself nor my supervisor identify as First Nations or Indigenous. My use and interpretation of the potlatch and those cultural and/or ritualistic elements surrounding it stem from an intention to understand how the potlatch, as an historically effective example of reciprocity and collective action, is capable of generating abundance in situations which western epistemologies have claimed can only generate scarcity.

2.3.1 The potlatch ceremony: an introduction

The potlatch tradition, with its wide range of ritual requirements and subtle social intricacies, was (and remains to some degree) a pivotal element of life in many First Nations, and was the foundation upon which a complex system of rank, rights and privileges rested on. The ceremony itself was a formal feast hosted by one of the houses, or clans, of the community, and served as the primary arena to announce and 'make real' any changes to the community's social structure – including births, marriages, deaths, and the ensuant naming of an heir (Beynon et al., 2000; Miller, 1997).

The idea of rank in Indigenous cultures is a very structured and respected concept, affording individuals with both the right and duty to be involved in community decision making, and sometimes the right and duty to manage part of the community's land. To have a rank meant to have the influence and privileges that came with it, and the duty to wield these responsibly in a way that would benefit the community. To have a rank was to be recognized, to be seen as a 'real' person. Without a rank, or with a low rank, individuals could not hold positions of power or respect; to try to exert any unearned amount of influence on a community was to open oneself to public insult and discreditation (Beynon et al., 2000; Morrison and Wilson, 2004; Steltzer, 1984).

The system required that an individual first prove to the whole community that they were capable of humility, generosity, and wisdom, and that they could foster respectful relationships with the community and the land. These traits had to be demonstrated over years of training and apprenticeship prior to petitioning for a rank, and then finally at a potlatch hosted by their clan. (Atleo, 2011; Beynon et al., 2000; Miller, 1997; Ringel, 1979; Steltzer, 1984).

The emphasis on respectful relationships is an expression of the fact that an individual's unique sense of self is a reflection of the nature and strength of their relationships with other members of the community and the land. Consequently, an individual's standing is highly dependent on earning respect from the community, largely by proving that they are able to contribute to the well-being and prosperity of the human *and* non-human entities that share the land (Atleo, 2011; Beynon et al., 2000; Morrison and Wilson, 2004; Ringel, 1979).

This strong relationality is also an important basis for the novel social structure of Indigenous communities. The necessity of earning the community's respect, and being recognised as a "real person" (Atleo, 2011) means that, although individuals have autonomy as unique individuals (in that they are, theoretically, free to make their own choices), their agency is nested within and guided by the agency of the community. This is facilitated by various socio-cultural structures (including the structured nature of the relationships themselves) that determine whether or not an individual's actions will be rewarded with social status and resource exchanges. The nested agency is also reflected in the fact that the unit of social and economic organisation is not the individual but the House, and it is the House (represented by the House chief and their advisors) which exerts agency over specific resources in the form of exclusive control (Halpin and Seguin, 1990; Miller, 1997; Morrison and Wilson, 2004).

In terms of community structure, each village was divided into houses, each of which represented one of the clans originating from the community's historical cosmology. Each house was headed by a chief, with one of these chiefs, or a separate chief, presiding over the village, or a cluster of smaller villages. Villages that were linked with common language, history and customs typically resided within, and defined the boundaries of, the territory of a single Nation. Inter-village, inter-house and inter-individual relationships were sustained through kinship and cross-clan marriage ties, as well as the exchange of resources and access to land. This structure not only maintained a large network of support for extended families during hard times, it also maintained strong relational connections *across* villages and clans that generated another set of levels within the nested agency of Indigenous cultures. This ensured that no group became isolated enough to act against the joint interest of the Nation as a whole. (Halpin and Seguin, 1990; Miller, 1997; Morrison and Wilson, 2004).

The importance of structured social relationships and relative ranks amongst clans and individuals were also strongly emphasized at potlatch feasts through complex and often ritualized expressions. These included clan-specific dances, performances and dramatized invitation announcements (all viewed as symbolic items of prestige), as well as more structural expressions such as relative seating arrangements, the items contributed to the host and distributed to the guests, and the amount of food received by the guests. The importance of rank and status at a potlatch was further emphasized by the fact that only clan members who had successfully earned a name were allowed to attend and participate in the rituals (Beynon et al., 2000; Halpin and Seguin, 1990; Steltzer, 1984).

At feasts, chiefs and other highly ranked individuals of the hosting clan were expected to demonstrate the power of their house, and "continually validate their rights and responsibilities to the people, their lands, and the resources contained within them" (Beynon et al., 2000, 31). Some of the most important demonstrations involved the contribution and distribution stages of the potlatch, both of which were very public (Beynon et al., 2000; Halpin and Seguin, 1990; Morrison and Wilson, 2004; Ringel, 1979).

During the contribution stage, members of the hosting clan would enter the ceremony location one by one and bring their rank-appropriate contributions to a central collection point. The individual collecting would count the contribution and publicly announce it for all those in attendance. All clan members contributing as expected of their own and their clan's rank was considered a show of strength of the entire clan (Beynon et al., 2000; Halpin and Seguin, 1990).

During the distribution phases the non-symbolic items gifted to guests, including the food items, were a public declaration that the house and its Titleholders were able to manage their territories and successfully trade with others. For the hosting clan, if demonstrated consistently in the long run, this proved that the clan was capable of *sustainably* maintaining their land, with respect for all entities that shared it and future generations (Beynon et al., 2000; Halpin and Seguin, 1990; Ringel, 1979).

The gifting process was also an important facet of rank, providing yet another opportunity for public expression of disapproval or validation. Specifically, the hosting clan was expected to a) hand out gifts in the exact order of the relative ranks of the attending guests and b) divide the size of the gifts so that individuals of relatively higher rank received gifts of higher worth. On the other hand, members of the guest clan were expected to accept the gift only if they decided to validate the change in social structure that was being marked by the feast. This provided both host and guest with an opportunity to publicly signal their disapproval of an individual and their clan by extension. Not gifting according to rank, or not accepting a gift, was considered a formal insult to the other individual and their clan, and required an answer from the insulted party (Beynon et al., 2000; Halpin and Seguin, 1990; Ringel, 1979).

As such, the potlatch ceremony was also an opportunity for ranked individuals from both guest and host clans to formally and publicly air their grievances and settle them with the guiding presence of the attending chiefs and advisors. These disputes were often related to a failure to fulfill rank-related duties, an abuse of privilege, or a previous insult that needed to be answered (Miller, 1997; Ringel, 1979).

Note that responses to insults were also formal affairs and required preparation. Thus, answers were rarely given at the same potlatch as the insult, and sometimes required an entire additional cleansing / apology potlatch. Failing to answer insults was seen as an admission of guilt, or agreement with the insult. This would lead to loss of rank, power and influence for the individual and their clan – and as a biproduct, all clan members would receive a reduced share of resources until rank could be regained (Beynon et al., 2000; Morrison and Wilson, 2004).

2.3.2 Northwest Coast – European contact and colonization

The process of colonisation by European settlers brought with it a host of changes to the organisation and culture of the Indigenous groups in the Northwest. The earliest explorers are recorded as having traded and otherwise interacted with Indigenous peoples without purposefully attempting to influence or force cultural change. The main item in trade was the fur sourced from within Indigenous lands, and the items used as payment by the Europeans were regarded as prestige items, many of which were useful tools. The fur trade grew quickly; however, at the same time, new diseases decimated the Indigenous populations and left many ranked positions in the houses, clans and villages without successors. The reduced population and resultant reduced demand for resources additionally created surpluses that could now be sold in the market for profit. The individuals that perceived the potential gain in both this and the fur trade increased their wealth exponentially (Morrison and Wilson, 2004; Ringel, 1979).

These changes impacted the potlatch as well. The unprecedented vacancies in the rank system in combination with a sudden and massive surplus in personal wealth for those engaged in trade led to individuals (instead of houses) holding competitive potlatches to earn vacant titles (instead of holding potlatches to validate the competency of an individual with inherited rights to a title). Potlatches became extravagant in their new purpose of re-establishing social order, with an important change – prestige was now earned by distributing *as much* material wealth as possible, *without limits* (Halpin and Seguin, 1990; Miller, 1997; Morrison and Wilson, 2004).

The next wave of colonisation – missionaries, adventurers, miners, settlers – had no tolerance for the Indigenous cultures, and no respect for their rights to land that had been carefully managed by generations of families for centuries. The colonisers began appropriating resources without agreement, and without adherence to local management rules. Western government and policy were established and forced onto the Indigenous groups, who no longer had the power of force to oppose the change. The Indian Act of 1876 divided traditional lands into small reserves for each local group, effectively isolating communities from one another (Morrison and Wilson, 2004; Ringel, 1979).

The potlatch, especially in its more recent extravagance, suffered from the new laws forced into existence, and the ceremony was banned in the nineteenth century. Having been viewed through the lens of Victorian culture and the traditional economics of the time, the "lavish" (Morrison and Wilson, 2004, 405) and voluntary distribution of personal material wealth went against everything that the Europeans understood about accumulation and progress. Instead the tradition was viewed as primitive, and a hindrance to the communities' progress towards 'modern civilisation' (Ringel, 1979).

2.4 Identifying potlatch mechanisms

Drawing from the various texts described section 2.3.1, one can identify a set of socio-cultural and ritualistic mechanisms that act to enforce the resource reciprocity found in Indigenous communities. These can be separated into underlying mechanisms, and structural mechanisms based on the level at which they operate and impact reciprocity.

Before detailing these mechanisms, it must be noted that the definition of the potlatch used from here onwards is narrowed down to consider only the subset of potlatches that are held in honor of major events that would directly impact both an individual and their clan's social status, and were dependent to a large extent on the age of the individual(s) in question. These included primarily the succession and funerary feasts, as well as house-raising feasts and the marriage feasts of very highly ranked individuals; events which were important enough to require the clan as a whole to host the feast and spend a number of years gathering and saving resources for the ceremony (Grumet, 1975; Steltzer, 1984).

2.4.1 Underlying mechanisms

Underlying mechanisms are those community-level processes that enforce the potlatch and its peripheral traditions. In terms of model building, they aren't explicitly programmed for, but are rather implicitly found in agent behaviours and characteristics. They can be summed up into the following three mechanisms:

First, there is the mechanism of **ranked names**, which encapsulates the very high value that Indigenous communities place on social status. Ranked names are symbolic items that are actually owned by a clan and are in a sense given temporarily to an individual for safe keeping once that person is deemed capable of doing so. Traditionally, ranked names were only available for inheritance to members of the clan who were either matrilineally, patrilineally or bilaterally (depending on the Nation in question) descended from the previous holder, and only at the previous owner's time of death (note that, as discussed previously, this tradition deteriorated in varying degrees as a result of European colonization). However, whilst the opportunity to hold a ranked name is inherited, the actual right to do so must be earned and continually maintained by:

a. Demonstrating the ability to provide for the community at the rank-appropriate level, without harming the land or depleting the resource the name is responsible for.
b. Maintaining respectful relationships with all members of the community, including the land and all human and non-human entities sharing it.

This mechanism enforces the potlatch and the reciprocity enacted during it because both of the requirements stated above must be publicly demonstrated at a succession potlatch for community validation and approval. Without this demonstration, the ranked name cannot be granted, and so the act of resource sharing during the potlatch becomes a necessity and is effectively enforced.

Secondly, there is the broad social mechanism that can be labelled as **public accountability**. This mechanism in fact governs or encompasses a wide range of more specific structural mechanisms that monitor and publicize agent behaviour, providing opportunities for the community to be aware of and to limit undesired and harmful individual behaviours.

This feature of Indigenous social norms is in fact intrinsic in all facets of community life, and any decision or action taken by an individual or clan that could potentially affect other members of the community (again, human and non-human) must be announced to the community, and approved by a committee of high-ranking community members. Essentially, by reducing agent anonymity (a factor that strongly increases the reward for defection), this mechanism stands as a heightened guarantee to individuals that they will be punished, socially and materially, for almost all of their unacceptable behaviours.

In the context of the potlatch, this is applied at every structural mechanism that could impact the social status or rank of any individual in attendance – such as the reciprocal gifting processes that demonstrate the ability to provide for the community. Thus, the enforcement of said reciprocity is effectively augmented.

The final mechanism is the specific form of governance typical to most Indigenous Nations. The communities within most Indigenous Nations are given a level of autonomy that allows for highly contextualized and dynamic decision-making, which can be understood as a form of Ostrom's decentralized management as defined in section 2.2.2.

This mechanism is in part linked to the previous mechanism of public accountability, in that nearly all decisions that would affect the community are publicly discussed and, in the end, agreed upon collectively. Decisions made by an individual that might affect the clan are discussed and approved by the clan chief and their advisors; similarly, decisions made by a clan that might affect the village would have to be discussed and approved by the village chiefs and their advisors; and so on at the different levels of this nested hierarchy of governance.

The chiefs and their advisors are in turn held accountable in the sense that they are, to a large extent, appointed to these positions by the community, and the community does have the power to remove these privileged titles from individuals upon consensus that the individual is harming the welfare of the community.

In summary, there is little top-down, authoritarian control, and a lot of bottom-up, highly contextualized and discursive decision making in Indigenous societies as a whole. This enforces the potlatch and its traditions indirectly, in that it actually allows for the contextualized allocation of ranked names, augmenting the efficacy of the first underlying mechanism; and it allows for the mechanism of public accountability to be not just a potlatch-specific tradition, but a wholly entrenched social norm, further augmenting its efficiency and efficacy. This mechanism, or rather, this form of governance, can perhaps be considered as the necessary foundation for the potlatch system to exist and function as effectively as it did prior to colonization.

2.4.2 Structural mechanisms

The structural mechanisms are those that form the potlatch ceremony and facilitate resource flows and their accompanying impacts on social status. These are the mechanisms that are explicitly coded into the agent-based model, primarily in the form of agent behaviours. Before discussing these in any detail, it is very important to clarify how the ranking system was approached when interpreting it as a structural mechanism for a model.

In practice, each name occupies a unique rank relative to all others; no one name has the same level of social status as any other. Unique agent properties, however, can significantly complicate models, reduce the robustness of results and introduce a lot of noise into data.

Fortunately, for the purpose of modelling resource flows and payoffs, individuals could be quite realistically grouped according to their productive and potlatching duties. These groupings also coincided with large differences in the amounts that agents would expect to contribute to and receive at potlatches, and with whether they own a ranked name. The three rank groupings therefore used in the model are Chiefs, Titleholders, and Noranks (i.e. unranked agents).

Chiefs are those individuals who have inherited and earned ranked names associated with the position of clan leader and are thus responsible for managing the welfare of their house and its members. This includes managing and monitoring extraction by clan members and organizing and hosting potlatches, at which they are responsible for correctly distributing the gathered contributions. They also attend potlatches of other clans and receive the largest gifts at these.

Titleholders are members of the clan who have also earned a ranked name and hold social status just below that of the chief. Some may share in the management of the clan, usually as advisors to the chief, but all are expected to be productive and provide for their house / clan. They also attend the potlatch ceremonies of other clans, where they directly receive gifts, and are expected to contribute to their own clan's potlatch.

Noranks are those clan members who have not earned a name or did not inherit the opportunity to do so. They extract at typically lower levels than is expected from Titleholders and contribute to their clan's potlatches. They do not attend potlatches but do receive some of the distributions when their chief returns and shares a large part of his own gift with them.

The gifting process itself is the main structural mechanism used to facilitate resource flows, but it is also a significant, and bidirectional, mechanism used to signal approval or validation during the potlatch. A host can signal disapproval of a guest by gifting an inappropriate amount relative to their rank, or gifting in the wrong order, implying that the individual is not worthy of his name. Conversely, a guest can signal disapproval of the host by refusing to accept their gift, thus invalidating their claim to a change in social status.

Regardless of the direction, whenever disapproval is signaled, the individual in question must ritually repent in order to maintain their social status which usually involves distributing apology gifts at a separate ceremony. If this apology is not acceptably conducted by the defector, or their behaviours were considered severe enough, the community held the power to, by consensus, remove a ranked name or reduce the social standing of the defecting individual, simultaneously removing their privileges and responsibilities. This is an especially important enforcement mechanism for those members of the community with important duties to manage land and resources. For this project, the aspect of the apology potlatches which affects social status will not be explicitly included in the model. However, the aspect which impacts resource-based incentives will be included in the model.

As a result of the apology potlatches, the gift-giving process contains a *redistribution* mechanism that activates when there are defectors in the community. The apology potlatches essentially ensure that defectors do not reap the (short-term) rewards of their behaviour. This is because they require them to contribute resources to the community twice in the same period that cooperators only need to contribute once, and the second contribution is not reciprocated. The extra resources gained via defecting behaviours are removed from defectors and redistributed to cooperators, compensating them for the extractive losses that they have or will experience because of the defecting behaviour.

3. METHODOLOGY

The underlying and structural mechanisms identified in the potlatch ceremony and its associated socio-cultural elements were translated into an agent-based model which was programmed to output data used to a) create a set of clan-level payoff matrices and b) examine the impact of certain potlatch mechanisms on behavioral incentives at the individual level.

There are many programs that can be used to create ABMs, including Python, R and MATLAB. The model described here was designed using NetLogo (Wilensky, 1999), an open source software with a visualisation tool that allows users to physically see the model as they program it, a feature that is particularly valuable if the model has space dependencies. The software was developed by Uri Wilenski of Northwestern University's Center for Connected Learning and Computer-Based Modeling, and is often the software of choice for beginners, due to its very intuitive coding language (Banos et al., 2015; Wilensky, 1999).

As previously discussed, ABMs are particularly well-suited to examining the mechanisms and structures of collective action systems such as the potlatch, primarily because they can accommodate agent heterogeneity on multiple levels and can simulate the complex, multi-conditional interactions and behaviours that are created by the system. In allowing for a holistic modelling of this complexity, the ABM approach lets us open up the black box that is the House, or clan, and begin to also understand how the potlatch system – and other similar collective action systems – create effective incentives at the individual level.

The structural mechanisms, and implicitly the underlying mechanisms, identified in section 2.4 for the subset of major potlatches being focused on were built into the ABM as agent behaviours and various potlatch processes. How the ABM was built, including the rules governing agent behaviour and environmental change over time and any associated simplifying assumptions, as well as how the output was generated for both the clan-level payoff matrix and the examination of individual-level incentives, will be outlined in detail for the bulk of this section.

3.1 Agent-Based Model of the potlatch

3.1.1 Environment: building a dynamic world

NetLogo worlds are presented as rectangular assemblages of patches – pixel-like units with spatial orientations that can be programmed to have various dynamic and interactive characteristics. The size of the world, including the size and number of patches in it, can be customized by the user, as well as the porosity of the world's borders, which can be closed or set to loop, simulating a spherical world.

For this inquiry, the world was designed to mimic a tract of land assumed to contain a single CPR base that is shared by the Houses of a First Nations village. It is further assumed that this village has exclusive access to and control over the CPR in its entirety; thus, the outer borders of the world do not loop, agent and resource movement is limited by these outer borders, and there are no external influences on the resource or agents. The size of the world was set at 19x19 patches, and thus contained a total of 361 patches.

Houses within a village often had control over multiple fishing sites, hunting grounds or other resource appropriation sites and reserved the right to exclusively manage and make use of them – although this right was often transferred to other Houses as a gift or in service of a debt (Halpin and Seguin, 1990; Morrison and Wilson, 2004; Ringel, 1979).

However, for the purpose of this model and methodological development, a simplifying assumption was applied whereby each House maintains exclusive access to their various extraction territories at all times. Additionally, as only one type of common-pool resource was simulated in the model, the potentially multiple extraction sites that each House could own were combined into one territory per House.

The resulting world design divided the available land (i.e. the geographical range of the model CPR) equally so that each House had access to one territory, with House members being restricted to moving and extracting only within their House's territory. Territories did not, however, restrict the movement of resources across the world in any way (resource mobility will be described in further detail later on).

The simplifying assumption of no external influences was applied to maintain clarity and reduce noise in the data at these early stages of model development. Future work may attempt to broaden the range of environmental mechanisms that could impact the potlatch processes and payoffs, to test the robustness of the system in the face of environmental uncertainty.

Note that the 'resource units' in this model are programmed and defined based on a general understanding of the most typical characteristics of biological resources, namely a carrying capacity, an intrinsic reproductive rate, and a minimum viable population.

Following from this, each patch in this model represented a unit of resource-producing land and was programmed to have a 'stock' characteristic. This stock was set to have a maximum limit of 50 resource units, and a starting amount at t_0 of 30 units, allowing for resource growth as well depletion. Additionally, each patch's stock was programmed to be renewed, and to diffuse across the world from patch to neighboring patch, at the end of every time step.

Stock renewal was approached using thresholds, to simulate the fact that most natural resources (populations), should remain at or above minimum viability to avoid their extinction.

Note that in this model, each time-step is defined as one year, normalizing for any seasonal differences that would have to be accounted for otherwise. Additionally, one year is a realistic time frame to allow for the processes that occur in successive sub-steps within every time step[6], such as extraction and resource renewal.

The renewal process acts independently on every patch during the second sub-step and operates in accordance with the following rules:

IF …	THEN $rate_{pn}$[7] = …
$stock_{pn(1)}$[8] $=$ $stock\ max$	$0\ units$
$(stock\ max - 0.8) < stock_{pn(1)} < stock\ max$	$(stock\ max - stock_{pn(1)})\ units$
$10 < stock_{pn(1)} < (stock\ max - 0.8)$	$0.8\ units$
$4 < stock_{pn(1)} < 10$	$0.2\ units$
$0 < stock_{pn(1)} < 4$	$0\ units$

Table 4 Rules to determine renewal rate in a single patch.

[6] There are typically six successive sub-steps per time-step in this model, with sub-steps 2-6 each containing a process that affects patch stock levels, agents' stored resources and/or the chiefs' pots. The first sub-step contains the stock levels / stored resources / pots that were carried over from the last sub-step of the previous time-step. Every tenth time-step has an additional seventh sub-step in which a potlatch occurs and resources are distributed from one clan to another.

[7] $rate_{pn}$ is the renewal rate of patch p in the n^{th} time-step.

[8] $stock_{pn(x)}$ is the stock level of patch p in the x^{th} sub-step of the n^{th} time-step.

Once renewal rates are determined, stock levels are adjusted so that:

Eq. (1) $stock_{pn(2)} = stock_{pn}(1) + rate_{pn}$

Stock diffusion then occurs in the next sub-step, allowing all patches to disperse 50% of their stock across all of their neighbors (including diagonal neighbors), smoothing out any large and sudden differences between stock levels across space. As mentioned previously, this diffusion process can occur across House territory lines, and was included in the model to simulate that many biological CPRs are not fixed in space over time.

After diffusion, stock levels on each patch are adjusted so that:

Eq. (2) $stock_{pn(3)} = stock_{pn(2)} + (in\text{-}diffusion - out\text{-}diffusion)_{pn}$[9]

The model also logs the total resource stock of the world at the end of every time-step. If this total falls to 0, a stop condition will end the simulation under the assumption that the environment is irreversibly depleted, and the human community can no longer survive on the land. If on the other hand total stock were to reach its maximum of 18,050 units, the simulation would simply continue with renewal rates set to 0 units per time-step until extraction reduced total stock below its maximum and triggered positive renewal rates once again.

However, total stock can never reach this maximum as extraction and renewal both occur within every time-step in this model, and there is never zero extraction. It is, however, capable of *approaching* the maximum, as total cooperative extraction levels were intentionally programmed to be slightly lower than the exact MSY of the world (see section 3.1.2).

Individual patches also cannot achieve their maximum stock as the smoothing effect of the diffusion process results in all patches in the model sharing in the losses caused by extraction to some degree. Note that the inability to reach maximum stock levels is a *condition* of the model created by programming extraction and resource renewal to occur together in every time-step.

If there is no complete resource depletion and the first stop condition is not triggered, a second stop condition is programmed to end the simulation at the 800th time-step. Note that,

---

[9] $(in\text{-}diffusion - out\text{-}diffusion)_{pn}$ is the net change in stock level due to diffusion that occurs in patch *p* during the n^{th} time-step.

while this time frame seems unrealistic given that no births or deaths occur in the model, the traditions of inherited ranks, responsibilities and privileges (plus stable population levels pre-colonization) allow this time frame to be appropriate in this specific case. In other words, as each agent can be considered to represent one ranked name in a stable population of names (instead of an individual) the limitation of human life spans can be omitted here.

3.1.2 Agents: building an interactive, heterogenous community

As mentioned previously, the world is designed to simulate a territory of resource-producing land exclusively belonging to an Indigenous village. To simulate the social structure of Indigenous clans within a village, and the tradition of social rank maintained by the potlatch system, agents in this model belong to one of two clans, and one of three ranks.

Agents are separated into two clans and are restricted to moving in and extracting resources from their associated territory. This follows from historical records of each clan in a village being given exclusive access to and management over a specific resource used by the village and/or Nation. Both clans in the model have an equal number of agents, for simplicity and noise reduction in the data. Following the simplified three-rank system designed for this model, each clan has one chief, four Titleholders, and eight Noranks based on evidence from Beynon et al. (2000) that individuals of lower rank, even amongst those allowed to attend a potlatch, were more abundant.

At t_0, these 26 agents are spawned at a random location in the territory associated with their assigned clan. At every following time-step, each agent, depending on rank, performs a set of actions according to their programmed behaviours, some of which are additionally conditional on the environment or the programmed scenario under which the model is running.

At every time-step, **Noranks** and **Titleholders** are programmed to:

a) Move to a new patch within their territory
b) Attempt to extract from the patch at a conditional level and store the actual yield
c) Contribute a conditional number of stored resource units to their chief
d) Consume a fixed proportion of the remaining stored resources
e) And finally, save, or retain, any remaining stored resources.

Agent movement, considering that each time step represents one year, is not limited by distance. Instead, agents are programmed to move to one of the patches within their territory that has the highest stock available[10]. Once they have landed on a new patch, they will attempt to extract from it. Their actual yield is governed by two factors.

Firstly, from the agent's side, the resources each agent is expected to attempt to extract (a.k.a expected yield) is determined by a) their rank, and b) whether they are set to cooperate or defect. Note that **cooperation** is defined as the decision to extract at or below the per capita MSY, and **defection** is defined as the decision to extract above it. Regardless of this decision, *every* agent in the model contributes to their clan's potlatches.

The expected yields for cooperative agents were calculated using the MSY principle, using the total maximum renewal rate of the world, and historical evidence from the Gitskan Nation that the ratio of contribution levels used in their potlatches – and therefore extraction levels, following from evidence that contribution levels were proportionally dependent on extraction levels – was roughly 3:1, high-ranked to low-ranked (Beynon et al., 2000). The calculations for cooperative levels of expected yield per time-step were therefore as follows (where T_{Ec} and N_{Ec} are the expected yields for a single cooperative Titleholder and cooperative Norank, respectively):

Eq. (3) *No. of patches * max renewal rate per patch = total MSY*

*361 patches * 0.8 units per patch =* ***288.8 units***

Eq. (4) *Total MSY = total cooperative yield*

$$\text{Total cooperative yield} = (\text{No. of Titleholders})*(T_{Ec}) + (\text{No. of Noranks})*(N_{Ec})$$

$$288.8 = 8T_{Ec} + 16N_{Ec}$$

Eq. (5)

$$T_{Ec} = 3N_{Ec}$$

$$288.8 = 8*(3N_{Ec}) + 16*N_{Ec}$$

$$\mathbf{N_{Ec}} = 288.8 / 40 = 7.22 \approx \mathbf{7\ units}$$

$$\mathbf{T_{Ec}} = 3*N_{Ec} = 21.66 \approx \mathbf{21\ units}$$

[10] See Figure I in Appendix 2 for screenshots of how our potlatch model evolved visually over one run.

Both T_{Ec} and N_{Ec} were rounded down for two main reasons. The first was the fact that the exact MSY of a CPR can only be found by overexploiting it at some point. At the same time, the MSY also fluctuates over time due to dynamic environmental conditions. Realistically, this means that communities never have perfect information about the MSY (Hilborn et al., 1995). Considering this, we assumed that communities that successfully maintained sustainable extraction rather erred on the side of caution and aimed to extract less than the estimated MSY of the CPR.

The second reason follows from the first, and this was to observe in the model the growth, or generation of abundance, in the CPR itself that has been observed in First Nations lands and speculated to be the result of the careful management and 'tending' of the land and its resources over generations (Morrison and Wilson, 2004).

Expected yields were therefore programmed as follows:

a. Cooperative Noranks: 7 resource units.
b. Defecting Noranks: 10 resource units.
c. Cooperative Titleholders: 21 resource units
d. Defecting Titleholders: 30 resource units.

The expected yields for defecting agents were set to be arbitrarily higher than those of the corresponding cooperative rank, although the 3:1 ratio was maintained and defecting Noranks still extracted less than cooperative Titleholders. This was the result of an assumption that Noranks would not be *capable* of extracting more than Titleholders, based on the fact that rank was largely earned by an individual proving that their extractive ability was sufficient for their rank (Halpin and Seguin, 1990; Miller, 1997; Morrison and Wilson, 2004; Ringel, 1979; Trosper, 2009).

Expected yields are permanently set for each agent at t_0, under the assumptions that a) the underlying mechanisms of ranked names and social organization are strictly enforcing extraction levels in the case of cooperators, and b) as an earned rank is to a large extent a reflection of an individual's ability to provide for the community, defecting agents will also have varied extraction levels according to rank

Secondly, from the environmental side, the availability of resources on the patch in question also limits actual yield. No negative stock levels are allowed in this model, as they are wholly unrealistic in the context of natural resources. The following conditions show how the amount to be extracted from each patch during sub-step 4 is determined:

IF …	THEN …
Agent *y* present AND $expected\text{-}yield_{yn} < stock_{pn(3)}$	$amt\text{-}extracted_{pn}$[11] $= expected\text{-}yield_{yn}$
Agent *y* present AND $expected\text{-}yield_{yn} > stock_{pn(3)}$	$amt\text{-}extracted_{pn} = stock_{pn(3)}$
No agent present	$amt\text{-}extracted_{pn} = 0$

Table 5 Rules determining the amount agent y can extract based on available stock.

Stock levels on patch *p* would then be adjusted so that:

Eq. (6) $$stock_{pn(4)} = stock_{pn(3)} - amt\text{-}extracted_{pn}$$

$Stock_{pn(4)}$ is the final stock level of each time-step and is therefore the stock level that an individual patch will carry forward into the next time-step. Note that whilst renewal and diffusion occur in every patch, extraction will only occur in the patches that an extractive agent moves to. On the patches where an agent is present, the calculated $amt\text{-}extracted_{pn}$ is added to agent *y's* collection of stored resources so that:

Eq. (7) $$res\text{-}stored_{yn(4)} = res\text{-}stored_{yn(1)} + amt\text{-}extracted_{pn}$$

Following this sub-step, the potlatch contributions from Noranks and Titleholders are removed from their stored resources and transferred to their chief.

---

[11] $amt\text{-}extracted_{pn}$ is the amount of resources extracted from patch *p* in the n^{th} time-step.

Firstly, as there is little agreement on exactly what proportion of resources was expected to be contributed, and some speculation on how the expected proportion would affect agent behaviour, the model is programmed so that:

Eq. (8) $contribution_{yn}$[12] $= \%contributed * R$

where R is a placeholder for the chosen subset of stored resources used to calculate contribution, and *%contribution* is a variable that can be controlled in the user interface with a slider, varying from 10% to 90% in increments of 10%. The upper limit is set at 90% as at least some resources should be available for the next step of consumption.

Two possible subsets of resources (R) used for calculating contribution levels were programmed into the model, which the user can switch between on the NetLogo interface. These contribution rules were created in order to investigate the two primary understandings in the literature of how contribution levels were determined. The contribution rules are:

1. *"%Yield" (%Y):* $ex\text{-}con_{yn} = \%contribution * (expected\text{-}yield_{y})$.
   This understanding is found in Trosper's game theoretic interpretations of the potlatch (2009), as well as Walen's (1981, 49-50) exploration of the annual cycle of food gathering and contribution to the chief, and the symbolism involved in the sizes of the boxes in which the food is stored or transported. Note that for this model, the amount contributed is dependent on *expected yield* instead of actual yield, following from the fact that contributions are rank dependent, and that to maintain rank a certain amount must be provided to the community, regardless of extractive success.
2. *"%Stored Resources" (%RS):* $ex\text{-}con_{yn} = \%contribution * (res\text{-}stored_{yn(4)})$.
   This understanding comes from many anthropological accounts of the potlatch, where the 'emptying of the house' that occurs during or before a potlatch is described as both a social and ritualistic requirement, and was explained as being a distribution of a proportion of all of the resources gathered by the house as a

[12] $contribution_{yn}$ is the actual amount contributed to agent *y*'s chief during the n^{th} time-step.

whole up until that point in time (Halpin and Seguin, 1990; Morrison and Wilson, 2004; Ringel, 1979; Steltzer, 1984). It can realistically be assumed that, as individuals in Indigenous societies, particularly in pre-European contact times, were considered an extension of the social unit of organization of the house, this would most likely have applied at the individual level as well.

Finally, contribution is also limited by the number of stored resource units actually available to the agent at that time. For this model, agents are not allowed to accumulate debt, as this added complexity has little meaning when used with arbitrary resource units.

As such, the following rules govern how much an agent contributes during sub-step 5 of every time-step:

IF …	**THEN …**
$res\text{-}stored_{yn(4)} > ex\text{-}con_{yn}$	$contribution_{yn} = ex\text{-}con_{yn}$[13]
$res\text{-}stored_{yn(4)} < ex\text{-}con_{yn}$	$contribution_{yn} = res\text{-}stored_{yn(4)}$

Table 6 Rules determining agent *y*'s contribution size based on agent *y*'s stored resources.

Note that under the %RS rule $res\text{-}stored_{yn(4)} < ex\text{-}con_{yn}$ will never occur because $ex\text{-}con_{yn}$ is calculated using $res\text{-}stored_{yn(4)}$ and thus cannot exceed it.

During sub-step five, the calculated contribution level with be removed from each agent's stored resources so that:

Eq. (9) $$res\text{-}stored_{yn(5)} = res\text{-}stored_{yn(4)} - contribution_{yn}$$

A survival threshold was considered for this model; however, it was decided not to include this concept for two reasons. The first reason concerns the communal way of life of the Houses and the Nations as a whole. Chiefs, and by extension the members of their House, had a social responsibility to ensure the survival of their fellow House members, and even to provide

[13] $ex\text{-}con_{yn}$ is the contribution expected from agent y during the n^{th} time-step. For the contribution rule %Y, $ex\text{-}con_{yn}$ remains constant throughout the run.

aid to other Houses when they could do so. These favors were also eventually repaid, forming part of another facet of the potlatch system – debt – which is not explored in this version of the model (Halpin and Seguin, 1990). The second was that the model output was shown to be very sensitive to small changes in the parameters of a survival threshold when it was first attempted; and considering that the model uses arbitrary resource units, there was little factual basis upon which to base the choice of those parameters.

With these two reasons in mind, it was decided that it was neither necessary nor sensible to include a survival threshold for each individual in the model. However, ideas of agent and community survival in the face of depletion, and the potential to 'borrow' resources to survive, will be explored in future work.

The next process a Norank or Titleholder will go through before storing their remaining resources for the following time step is consumption, which happens in the 6th sub-step of every time-step. The rules governing this process are as follows:

IF …	THEN …
$\textit{res-stored}_{yn(5)} > 0$	$\textit{consumption}_{yn}$[14] $= 0.5 * \textit{res-stored}_{yn(5)}$
$\textit{res-stored}_{yn(5)} = 0$	$\textit{consumption}_{yn} = 0$

Table 7 Rules governing consumption levels of agent *y*.

Despite the choice of 50% being based off of a summary of statistics produced by The World Bank (Statistics Canada, 2014; The World Bank, 2014), it is recognized that this is a strong simplifying assumption, and that the relationship between consumption and available resources is not fully linear. The rules governing consumption will be further developed along with the concept of debt in future work.

Each extractive agent's stored resources at the end of sub-step 6 are then altered so that:

Eq. (10) $$\textit{res-stored}_{yn(6)} = \textit{res-stored}_{yn(5)} - \textit{consumption}_{yn}$$

---

[14] $\textit{consumption}_{yn}$ is the amount of resources consumed by agent *y* in the n^{th} *time-step.*

And, if a potlatch is not going to occur during the time-step in question, $res\text{-}stored_{yn(6)}$ will be carried over into the next time-step so that:

$$Eq.\ (11) \qquad res\text{-}stored_{yn(6)} = res\text{-}stored_{y(n+1)(1)}$$

At every time-step, **Chiefs** are programmed to add the contributions from their clan members to a 'pot' of stored resources that grows over time until it is their turn to host a potlatch and distribute a variable percentage of these stored resources to the other clan's ranked members. The contributions are added in sub-step 5 of every time-step; the same sub-step in which contributions are removed from all extractive agents' stored resources. Each chief's pot is altered so that:

$$Eq.\ (12) \qquad pot_{cn(5)}[15] = pot_{cn(1)} + ttlC_{cn}[16]$$

Remember that this model is based on the major potlatches, which were to a large extent dependent on the age and personal successes of certain individuals. As such, they were effectively held at random by whichever clan needed to observe a major event, rather than periodically as the smaller and specifically reciprocal potlatches were – such as challenge feasts and the responding feasts needed for "wiping out [the] insult or shameful event" (Grumet, 1975, , 301). Additionally, these major potlatches were observed to be held a number of years apart.

Following from this, and from an interest in observing how stored resources fluctuate between potlatches, the model was programmed to choose one chief at random, every ten years, to host a potlatch and distribute their collection of resources as potlatch gifts to the chief and cooperating Titleholders of the other clan.

The amount of resources from the hosting chief's pot that would be distributed at a potlatch was calculated so that:

[15] $pot_{cn(x)}$ is the collection of accumulated contributions being held by the chief of the c^{th} clan at the x^{th} sub-step of n^{th} time-step.

[16] $ttlC_{cn}$ is the sum of contributions from all Titleholders and Noranks of the c^{th} clan during the n^{th} time-step.

Eq. (13) $total\text{-}gift_{cn}$[17] $= \%potlatch * pot_{cn(5)}$

Where *%potlatch* is a variable that can be varied by the user in increments of 10%, ranging from 10% to 90%. This upper limit was chosen under assumption that a minimum of 10% of the contributions given to the chief would be used to cover their living expenses, based on historical evidence that the chiefs are economically supported by the extractive / productive members of the clan.

This $total\text{-}gift_{cn}$ was divided up according to the rank and number of the members of the guest clan. The break-down was as follows[18]:

- $Titleholder\text{-}gift_n = 0.1 * total\text{-}gift_{cn}$; where all Titleholders together receive 40% of the total gifts distributed.
- $Chief\text{-}gift_n = 0.6 * total\text{-}gift_{cn}$
- $Norank\text{-}gift_n = (0.8 * chief\text{-}gift_n) / 8$; simulating that, although only ranked individuals attend potlatches and directly receive gifts, the guest chief receives a substantially larger gift with the expectation that they will take a large proportion of it and share it amongst the cooperating unranked members of their clan.

Note that defecting Noranks and Titleholders do not receive potlatch gifts in the model, although they sometimes do receive them in practice. This is a simplification representing the assumption that the apology gifts that are expected to be distributed by defectors at some point after a potlatch are in size equal to (if not more than) any gift received at said potlatch. Additionally, cooperating agents would not receive a larger proportion of the total distribution if there are more defecting agents in their clan.

The potlatch distributions occurred during the 7th and final sub-step of every tenth time-step in the model. The following rules determined the gift received by each Norank and

[17] $total\text{-}gift_{cn}$ is the total amount of resources that the chief of the c^{th} clan will distribute during their potlatch in the n^{th} time-step.

[18] These proportions were based on the same set of historical evidence as the contribution ratios were, found in Beynon's observations of the Gitskan potlatches. The ratio of gift distributions typical for this Nation, high-ranked to low-ranked, was approximately 1.5:1. $Titleholder\text{-}gift_n$, $Chief\text{-}gift_n$, and $Norank\text{-}gift_n$ are the amount of resources that each of those ranks could receive from the potlatch being hosted in the n^{th} time-step

Titleholder of the guest clan:

IF …	**THEN …**
Agent *y* is cooperative AND Norank	$actual\text{-}gift_{yn}$[19] $= Norank\text{-}gift_n$
Agent *y* is cooperative AND Titleholder	$actual\text{-}gift_{yn} = Titleholder\text{-}gift_n$
Agent *y* is defecting	$actual\text{-}gift_{yn} = 0$

Table 8 Rules determining the size of gift received by agent *y*.

Agent *y*'s stored resources are then altered so that:

Eq. (14) $$res\text{-}stored_{yn(7)} = res\text{-}stored_{yn(6)} + actual\text{-}gift_{yn}$$

What happens to gifts intended for defecting agents depends on which level of agency is being examined at the time. This is governed by two different sets of distribution rules in the model: one that is used when generating the clan-level output, and one that is used when generating the individual-level output.

When generating the clan-level output, Chiefs in defecting clans were treated as defecting players along with the rest of their clan, under the assumption that the defection of the entire clan would be considered a failure to cooperate on the Chief's part as well. This maintained behavioral homogeneity throughout the clan which was necessary for the clan-level matrices. As such, the following rules were applied:

- If the guest clan is cooperative, the host clan distributes their $total\text{-}gift_{cn}$ in full, and all three ranks of the guest clan receive gifts as per the distribution break-down on the previous page.
- If the guest clan is defecting, the host clan retains its calculated $total\text{-}gift_{cn}$ and the none of the ranks of the guest clan receive any potlatch gifts.

[19] $Actual\text{-}gift_{yn}$ is the amount of resources received by agent *y* at a potlatch during the n^{th} time-step.

In summary:

IF …	THEN …
Guest clan is cooperating	$clan\text{-}gift_{cn}$[20] $= total\text{-}gift_{cn}$
Guest clan is defecting	$clan\text{-}gift_{cn} = 0$

Table 9 Rules for determining size of gift to be given to clan *c* based on behavioral status.

Thus, for the purposes of the clan-level analysis, the hosting chief would retain all gifts meant for defectors, and their pot would (or would not) change according to following calculation:

$$pot_{cn(7)} = pot_{cn(6)} - clan\text{-}gift_{cn} \qquad \text{Eq. (15)}$$

And the guest chief's pot would (or again, would not) be altered so that:

$$pot_{cn(7)} = pot_{cn(6)} + chief\text{-}gift_{cn} - TNG_{cn}{}^{21} - personal\text{-}gift_{cn}{}^{22} \qquad \text{Eq. (16)}$$

When generating the individual-level output, Chiefs act more as conduits or control points for resource flows, primarily because the focus is on the behavior of *extractive* individuals and how the system rewards or punishes them under various conditions. Additionally, as defection is defined in this model as extracting above the rank-dependent per capita MSY, the Chief is only considered to defect if their whole clan defects, and none of the individual-level scenarios meet this criterion.

Hence the following rules were applied so that:

- When a defecting agent of a guest clan is a Titleholder, the *host* Chief retains the gift meant for this defector.

---

[20] $clan\text{-}gift_{cn}$ is the total amount of resources distributed by clan *c* at a potlatch during the n^{th} time-step (when performing the clan-level analysis).

[21] TNG_{cn} is the sum of *actual-gifts* to be given to the Noranks of clan *c* in the n^{th} time-step; *actual-gifts* are determined by the rules in Table 9. At this level of analysis, TNG_{cn} can only equal 0 or ($0.8 * chief\text{-}gift_{cn}$) because of clan homogeneity.

[22] $personal\text{-}gift_{cn}{}^{22}$ is the remainder of the $chief\text{-}gift_{cn}$ that is moved to chief *c*'s personal storage, and at this level of analysis can also only equal 0 or ($0.2 * chief\text{-}gift_{cn}$).

- When the defecting agent of a guest clan is a Norank, the *guest* Chief retains the gift meant for this defector.

These gifts are kept back and added to the relevant chief's pot for their next potlatch. Note that this recycling of defector gifts is an expression of the simplification of the redistribution mechanism that was explained in section 2.4.2. In practice, defectors receive potlatch gifts, but essentially give them back to the other clan at the required apology potlatch very soon after. In this model, one of the chiefs simply keeps the gifts and puts them back into their pot.

Cooperating Titleholders and Noranks from the guest clan will add their gifts to their stored resources for future consumption, contribution and accumulation – under *both* sets of distribution rules.

Finally, for the individual-level analysis the hosting chief's pot would be altered during a potlatch so that:

Eq. (17) $pot_{cn(7)} = pot_{cn(6)} - TAG_{cn}$[23]

And the guest chief's pot would be altered so that:

Eq. (18) $pot_{cn(7)} = pot_{cn(6)} + chief\text{-}gift_{cn} - TNG_{cn} - personal\text{-}gift_{cn}$

In summary, the following changes would occur to $stock_{pn}$, $res\text{-}stored_{yn}$ and pot_{cn} during the n^{th} time-step, if n contained a potlatch and $n\text{-}1$ did not:

Sub-step	Patch *p*	Agent *y*	Chief of clan *c*
1	$stock_{pn(1)} = stock_{p(n-1)(4)}$	$res\text{-}stored_{yn(1)} = res\text{-}stored_{y(n-1)(6)}$	$pot_{cn(1)} = pot_{c(n-1)(6)}$
2	$stock_{pn(2)} = stock_{pn(1)} + rate_{pn}$		

[23] TAG_{cn} is the actual amount of resources distributed by clan *c* at a potlatch during the n^{th} time-step (when performing the individual-level analysis). It is the sum of all *actual-gifts* owed to the Titleholders of the guest clan (as determined by the rules in Table 9) plus the *chief-gift* owed to the guest chief (which, at this level of analysis, is always positive).

3	$stock_{pn(3)} = stock_{pn(2)} + (in\text{-}diffusion - out\text{-}diffusion)_{pn}$		
4	$stock_{pn(4)} = stock_{pn(3)} - amt\text{-}extracted_{pn}$	$res\text{-}stored_{yn(4)} = res\text{-}stored_{yn(1)} + amt\text{-}extracted_{pn}$	
5		$res\text{-}stored_{yn(5)} = res\text{-}stored_{yn(4)} - contribution_{yn}$	$pot_{cn(5)} = pot_{cn(1)} + ttlC_{cn}$
6		$res\text{-}stored_{yn(6)} = res\text{-}stored_{yn(5)} - consumption_{yn}$	
7		$res\text{-}stored_{yn(7)} = res\text{-}stored_{yn(6)} + actual\text{-}gift_{yn}$	Host: a) $pot_{cn(7)} = pot_{cn(6)} - clan\text{-}gift_{cn}$ b) $pot_{cn(7)} = pot_{cn(6)} - TAG_{cn}$
			Guest: $pot_{cn(7)} = pot_{cn(6)} + chief\text{-}gift_{cn} - TNG_{cn} - personal\text{-}gift_{cn}$

Table 10 Summary of changes to $stock_{pn}$, $res\text{-}stored_{yn}$ and pot_{cn} when the n^{th} time-step contains a potlatch.

3.1.3 Scenarios: building heterogenous behavior patterns across clans and individuals

This model was designed to address two objectives, the first of which was to re-create the game theory representation of the potlatch with the two clans in the model as the two players in the game.

To create the matrices, the model was designed to output a set of payoffs that would represent the eight potentially unique payoffs in a two-person matrix. To output these payoffs, four scenarios were programmed into the model as another set of options that dictated whether each clan as a whole cooperated or defected in a particular run of the model, with each option essentially representing one of the four possible action profiles in a standard two-player Prisoner's Dilemma matrix.

The programmed scenarios were as follows:

- Mutual Cooperation (clan): all Noranks and Titleholders in both clans extract at cooperative levels and contribute to potlatches. Chiefs, Noranks and Titleholders all receive potlatch gifts.
- Mutual Defection (clan): all Noranks and Titleholders in both clans extract at defecting levels and contribute to potlatches. No members of any rank in either clan receive potlatch gifts.
- Defection – clan 1: Noranks and Titleholders in clan 1 extract at defecting levels and contribute to potlatches. They, along with their chief, do not receive potlatch gifts. Noranks and Titleholders in clan 2 extract at cooperative levels and contribute to potlatches. They, along with their chief, receive potlatch gifts.
- Defection – clan 2: Noranks and Titleholders in clan 2 extract at defecting levels and contribute to potlatches. They, along with their chief, do not receive potlatch gifts. Noranks and Titleholders in clan 1 extract at cooperative levels and contribute to potlatches. They, along with their chief, receive potlatch gifts.

Note that whilst the community structures and conditional extraction rules applied to both clans were identical, the agents' movement patterns (driven by stock-seeking behaviour) in combination with the diffusion process were expected to generate some dynamic environmental heterogeneity across the two territories, which would in turn generate slightly different actual yields and average payoffs at both the individual and clan levels. This did turn out to be the case, as can be seen by the fact that the clan-level matrices in section 4.1 are not symmetrical.

The second objective was to examine how the potlatch mechanisms programmed into the model – namely individual rank (encompassing social status, or title, and behavioral status), contribution of resources and distribution of potlatch gifts – interacted with one another to generate incentives to cooperate, given the behavioral status of the rest of the community and the contribution rule in effect.

Once again, to alter the behavioral status of the community a set of scenarios were programmed into the model in a similar manner as those used for creating the clan-level matrices. However, instead of acting on an entire clan, these scenarios dictated how many *rank-specific individual* cooperators and defectors there would be in a particular run of the model. No changes were made to the number of agents in each clan or rank; only the number of those agents that would be cooperating or defecting. The scenarios were as follows:

- Mutual Cooperation: all Noranks and Titleholders are set to extract at cooperative levels, contribute to potlatches and receive potlatch gifts.
- Mutual Defection: all Noranks and Titleholders set to extract at defecting levels, contribute to potlatches, but receive no potlatch gifts.
- Defection – all Noranks: all Noranks in both clans are set to extract at defecting levels, and all Titleholders in both clans are set to extract at cooperative levels. Both ranks contribute to potlatches, but only Titleholders receive potlatch gifts.
- Defection – all Titleholders: all Noranks in both clans are set to extract at cooperative levels, and all Titleholders in both clans are set to extract at defecting levels. Both ranks contribute to potlatches, but only Noranks receive potlatch gifts.
- Defection – half Noranks: half of each clan's Noranks, chosen at random, are set to extract at defecting levels (and the other half at cooperative levels). All Titleholders are set to extract at cooperative levels. Both ranks, regardless of behavioral status, contribute to potlatches. Defecting Noranks receive no potlatch gifts; cooperating Noranks and Titleholders do receive potlatch gifts.
- Defection – half Titleholders: half of each clan's Titleholders, chosen at random, are set to extract at defecting levels (and the other half at cooperative levels). Both ranks, regardless of behavioral status, contribute to potlatches. Defecting Titleholders receive no potlatch gifts; cooperating Noranks and Titleholders do receive potlatch gifts.

3.3 Model Output: running experiments in NetLogo's Behaviour Space

The NetLogo software package has a function called "Behaviour Space" that allows users to set up experiments with their models, using as many combinations of variables at as many intervals or settings as required. Once all variables and their intervals / settings have been specified, the software will run through the required number of iterations automatically, generating data for thousands of runs of the model and storing it in an excel spreadsheet for analysis. The potlatch model was run using this function to generate the final data used in creating the clan-level matrices and for the analysis of individual incentives.

The nature of these output data, how they were generated and further processed, and how they were applied to produce the results in section 4 will be described in the following sections.

3.3.1 Experiment parameters: re-creating the clan-level payoff matrix

To produce the clan-level payoffs the following variables and intervals were used:

- *%contribution*: varied from 10% to 90%, at 10% intervals
- %potlatch: varied from 10% to 90%, at 10% intervals
- Scenarios: Mutual Cooperation (clan); Mutual Defection (clan); Defection – clan 1; Defection – clan 2
- Contribution rule: Expected Yield; Stored Resources

Two totals of the net stored resources (payoffs) held by all clan members (one total per clan) were produced at the end of each time-step, and were calculated as follows[24]:

Eq. (19) $TtlPayoff_{cn} = NPayoff_{cn} + TPayoff_{cn} + CPayoff_{cn}$

Behaviour Space generates a mean value per run for each output variable, and these *time-averaged* clan-level payoffs are the values used to construct the clan-level matrices. Note that the chief's payoffs were calculated from a personal storage containing the portion of their potlatch gift that they kept for themselves, and not from the clan's pot of collected contributions.

3.3.2 Experiment parameters: understanding incentives at the individual level

To produce individual-level data, the model was run with the following variables and intervals / settings:

- *%contribution*: varied from 10% to 90%, at 10% intervals

[24] Where $TtlPayoff_c$ is the total payoff experienced by clan c in the n^{th} time-step; $NPayoff_c$ is the sum of all payoffs experienced by Noranks of clan c in the n^{th} time-step; $TPayoff_c$ is the sum of all payoffs experienced by Titleholders of clan c in the n^{th} time-step; and $CPayoff_c$ is the payoff experienced by the chief of clan c in the n^{th} time-step.

- %potlatch: varied from 10% to 90%, at 10% intervals
- Mechanism (a.k.a: Scenarios): Mutual Cooperation; Mutual Defection; Defection – all Noranks; Defection – all Titleholders; Defection – half Noranks; Defection – half Titleholders
- Contribution rule: Expected Yield; Stored Resources

The per-capita payoffs for each of the four possible ranks were recorded at the end of each time step of every run, and were calculated as follows[25]:

Eq. (20) $$AvgRank_{rn} = \frac{TtlPayoff_{rn}}{NumAgents_{r}}$$

Once again, the mean values per run of these rank-specific per-capita payoffs – i.e. the average payoff *over time* – are the values used in the analysis of individual incentives.

[25] Where $AvgRank_r$ is the per-capita payoff for rank r at the end of the n^{th} time-step; $TtlPayoff_{rn}$ is the sum of payoffs experienced by all agents of rank r at the end of the n^{th} time-step; and $NumAgents_r$ is the number of agents of rank r in the model during a given run.

4. RESULTS

4.1 Modifications to the Prisoner's Dilemma at the clan level

The clan-level data produced in the Netlogo Behaviour Space (see section 3.3.1) was used to produce 162 sets of payoffs which are presented in full in Tables I and II in Appendix 1. The four matrices in Table 11 (below) show the payoffs produced at the upper and lower limits of the two reciprocity variables *%contribution* and *%potlatch*, and under the two contribution rules %Y and %RS.

%Y %C = 10 | %P = 10		**Clan 1** C	**Clan 1** D
Clan 2	C	380 / 348	161 / 121
	D	120 / 170	133 / 137

%RS %C = 10 | %P = 10		**Clan 1** C	**Clan 1** D
Clan 2	C	602 / 575	168 / 116
	D	116 / 176	127 / 128

%Y %C = 90 | %P = 90		**Clan 1** C	**Clan 1** D
Clan 2	C	3,323 / 3,334	1,011 / 8
	D	7 / 1,049	9 / 9

%RS %C = 90 | %P = 90		**Clan 1** C	**Clan 1** D
Clan 2	C	19,820 / 19,756	1,021 / 8
	D	7 / 953	8 / 8

Table 11 Clan-level payoffs for both contribution rules at the upper and lower limits of two reciprocity variables. *%C and %P represent %contribution and %potlatch respectively. C and D represent the available actions for each player, which are to cooperate (C) or defect (D).*

At *%contribution* = 10 and *%potlatch* = 10 we see that the interaction between Clan 1 and Clan 2 within a potlatch-type system results in a strictly dominant outcome of mutual cooperation, for both contribution rules. At *%contribution* = 90 and *%potlatch* = 90, we see this same strictly dominant outcome of mutual cooperation for both contribution rules, with larger payoffs for cooperation and smaller payoffs for defection.

These matrices support historical evidence that reciprocal systems provide incentives for collectives to cooperate with one another and sustainably extract from the same common-pool resource. They also support the outcomes of Trosper's game theory analysis of the potlatch (2009) in that mutual cooperation is the Nash Equilibrium of the potlatch modification of the Prisoner's Dilemma. From the data presented in this thesis we can additionally see that this is true at all values of *%contribution* and *%potlatch* and under both understandings of how contribution is calculated. This suggests that, at the level of the collective, the potlatch is a highly robust system capable of motivating sustainable resource extraction under a range of conditions.

The matrices in Table 11 differ from Trosper's analysis (2009) in two ways. Firstly, the payoffs are asymmetric (as opposed to symmetric), even though the clans have equal extractive capabilities and access to land. Secondly, the payoffs for each clan in the mutual cooperation cells far exceed the annual cooperative extraction levels of each clan.

There are two phenomena in the ABM that create the payoff asymmetry. Firstly, the agents' movement patterns and the resultant environmental heterogeneity created asymmetries in all payoffs, as expected (see section 3.1.1). This is not necessarily clear in Table 11 as payoffs have been rounded off to the nearest whole number, but it can clearly be seen in Tables I and II in Appendix 1. Secondly, in the cells where one player cooperates and the other defects an exacerbated payoff asymmetry is created by the rule that defecting clans receive no potlatch gifts. This asymmetry increases as *%contribution* and *%potlatch* increase.

That average payoffs in the mutual cooperation cells exceed each clan's extraction levels per time-step is a result of a savings effect. This effect occurs over multiple successive potlatches and would therefore not be observed in analyses that only look at a single iteration of the potlatch. This phenomenon is explained and discussed in more detail in sections 4.2 and 5.1.

4.2 Impact of potlatch mechanisms at the individual level

The following section shows the results calculated from the individual-level output data produced in the Netlogo Behaviour Space (see section 3.3.2). The results produced under each of the six individual-level scenarios are presented in separate sub-sections, and each sub-section contains three figures that show the following data:

- Per-capita payoffs for each rank (time-averaged) vs. *%contribution.*
- Per-capita payoffs for each rank (time-averaged) vs. *%potlatch.*
- Total stock in the model world over time during one run.

Note that 'time-averaged' can be thought of as 'annual', as each time-step in this model is equal to one year. In each of the figures containing per capita payoffs the data produced under the two contribution rules (%RS and %Y) are displayed in separate graphs. In each of these graphs, there are nine trendlines per rank, each keeping *%potlatch* fixed when *%contribution* is on the x-axis and vice versa.

Note that when *%contribution* is on the x-axis, the trendlines are tilted upwards and to the left as *%potlatch* increases. When *%potlatch* is on the x-axis, trendlines belonging to *cooperating* ranks are shifted upwards and in some cases are also tilted towards the left, and those belonging to defecting ranks are shifted *downwards* as *%contribution* increases.

The total stock figures are screenshots taken directly from the Netlogo interface. The data in these figures are not shown separately for the two contribution rules, as they have no differential impact on extraction levels and CPR stock changes over time.

Note that, above certain minimum levels of reciprocity, none of the scenarios apart from mutual cooperation are realistic outcomes if agents in the model could actively choose between cooperation and defection based on best response principles. However, these trivial solutions are still presented and discussed in order to understand what actually makes them trivial, and whether there are any exceptions.

4.2.1 Scenario 1: Mutual Cooperation

The individual-level Mutual Cooperation scenario has all Noranks and Titleholders set to behave cooperatively. This means that they are extracting at their rank-dependent cooperative levels and are receiving gifts during potlatches. At the community level, the maximum possible extraction per time-step (280 units) is therefore slightly lower than the CPR's maximum sustainable yield (288.8 units).

In Figure 2 we see that the combination of behaviours in this scenario prevent CPR depletion from occuring, allowing the community to survive for the full 800 years of a single run. Total stock also grows over time and approaches its maximum because total extraction is slightly lower than the CPR's MSY.

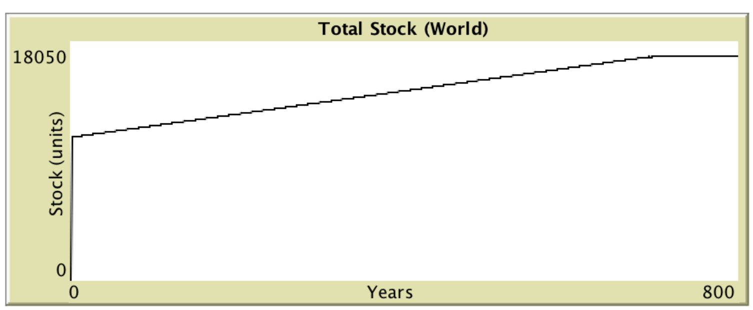

Figure 2 Total stock levels over time for one run of the model under the "Mutual Cooperation" scenario. *Data is not shown separately for the two contribution rules as they have no impact on world stock levels.*

Figure 3 firstly shows that under the Mutual Cooperation scenario cooperating agents experience a *positive* correlation between their average payoffs and *%contribution,* at all levels of *%potlatch* and under both contribution rules. The same savings effect mentioned in section 4.1 is the cause of this trend[26], and the effect itself is the the result of two factors.

Firstly, the losses incurred by increasing contributions to potlatches are balanced out by a corresponding increase in gifts received at potlatches. This is because *%contribution* is the same for both clans at all times – so any increase in *%contribution* causes a simultaneous increase in potlatch distributions across the board.

Secondly, if *%contribution* is increased, average consumption is actually reduced. This happens because the consumption phase is programmed to occur *after* the contribution phase, so relatively fewer resources are left over for consumption when *%contribution* increases.

In the end, with contribution losses cancelled out and average consumption reduced, we see a net increase in average payoffs for all cooperating agents as *%contribution* increases.

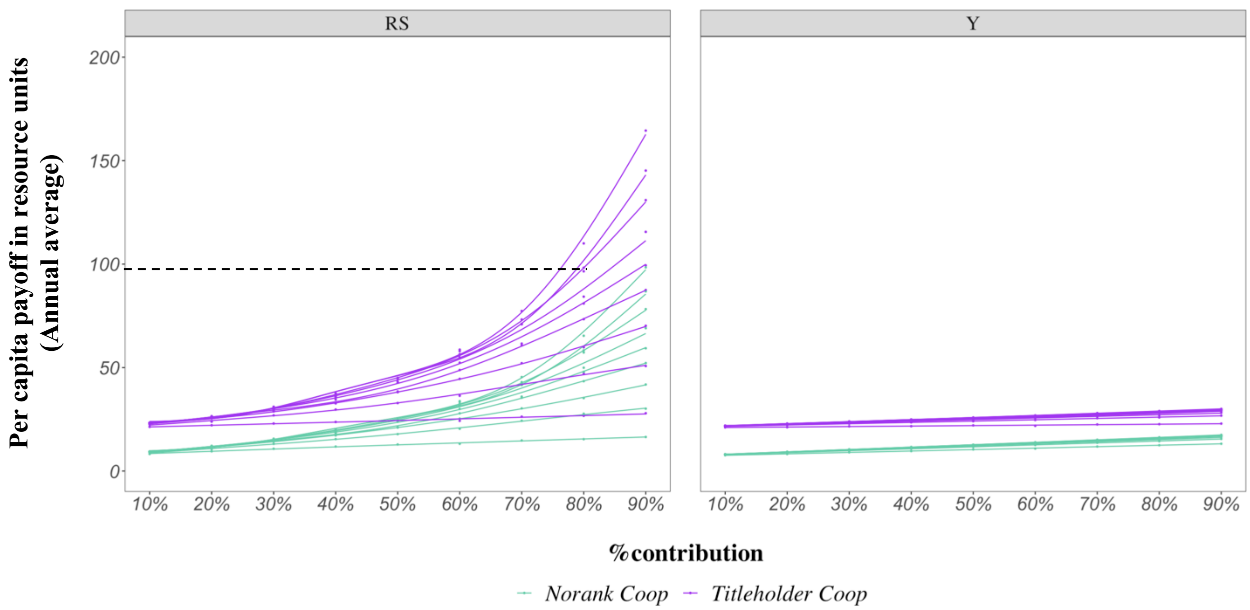

Figure 3 Per-capita payoffs versus %contribution for the individual-level "Mutual Cooperation" scenario under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %contribution for an agent of a certain rank at a fixed level of %potlatch.*

Under the %RS rule this savings effect has a strong impact on average payoffs. Because contribution sizes are dependent on stored resources, the size of contributions, gifts and

---

[26] See Tables III and IV in Appendix 1 for sample data showing how the savings effect impacts agent payoffs at the end of a potlatch, over a series of successive potlatches.

consequently the magnitude of the savings effect, all increase as a run progresses. We can see in Figure 3 and Figure 4 (below) that at high levels of *%contribution* and *%potlatch* this generates average payoffs for each rank that are much larger than their annual extraction levels.

For instance, when *%contribution* and *%potlatch* are each equal to 80%, the average annual payoff for a cooperating Titleholder is approximately 100 resource units (see the dotted line in Figure 3). This figure is nearly five times larger than their annual extraction level of 21 resource units. Note that in this scenario we see the highest cooperator payoffs produced under the %RS rule because there is no CPR depletion to counteract the savings effect. We will see what happens to average payoffs when CPR depletion does occur in scenarios 2 through 5.

The savings effect is weaker under the %Y rule, but it does still create a positive correlation between average payoffs and *%contribution*. This weaker savings effect is a consequence of the decoupling of contribution sizes from stored resources, which causes the savings effect under the %Y rule to stay constant during a single run (as opposed to increasing over time)[27]. This decoupling effect will be discussed in more detail in section 5.2.

Figure 4 shows that *%potlatch* has very little impact on average payoffs at low levels of *%contribution* under the %RS rule (note the trendlines that are flat at nearly all levels of *%potlatch* in the left-hand graph). Under the %Y rule, this is true at all levels of *%contribution.*

---

[27] See Tables V and VI in Appendix 1 for more detailed evidence of the difference in the savings effect between the two contribution rules.

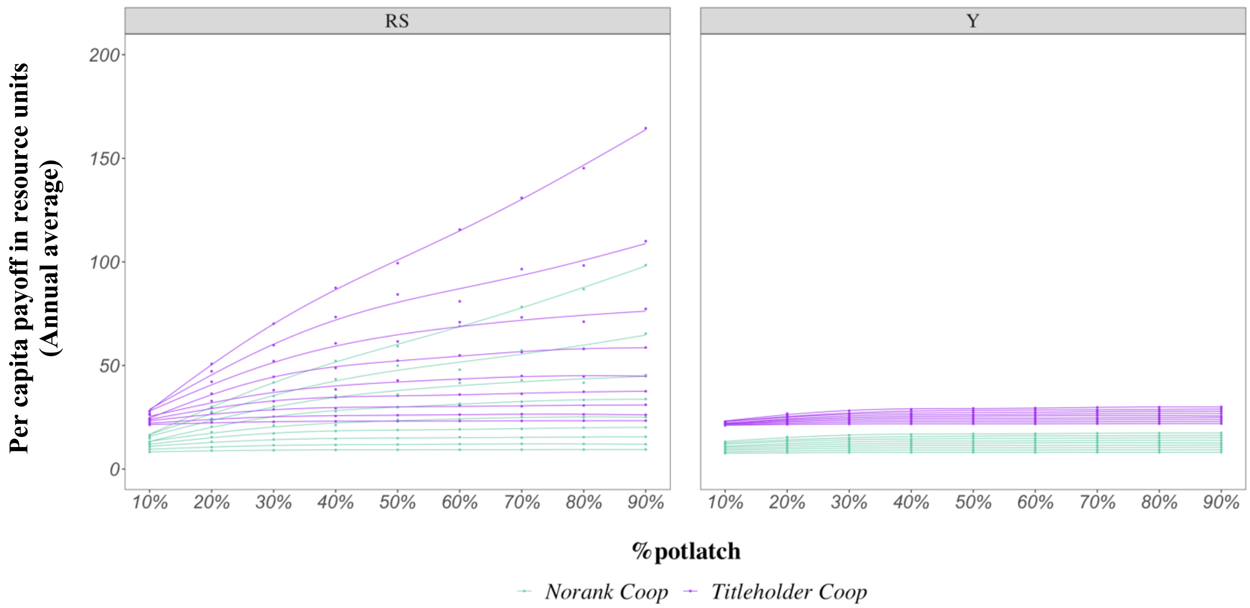

Figure 4 Per-capita payoffs versus %potlatch for the individual-level "Mutual Cooperation" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %potlatch for an agent of a certain rank at a fixed level of %contribution.*

This occurs because all agents are cooperating and all contributions are reciprocated with gifts, so the resource redistribution mechanism contained within the gift-giving process is dormant. In scenarios 2 through 5 we will see that *%potlatch* has a stronger impact on cooperator payoffs when there are defectors in the system, and the redistribution mechanism actively shifts resources from defectors to cooperators (refer back to section 2.4.2 for a detailed explanation of this mechanism).

4.2.2 Scenario 2: Defection – half Noranks

In this scenario we now have 4 of the 8 Noranks in each clan exhibiting defecting behaviour by extracting at non-cooperative levels, and consequently receiving no potlatch gifts. The addition of this defecting behaviour increases the community's maximum extraction level per time-step to 304 units, which exceeds the CPR's MSY (288.8 units).

Figure 5 shows that this generates CPR depletion in the model, as expected. The model's stop condition is triggered well before the 800-year time period is over, signaling the system's collapse.

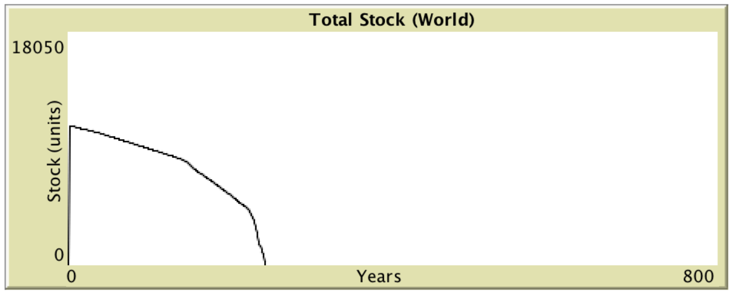

Figure 5 Total stock levels over time for one run of the model under the "Defection – half Noranks" scenario. *Data is not shown separately for the two contribution rules as they have no impact on world stock levels.*

We can see in Figure 6 that, unlike cooperating agents, defecting Noranks experience annual average payoffs that are *lower* than their annual extraction levels (represented by the dotted line on both graphs in Figure 6), and are *negatively* correlated with *%contribution*. This is a result of the condition that defecting agents receive zero potlatch gifts, which means that the savings effect cannot counteract the losses that they incur during the contribution phase to increase their average payoffs.

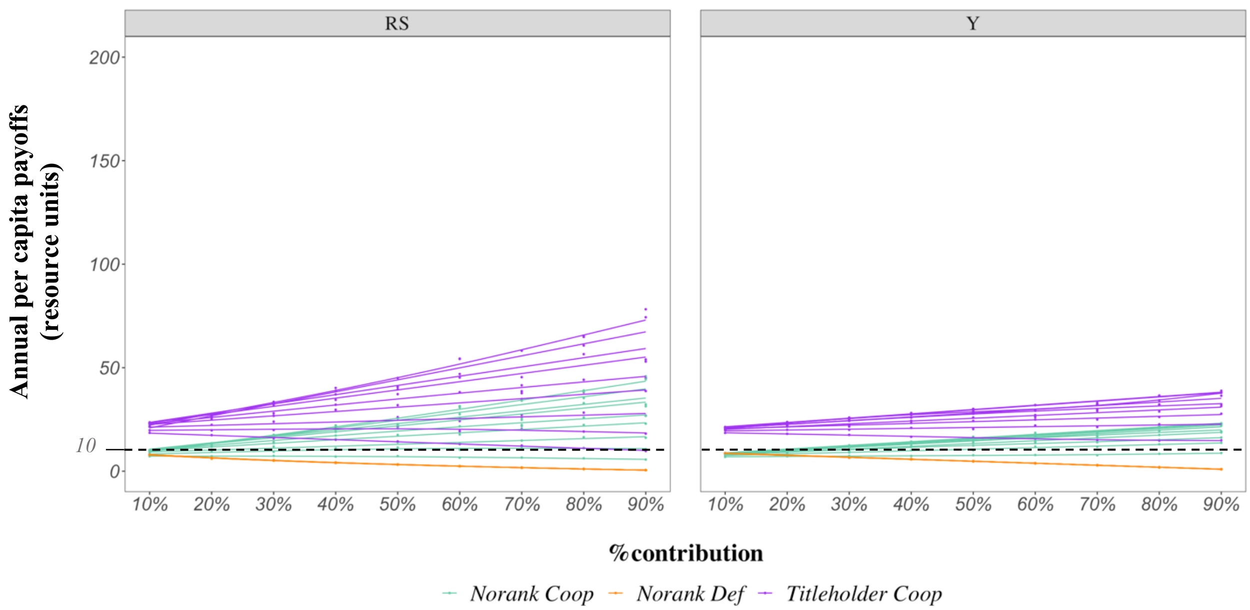

Figure 6 Per-capita payoffs versus %contribution for the "Defection – half Noranks" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %contribution for an agent of a certain rank at a fixed level of %potlatch.*

We also see in Figure 6 that a minimum of 20-30 *%potlatch* is now required for average payoffs to cooperators to be positively correlated with *%contribution* (under both contribution rules). In scenario 1, no minimum was required (see Figure 3). This occurs because the behavioral combinations in this scenario generate extraction levels that exceed the CPR's MSY, so the savings effect must now combat payoff losses due to contribution *and* CPR depletion.

We see further evidence of the impact of CPR depletion in the form of reduced average payoffs for cooperators under the %RS rule. Figure 6 and Figure 7 also show us that average payoffs for cooperating agents are lower in comparison to those seen in Figure 3 and Figure 4 (Mutual Cooperation). Under the %Y rule, however, average payoffs to cooperating agents are higher in *this* scenario, especially at high levels of *%contribution* and *%potlatch*. This relative increase can be explained by two phenomena.

Firstly, the decoupling effect mentioned in scenario 1 can mask extractive losses caused by CPR depletion even when depletion is reducing actual yields. If agents have accumulated enough resources, then under the %Y rule they can contribute their full expected amount for a number of time-steps. This means that the savings effect is not as severely weakened by depletion as it is under the %RS rule.

Secondly, when defectors are added to the system potlatch gifts to cooperating agents can increase in size. This can occur because the redistribution mechanism is shifting resource amounts from defectors to cooperators that have not been reduced by CPR depletion because of the decoupling effect.

Combining the masking of losses due to depletion with the larger potlatch distributions then results in cooperating agents receiving higher average payoffs when there are some defectors in the system, under the %Y rule.

Under the %RS rule these comparatively higher payoffs are *not* perceived because even though the redistribution mechanism is active, contribution sizes are coupled to the agents' stored resources so CPR depletion cannot be not masked once it impacts actual yields.

In this scenario we find that *%potlatch* now has a stronger impact on average cooperator payoffs because defection has been added to the system. We can see evidence of this in Figure 7, where *%potlatch* has a positive correlation with average payoffs at a much wider range of *%contribution* than it does in Figure 4.

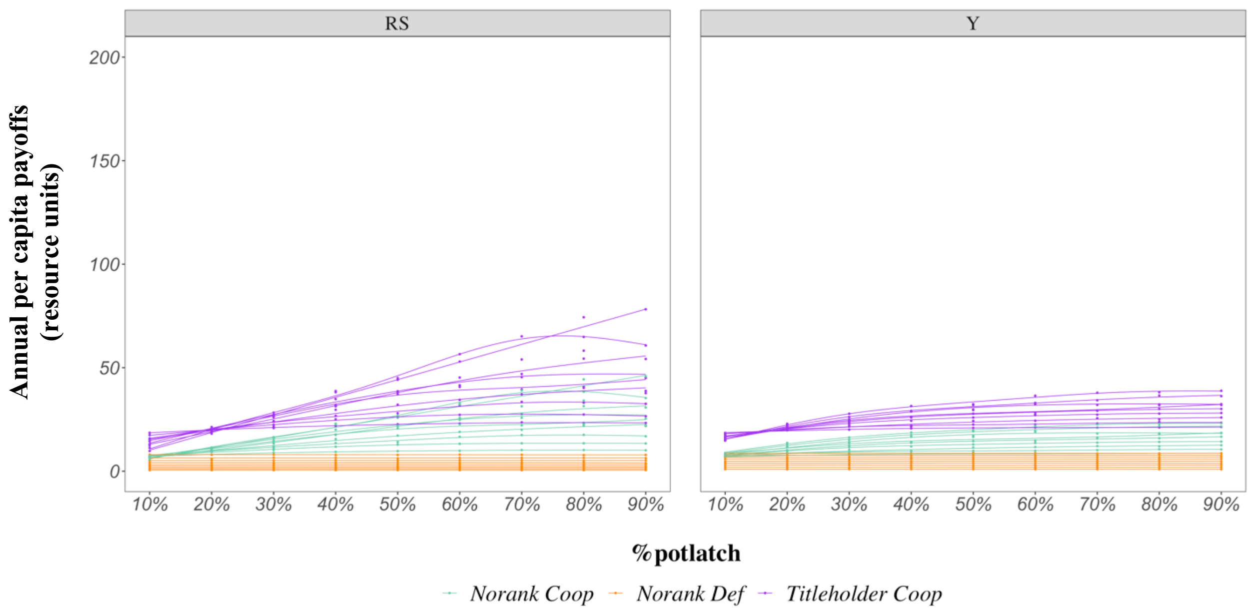

Figure 7 Per-capita payoffs versus %potlatch for the "Defection – half Noranks" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %potlatch for an agent of a certain rank at a fixed level of %contribution.*

As we already know, this is because the redistribution mechanism is actively shifting resources from defectors to cooperators during the potlatch. Figure 7 also shows for the first time that average payoffs for defectors have no relationship with *%potlatch.* This is due to the condition that defecting agents receive no potlatch gifts, which is linked to, or part of, the redistribution mechanism[28].

4.2.3 Scenario 3: Defection – all Noranks

In this scenario we have all Noranks in both clans set to exhibit defecting behaviour. All Noranks therefore extract at their defecting level and receive zero potlatch gifts. As is the case in the previous scenario, the community's maximum extraction level per time-step (328 units) exceeds the CPR's MSY (288.8 units).

As a result we again see CPR depletion and system collapse occuring within the 800-year run time in Figure 8. We also find that increasing the number of defecting Noranks increases the

[28] Future work will investigate if this pattern holds when defecting agents are programmed to receive gifts and then hold apology potlatches, instead of simply receiving no gifts.

rate of CPR depletion, causing system collapse to occur earlier than it does in Figure 2 and Figure 5.

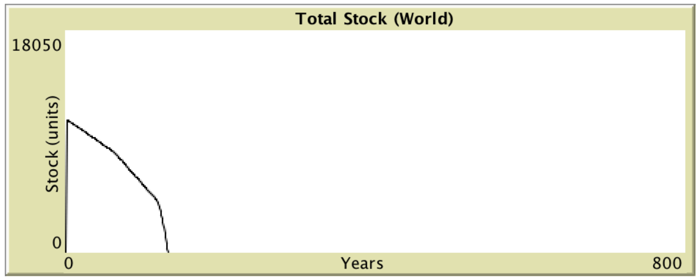

Figure 8 Total stock levels over time for one run of the model under the "Defection – all Noranks" scenario. *Data is not shown separately for the two contribution rules as they have no impact on world stock levels.*

Figure 9 shows us that with more defecting agents in the system, even higher minimum levels of *%potlatch* are required for *%contribution* to have a positive correlation with average payoffs for cooperating Titleholders. This is because the increase in defecting behaviour increases the rate of CPR depletion, which then counteracts the savings effect even more than it does in the previous scenario.

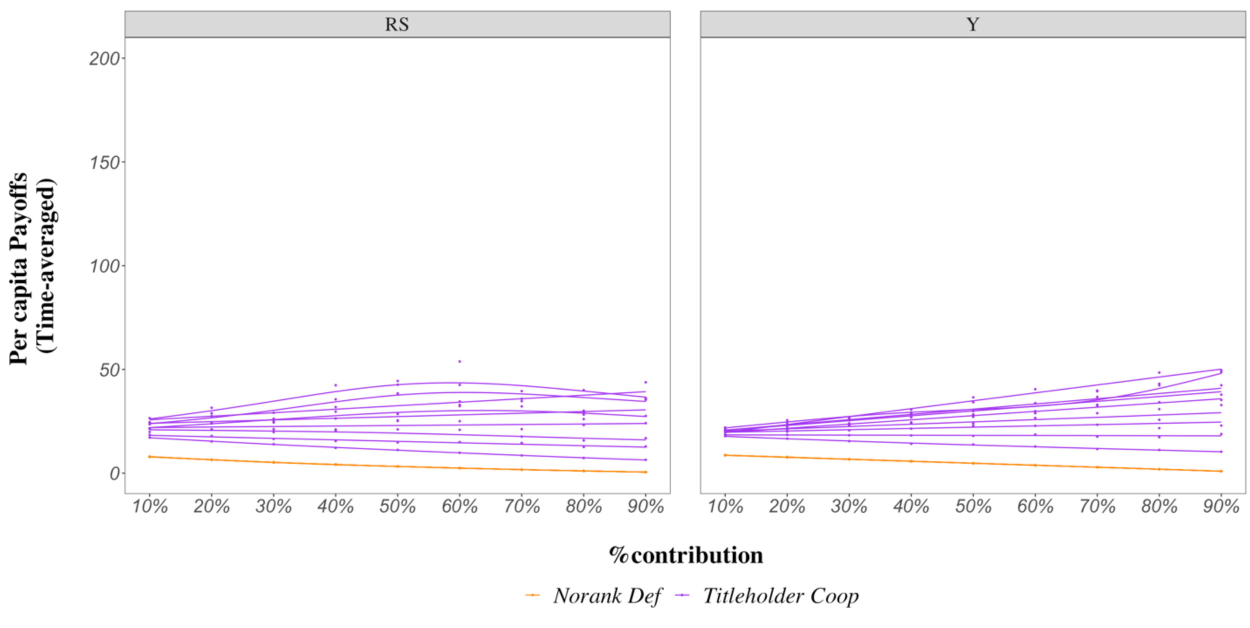

Figure 9 Per-capita payoffs versus %contribution for the "Defection – all Noranks" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %contribution for an agent of a certain rank at a fixed level of %potlatch.*

For this same reason, under the %RS rule cooperating Titleholders suffer higher losses when more Noranks defect. This can be seen in both Figure 9 and Figure 10, where average payoffs for cooperating Titleholders are lower than those found in Figure 6 and Figure 7[29].

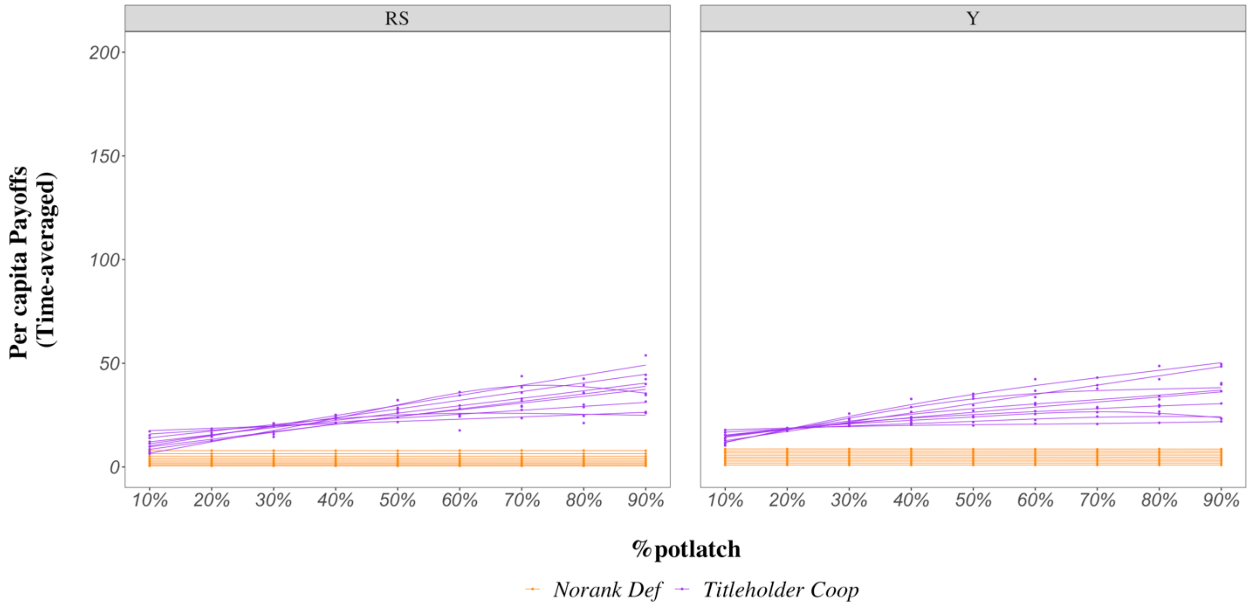

Figure 10 Per-capita payoffs versus %potlatch for the "Defection – all Noranks" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %potlatch for an agent of a certain rank at a fixed level of %contribution.*

Under the %Y rule however, cooperating Titleholders suffer fewer losses when more Noranks defect, particularly at high levels of *%contribution* and *%potlatch*[30]. Figure 9 and Figure 10 show us average payoffs for cooperating Titleholders are even higher in this scenario than they are in scenario 2 (Figure 6 and Figure 7). With more Noranks defecting the decoupling effect is creating even larger potlatch gifts whilst still masking the losses caused by depletion, in fact generating the *highest* average payoffs for cooperating Titleholders seen under the %Y rule.

[29] Note that in scenarios 3 and 4 we see an unusual parabolic trendline with inflection points between 50-70 *%contribution* when *%potlatch* is at 80% (Figure 6) and 90% (Figures 6, 8 and 9). The exact causes of these inflection points are unknown and will require more detail to be added to the model in future work.

[30] This result may seem to counteract the previous statement that overall payoffs for the community are lower in this scenario; however, the community-level losses under the %Y rule are borne primarily by the larger number of defecting agents.

4.2.4 Scenario 4: Defection – half Titleholders

This scenario has 2 out of the 4 Titleholders in each clan set to extract at defecting levels, and to consequently receive zero potlatch gifts. The community's maximum extraction level per time-step is therefore 316 units, which exceeds the CPR's MSY of 288.8 units.

Although the community's annual extraction level is higher in this scenario than it is in scenario 2 (Defection – half Noranks), Figure 11 shows that system collapse occurs later in *this* scenario, even though the rate of depletion before the turning points in Figure 8 and Figure 11 are very similar.

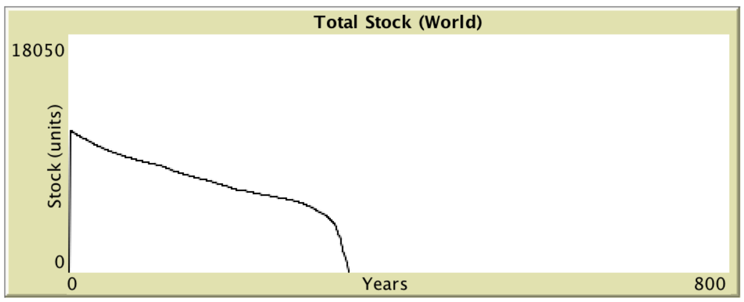

Figure 11 Total stock levels over time for one run of the model under the "Defection – half Titleholders" scenario. *Data is not shown separately for the two contribution rules as they have no impact on world stock levels.*

This delayed collapse is a consequence of the fact that *actual* yields are limited by available stock levels on the patches. Once these stock levels are reduced below the expected yield of defecting Titleholders, total extraction is curbed because agents can only move and extract once per time-step. The comparatively smaller number of defecting agents then delays the system's collapse.

The similar rates of CPR depletion in this scenario and scenario 2 means that the minimum levels of *%potlatch* required to generate positive correlations between payoffs and *%contribution* are approximately the same in Figure 12 and Figure 6.

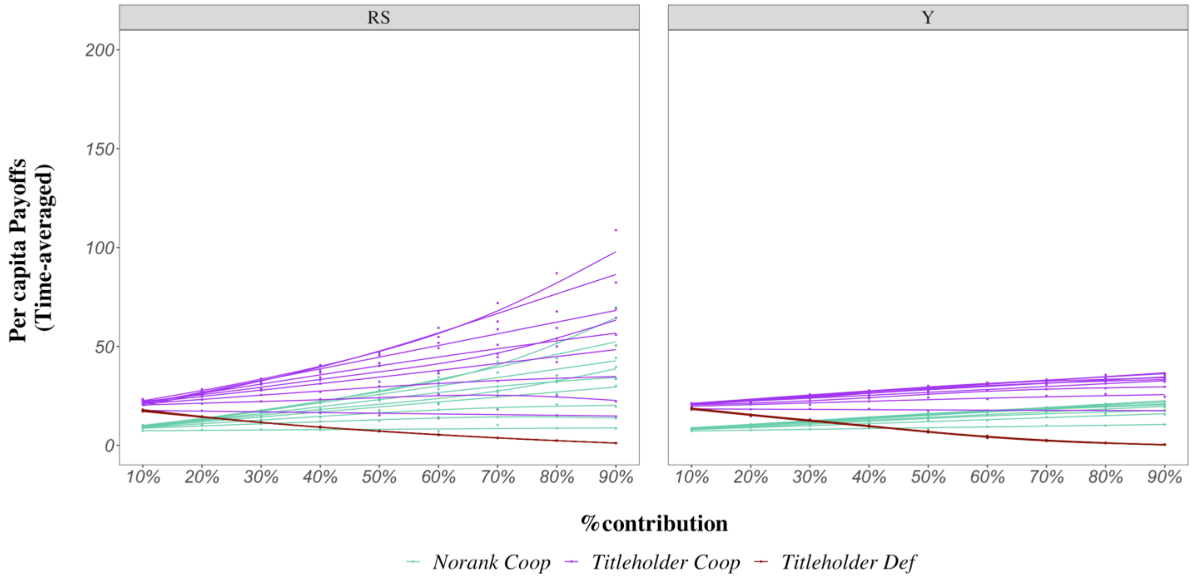

Figure 12 Per-capita payoffs versus %contribution for the "Defection – half Titleholders" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %contribution for an agent of a certain rank at a fixed level of %potlatch.*

The delayed collapse in this scenario, however, does allow cooperating agents to have slightly higher average payoffs than in scenario 2, under the %RS rule. This can be seen by comparing Figure 12 to Figure 7 (or Figure 13 to Figure 6). This happens firstly because agents have more time to accumulate resources and benefit from the strong savings effect. Additionally, 4 defecting Titleholders can extract and contribute 1.5 times the amount of resources that 8 defecting Noranks can, so the redistribution mechanism shifts more resources to cooperating agents in this scenario than it does in scenario 2.

However, under the %Y rule payoffs to cooperating agents are approximately equal to those produced under scenario 2. This is primarily because of the weaker savings effect, which lessens the impact of having more time to accumulate resources. It also reduces the impact of the redistribution mechanism because fewer resources are contributed to potlatches and shifted to cooperators in the long run.

We can see in Figure 12 and Figure 13 that when Titleholders defect they can receive higher payoffs than cooperating Noranks if *%contribution* and *%potlatch* are too low. However, above those low levels of reciprocity defecting Titleholders receive lower average payoffs than *all* cooperating agents, regardless of their rank. This result is an important characteristic of this system and its redistribution mechanism, and will be discussed in more detail in section 5.2.

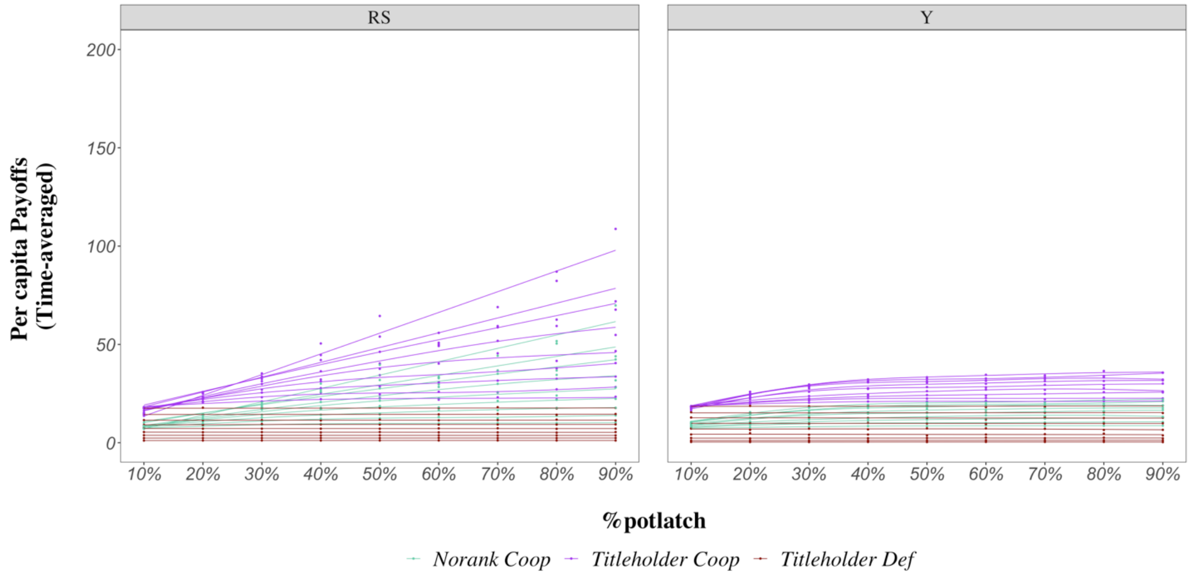

Figure 13 Per-capita payoffs versus %potlatch for the "Defection – half Titleholders" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %potlatch for an agent of a certain rank at a fixed level of %contribution.*

Finally, we find that *%potlatch* has a stronger impact on cooperator payoffs when defecting agents are of a higher rank. We can see evidence of this by comparing the slope of the trendlines belonging to cooperating agents in Figure 13 to those in Figure 7 and Figure 10. This is once again due to the redistribution mechanism having a larger impact when the defecting agents are extracting and contributing at high levels. Remember that this mechanism is contained within the gift distribution mechanism and hence the *%potlatch* variable.

4.2.5 Scenario 5: Defection – all Titleholders

In this scenario we have all 8 Titleholders in the community extracting at defecting levels and receiving zero potlatch gifts. The community's maximum extraction per time-step is therefore 352 units, which exceeds the CPR's MSY of 288.8 units.

Figure 14 shows that initially, with more Titleholders defecting, the rate of CPR depletion is higher in comparison to Figure 11. However, the rate of depletion slows down early in the run, after which total stock almost plateaus for a long time before suddenly reaching a tipping point that leads to the system's collapse. The exact reason for this plateau and extended delay with *additional* defecting Titleholders is still to be determined, and will be explored in future versions of the model with additional output variables.

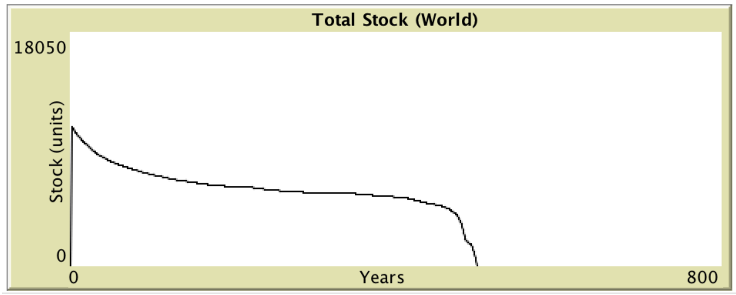

Figure 14 Total stock levels over time for one run of the model under the "Defection – all Titleholders" scenario. *Data is not shown separately for the two contribution rules as they have no impact on world stock levels.*

We can see in Figure 15 (and Figure 16) that when more Titleholders choose to defect, cooperating Noranks receive much higher payoffs under both contribution rules. This increase can be explained by the longer delay to the system's collapse, which allows agents in this scenario to have even more time to accumulate resources and benefit from the savings effect.

Additionally, the long plateau followed by the sudden collapse in stock levels means that CPR depletion only severely impacts payoffs for a very short time in this scenario. CPR depletion therefore does not have an increased impact on average payoffs in comparison to scenario 4, despite the larger number of defectors.

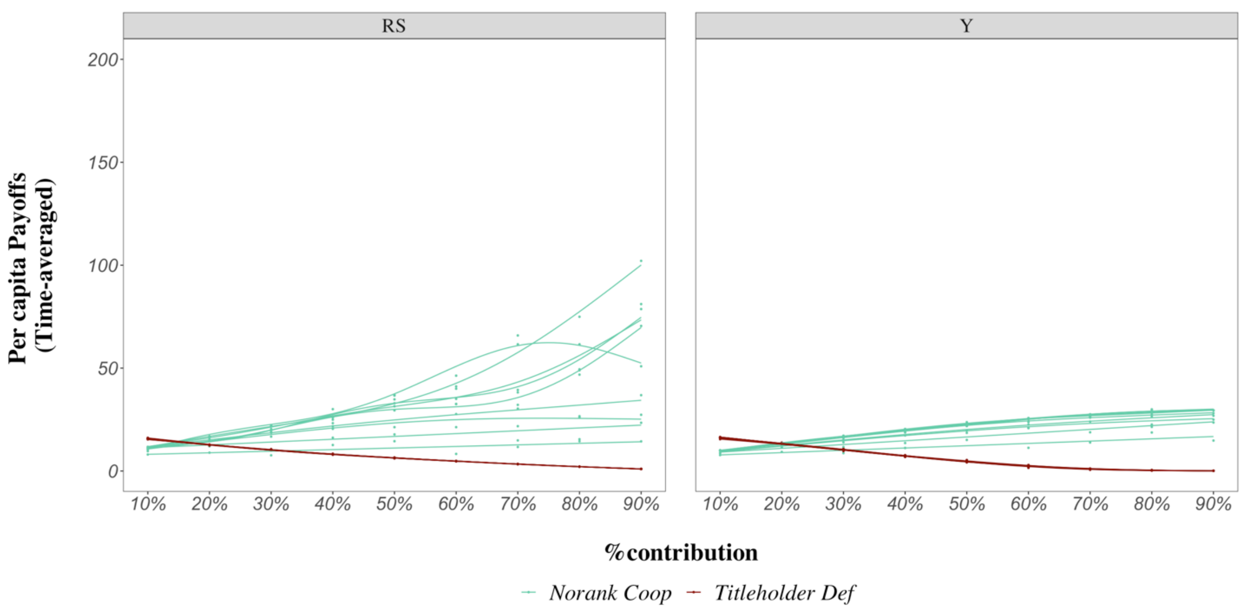

Figure 15 Per-capita payoffs versus %contribution for the "Defection – all Titleholders" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %contribution for an agent of a certain rank at a fixed level of %potlatch.*

The redistribution mechanism also has an increased impact on average payoffs with more defectors in the system in comparison to scenario 4. Evidence of this can be seen in Figure 16, where *%potlatch* has a slightly stronger impact on cooperating Norank payoffs relative to Figure 13 (once again this can be seen by comparing the slope of the trendlines belonging to Norank cooperators in both Figures).

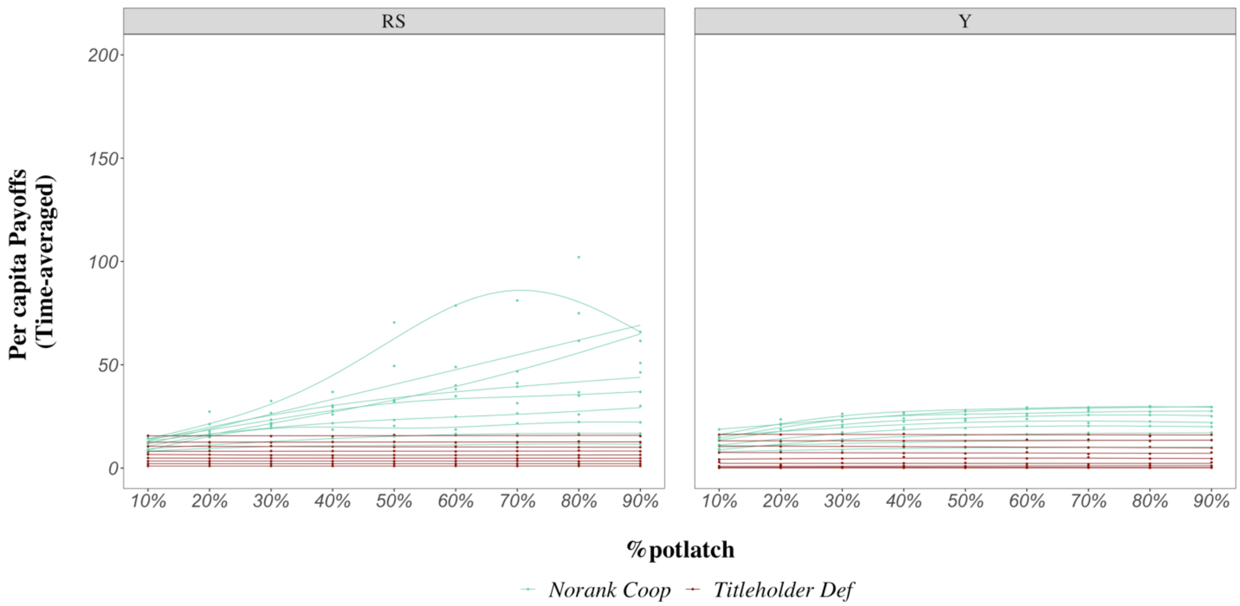

Figure 16 Per-capita payoffs versus %potlatch for the "Defection – all Titleholders" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %potlatch for an agent of a certain rank at a fixed level of %contribution.*

With scenarios 2 through 5 explored, we can now see that under the %RS rule defecting Noranks create larger losses for the community than defecting Titleholders do. This is important to note because, in practice, Titleholders have some power over the extractive behaviour of the clan – and this pattern suggests that the potlatch creates incentives for Titleholders to use that power appropriately and assist the chief in properly managing extraction.

Under the %Y rule however, cooperating Titleholders experience the highest average payoffs under the "Defection – all Noranks" scenario. Once again, because they have some power over the clan, this scenario has the potential to become a possible outcome.

However, remember that the per capita payoff figures produced by the model are *time-averaged* and hence do not reflect the fact that the system also collapses the earliest under this scenario (after the Mutual Defection scenario). Future work would benefit from examining total payoffs as well as average payoffs for a more holistic picture of resource-based incentives.

4.2.6 Scenario 6: Mutual Defection

In this final scenario, all Noranks and Titleholders are set to extract at defecting levels, and none of them receive potlatch gifts. The community's maximum extraction per time-step is at its highest level possible of 400 units, far exceeding the CPR's MSY of 288.8 units.

This level of extraction, as expected, creates the fastest rate of decline seen in all the scenarios, as well as the earliest system collapse. This can clearly be seen in Figure 17.

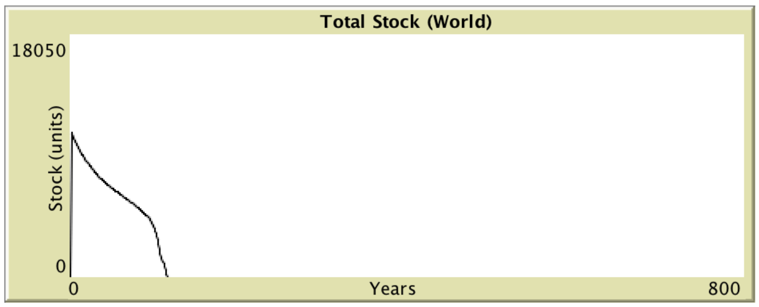

Figure 17 Total stock levels over time for one run of the model under the individual-level "Mutual Defection" scenario. *Data is not shown separately for the two contribution rules as they have no impact on world stock levels.*

In Figure 18 we can clearly see that increasing *%contribution* leads to reduced average payoffs for defectors of all ranks, as we have seen in scenarios 2 through 5. As explained in section 4.2.2, this is because defecting agents cannot benefit from the savings effect that reverses this trend for cooperating agents.

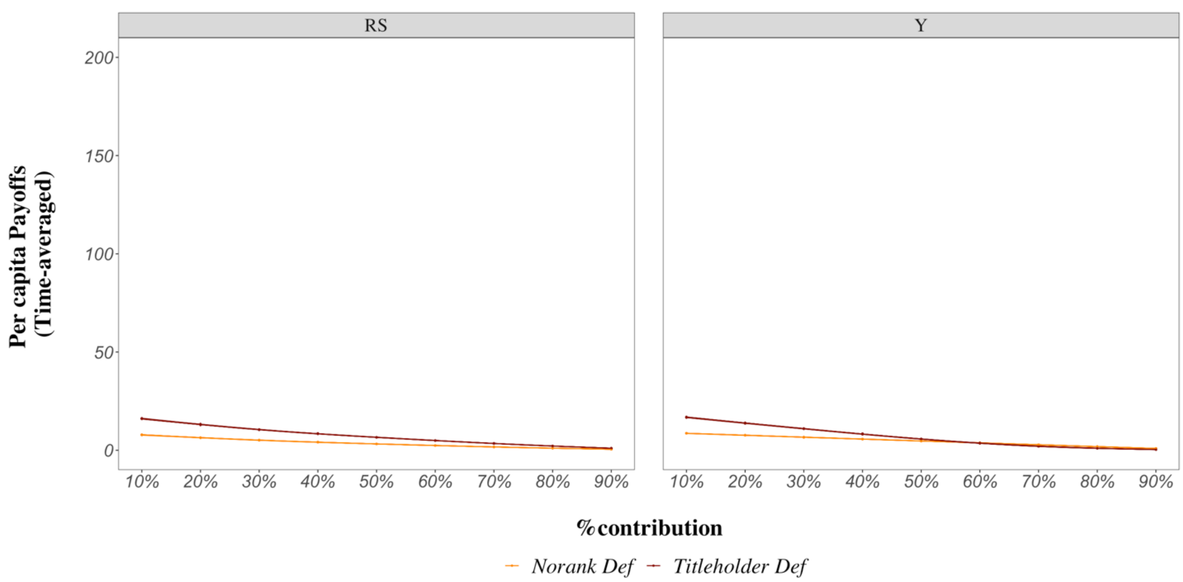

Figure 18 Per-capita payoffs versus %contribution for the individual-level "Mutual Defection" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %contribution for an agent of a certain rank at a fixed level of %potlatch.*

A comparison of the trendlines in Figure 18 and Figure 19 to the trendlines for defecting agents in any of the previous scenarios will show that defecting agents receive nearly identical average payoffs regardless of the rate of CPR depletion. This suggests that the low average payoffs received by defectors are primarily dependent on the condition that defectors receive no potlatch gifts.

Once again, *%potlatch* has no impact on average payoffs for defecting ranks, as can clearly be seen in Figure 19. This is also a consequence of defectors receiving zero potlatch gifts.

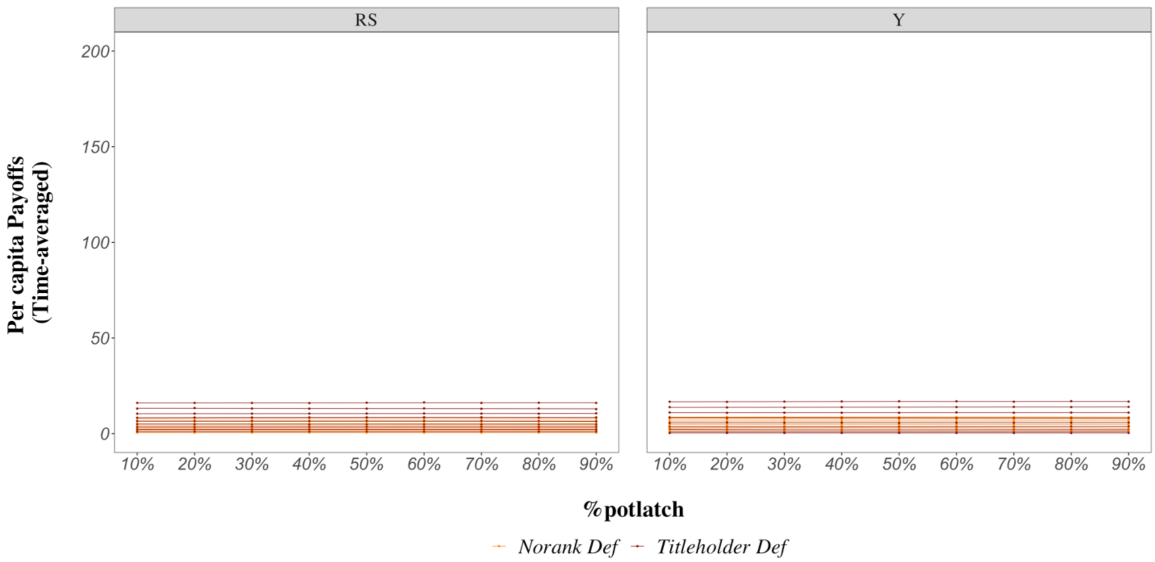

Figure 19 Per-capita payoffs versus %potlatch for the individual-level "Mutual Defection" scenario, under the %RS and %Y contribution rules. *Each trendline shows how per capita payoffs vary with changes in %potlatch for an agent of a certain rank at a fixed level of %contribution.*

5. DISCUSSION

5.1 Clan-level Agent-Based Model of the potlatch

The results of the clan-level model indicate that the mere presence of a resource management system based in reciprocity can shift equilibrium outcomes in common-pool resource problems from mutual defection to mutual cooperation at the level of the collective.

However, that *any* level of reciprocity works is conditional on the existence of some form of punishment for defecting clans, which in this model is that defectors receive no potlatch gifts. This condition is the result of the assumption that the resources that a defector would be required to give to the community at the required apology potlatch would be at least equal to if not larger than any potlatch gifts received in that time step (see section 3.1.2). Without this punishment there would be no redistribution mechanism, and the reciprocity modeled in the ABM would be less comprehensively effective. A strict minimum level of *%contribution* and *%potlatch* would be required to guarantee the shift to mutual cooperation. Hence the concept of the apology potlatch – or any other type of redistribution mechanism – is a very effective resource-based enforcement mechanism.

In practice, the potlatch system also makes use of highly contextual punishments involving social capital to additionally motivate cooperation, which lessen the need to accurately identify and adhere to reciprocity thresholds in practice. However, this review and analysis of the collective action system necessarily glosses over many of the highly complex and story-rich cosmologies, mythologies and religions of these cultures and their role in the creation of the traditions and rituals that were included in the model. This is because such qualitative and irreducible elements cannot adequately be modelled in the quantitative spaces used in this analysis. Additionally, they are uniquely specific to the Northwest Coast Nations and would not be transferable to a more generalized model of collective action systems.

However, it is important to acknowledge the contribution of these elements to the success of sustainability in Indigenous lands. It is also important to acknowledge that without them, there *is* a possibility that the ranking system would not be as important to the communities, and thus not as effective at enforcing the reciprocity that the collective action system is based on.

5.2 Summary of main findings: Individual-level ABM of the potlatch

The results from the individual-level ABM provide some insight into how the various potlatch mechanisms impact payoffs and incentives at the individual level, so that the collective-level outcome of mutual cooperation can occur. This section will summarize the main findings from section 4.2 that illustrate these mechanisms and their impacts, as well as findings that show how different types or combinations of defecting behaviour impact the pattern of CPR depletion (or growth).

5.2.1 The composition of individual behaviours differentially impacts CPR abundance

Figure 2 shows that when there is mutually cooperative behaviour at the individual level and thus extraction is sustainable, there is no depletion of the CPR. In fact, with the community's total level of extraction programmed to be slightly lower than the CPR's MSY, we see growth in total stock over time, leading to an abundance of the resource.

In all other scenarios however, the CPR is depleted and the system collapses. The rate of depletion and the timing of this collapse differs in these scenarios depending on the combination of behaviours exhibited by the agents. Overall, three main trends can be identified:

a) As the number of defecting Noranks increases (with all Titleholders cooperating) the rate of CPR depletion increases, and system collapse occurs earlier in the run.
b) As the number of defecting Titleholders increases (with all Noranks cooperating) the rate of CPR depletion increases only at the beginning of the run, and system collapse occurs *later* in the run.
c) In both scenarios that have Noranks defecting, system collapse occurs earlier than it does in *either* of the scenarios that have Titleholders defecting.

These patterns suggest that the number of defecting agents in the system has more impact on the rate of CPR depletion than both the extraction level (or rank) of those agents and the community's maximum extraction level[31], although rank still creates important variability. If we

[31] Note that in this model the available stock levels in the patches also places a strong limit on actual yields, especially for those agents with very high expected yields. This contributes to the relative importance of the number of defectors over their rank. Future work should see if this pattern will change if agents can extract from more than one patch during a time-step.

reframe this pattern in terms of CPR *availability*, we find that these results provide evidence in support of the theory of critical mass in the context of collective action (Marwell and Oliver, 1993; Oliver et al., 1985).

The main idea behind critical mass theory is that some minimum number of participating (i.e. cooperating) agents is required for a collective system to become viable, and that the more agents participate in a collective, the more successful it will be at generating abundance (Oliver et al., 1985). A comparison of the total stock graphs throughout section 4.2 shows that the number of cooperating agents (i.e. participants) is indeed positively correlated with the long-term availability of resources in the environment, and that there is a critical mass of cooperators that generates growth in total stock levels. Given the community's rate of extraction, this critical mass is nearly all of the extractive agents in the system (nearly, because total cooperative extraction is slightly less than the CPR's MSY).

Now, our results also show that there is a separate critical mass at the level of generating abundance for the group. The critical mass of cooperators at this level is more complicated to define, as it varies with the chosen values of *%contribution* and *%potlatch*. In general however, we can define the critical mass for payoff abundance at a given level of reciprocity as *the number of cooperators that exist when the per capita payoff for each cooperative rank is higher than their per capita payoff would be as a defector*. At this point, the system is generating abundance for each individual beyond what they could achieve on their own, and the collective is viable in terms of group abundance.

We see different patterns in abundance generation under the different contribution rules:

1. %RS rule: a comparison of the per capita payoff graphs in section 4.2 shows that, overall, average payoffs (for cooperating agents) are positively correlated with the number of cooperating Noranks, but negatively correlated with number of cooperating Titleholders (when there is defection in the system). Here we see evidence of the claim that group heterogeneity is a key facet of determining the "probability, extent, and effectiveness of collective action" (Oliver et al., 1985, 524).
2. %Y rule: overall, average payoffs (for cooperating agents) are *negatively* correlated with the number of cooperating agents. This does not mean that there is no critical mass under the %Y rule. Rather, it means that the highest payoffs for

cooperating agents exist at the critical mass of cooperators, instead of above it. This is problematic, because the critical mass for environmental abundance does not converge with the critical mass for group abundance.

5.2.2 The savings effect generates abundance for cooperating agents

The relative payoff losses that cooperating agents experience when contribution sizes increase are counteracted by the savings effect in the long term to produce average payoffs that have a positive correlation with *%contribution* instead of a negative one. The savings effect exists due to a combination of two phenomena:

a) *%contribution* increases across runs for both clans simultaneously, allowing the losses from increased contributions to be cancelled out by corresponding increases in potlatch gift sizes.
b) Consumption occurs after contribution, so as *%contribution* increases across runs average consumption per run decreases.

The savings effect is an important mechanism because it ensures that the potlatch system is effective at wide ranges of both reciprocity variables. It is also the mechanism that allows the potlatch to actually generate abundance in CPR situations, which are typically understood to create scarcity instead.

In particular, we see that reduced or limited consumption is the key to this generation of abundance. This outcome supports findings from multiple ethnographic texts that are explored by Marshall Sahlins in *Stone Age Econonics* (2017). In this book, Sahlins details the economic systems of a wide range of Indigenous communities across the globe, describing the abundance of resources in the communities and their lands, and how this abundance is linked to their limited consumption (Sahlins, 2017). Essentially, labour output in many communities[32] was observed to be only as high as was required to sustain the community, because consumption in these cultures was a means of survival, not of gaining status (Grey, 1841; Lee, 1969; Oliver, 1949; Sahlins, 2017; Woodburn, 1968). Furthermore, many Indigenous communities defined 'wealth' by the

[32] Examples given included the San People of the Kalahari, the Siuai of Solomon Islands, the Aboriginals of western Australia, and the Hadza of Tanzania, among many others.

productivity and richness of their lands, and would limit consumption to ensure that this expression of wealth was sustained (Halpin and Seguin, 1990; Miller, 1997). Limiting consumption was in turn found to generate "a surprising abundance" (Lee, 1969, 59) of resources, even in highly arid environments, and a further great abundance of resources in the communities themselves (Eyre, 1845; Grey, 1841; Lee, 1969; Sahlins, 2017). Thus the limiting of consumption was determined to be an important factor in the long survival and success of these communities, prior to colonisation of their traditional lands (Sahlins, 2017).

Understanding the importance of the savings effect and limited consumption leads us to a divergence between the two contribution rules. Under the %RS rule, the savings effect is quite strong and significantly increases average payoffs at high levels of reciprocity. This is possible because contributions and distributions are dependent on stored resources, and therefore increase as agents accumulate resources during a single run. The savings effect therefore increases in magnitude within *and* across runs.

Under the %Y rule however, the savings effect is only strong enough to generate small increases in average payoffs as *%contribution* increases. This weakened savings effect occurs because of the decoupling effect. As contributions and distributions are dependent on expected yield only, they do not increase as agents accumulate resources. The savings effect therefore remains constant within a single run, generating far smaller gains in average payoffs in comparison to the %RS rule, both within a run and across runs as *%contribution* increases[33].

The divergence between the two contribution rules suggests that a system like the potlatch is more successful at generating abundance when contributions to the reciprocal resource exchange are calculated using what individuals have, instead of what they earn in a given time period.

The 'Defection – all Noranks' scenario is an exception to this divergence, and it is a combination of the decoupling effect and the early system collapse (Figure 8) that closes the gap between the two contribution rules (see Figure 9 or Figure 10). The decoupling effect results in relatively high payoffs for cooperating Titleholders under the %Y rule, because losses due to

---

[33] See Tables III and IV in Appendix 1 for sample run data showing this difference between contribution rules.

depletion are masked and potlatch gifts are larger with many defecting Noranks in the community. The early system collapse results in relatively low payoffs under the %RS rule, because there is little time for the savings effect to increase in magnitude and additionally CPR losses due to depletion are not masked.

5.2.3 The redistribution mechanism adds vigor to reciprocal systems

In all scenarios where the community is comprised of a mix of defecting and cooperating behaviours (scenarios 2 through 5) we can see that the redistribution mechanism is active. We also find that the impact of this mechanism on cooperator payoffs increases with higher totals of defector contributions, and therefore is proportional to the number and rank of defecting agents.

Recall that this mechanism is contained within the programmed rules of the gift distribution phase of the model, and represents the impact of the apology potlatches through the following model conditions:

a) Defectors do not receive potlatch gifts.
b) Gifts meant for defectors are recycled into a chief's pot, increasing the size of gifts to cooperators in future potlatches (provided depletion does not counteract the increase).

In this way, defectors are punished for their behaviour, and cooperators are compensated for any losses they have or will experience due to the depletion that the defectors caused.

This redistribution mechanism has a number of important impacts on payoff patterns at the individual-level. The first, and arguably most important, is that it very effectively prevents defecting agents from benefitting from higher extraction levels in comparison to cooperating agents of the same rank. In Figure 6 and Figure 12, we see that average payoffs for defectors are never higher than those for cooperators of the same rank, regardless of contribution rule and the level of reciprocity.

Additionally, at high enough levels of reciprocity defecting Titleholders receive lower payoffs than cooperating *Noranks*. This shows that, for defectors, the punishment of the apology potlatches is strong enough to mitigate the incentive to defect that can be created by large wealth asymmetries[34]. If the income of one agent is more than double the income of the other, no level of reciprocity can be high enough for only the pooling and sharing of income to motivate the wealthier agent to cooperate, which is the case in this model. An additional punishment for defectors is therefore necessary to increase the robustness of reciprocal systems.

Examples of this necessity can also be found in the progressive tax system model. It has been shown that the large income gaps between the high wealth and low wealth groups in a country necessitate the implementation of a fine system that *adequately* punishes defectors (tax evaders) for their behaviour (Cowell, 1985; Graetz et al., 1986; Kirchler and Wahl, 2010).

The results from the model support these conclusions and show that establishing proper punishments or sanctions for defectors is key to ensuring that reciprocal systems are robust even in the face of large wealth asymmetries.

5.2.4 The decoupling effect has problematic impacts on resource-based incentives

The decoupling effect refers to a phenomenon observed under the %Y rule that occurs because, under this interpretation of the contribution process, the agents' contribution sizes are determined with no consideration of their stored resources (see section 3.1.2). Instead, contribution sizes are dependent on rank-specific expected yields and are thus decoupled from the agent's actual ability to contribute. This has a range of negative side effects on the model communities.

As discussed in section 5.2.2, under the %Y rule this effect limits the generation of abundance in stored resources by weakening the savings effect. This results in cooperating agents receiving lower payoffs than they would under the %RS rule (in most cases), especially at high levels of reciprocity.

We also see that the decoupling effect weakens the impact of the redistribution mechanism across contribution rules. As there are fewer resources being contributed to and distributed at potlatches under the %Y rule, there are fewer resources that the mechanism can

[34] Power asymmetries can also provide an incentive to defect. However, this has more to do with elements such as political influence and corruption reducing this risk of being punished for defection. As the assumption in this model is that defectors are always punished, we cannot draw conclusions about the impact of the redistribution mechanism on power asymmetries.

shift from defectors to cooperators. The redistribution mechanism is still strong enough to ensure that defectors receive lower payoffs than cooperators of the same rank, but cooperators are compensated less than they are under the %RS rule.

On the other hand, if we compare the results from different scenarios within the %Y rule, we see that the decoupling effect allows cooperating agents to *benefit* from having defectors in the system. By masking the losses caused by CPR depletion, it allows the increased size of potlatch gifts (caused by defector contributions) to be realized as increased average payoffs for cooperating agents.

Now, this means that under the %Y rule there can be an increased incentive to monitor for defectors, which makes this interpretation of the system more effective at punishing free riders. However, it can also create an incentive to falsely identify defectors, or to sabotage other cooperators in order to generate higher payoffs for oneself.

We can find examples of this in systems that offer payment incentives to whistleblowers in order to increase the reporting of illegal behaviour (Miceli and Near, 1994). Whistleblowing in the USA became a highly profitable act as early as the 1980s, when the discovery of fraud and corruption linked to defense contracting in the USA resulted in "successful whistleblowers [coming] away multimillionaires" (Callahan and Dworkin, 1992, 282).

These large monetary rewards for whistleblowing have indeed been found to be effective at increasing the detection of fraud (Callahan and Dworkin, 1992; Dyck et al., 2010; Howse and Daniels, 1995) – but only if the reward mechanism is balanced by parallel mechanisms that investigate claims and enforce sufficient punishments for false and malicious reporting (Buccirossi et al., 2017; Howse and Daniels, 1995).

So, we see that if the system incentivizes false identification of defectors in any way, it requires a whole other set of mitigating rules and monitoring systems to authenticate defecting behaviours (Buccirossi et al., 2017; Miceli and Near, 1994). This makes the system less efficient (though perhaps not ineffective) at punishing true defectors, which is an essential component of the robustness of the potlatch system.

That the %Y rule and its associated decoupling effect allow cooperating Titleholders to receive higher payoffs when there is defection in the system is especially problematic. This is because their payoffs are *positively* correlated with the number of defecting Noranks in the community, suggesting that under this interpretation of the contribution process Titleholders have some incentive to use their influence to generate defecting behaviour in the lower ranks[35].

A final important impact of the decoupling effect and its masking of CPR depletion is that it weakens or makes unreliable the use of contribution sizes as a public and immediately visible signal of resource depletion. In practice, an unreliable monitoring mechanism would interfere with the management of the community's extraction by providing decision-makers with delayed or even false information.

5.2.5 The %RS contribution rule motivates proper management of extraction

Comparing the scenarios with defecting Noranks (2 and 3) to those with defecting Titleholders (4 and 5) shows that, under the %RS rule, defecting Noranks create larger losses for the community than defecting Titleholders do. This is expressed in both lower average payoffs for cooperators and earlier system collapses. This pattern occurs even though a given number of Titleholders will extract more per time-step than double that number of Noranks (see section 4.2.4).

The interesting aspect of this finding is that under the %RS rule cooperating Titleholders experience their lowest average payoffs when all Noranks defect (Figure 9), and their second lowest average payoffs when half of Noranks defect (Figure 6). Because Titleholders have some influence over the community's decision-making and management processes, this suggests that there is an additional incentive for Titleholders to use this influence to properly monitor and promote cooperative behaviours amongst the Noranks of their clan.

Recall that this is *not* the case under the %Y rule, where the decoupling effect creates an incentive for Titleholders to promote defecting behaviour amongst the Noranks of their clan instead (see section 5.2.3)[36]. This difference between the two contribution rules or systems is important because it speaks to the equity of these systems and how they deal with the power asymmetries that are created by the ranking system.

---

[35] Again, note that rates of environmental depletion are weakly reflected in the chosen time-averaged payoff variables. As a result, differences in overall or long-term payoffs are also not well-reflected.

[36] Also recall that this incentive may not exist if we were to consider total payoffs and survival of the community as incentive mechanisms in addition to average payoffs.

There are many examples of leaders of a collective purposefully mismanaging their community's land and resources to further their own interests when they are presented with an incentive to do so (Amanor and Ubink, 2008; Asiamah, 2000; de Blas et al., 2011; Okali, 1983; Simensen, 1975; Ubink and Quan, 2008). However, if there are socio-cultural structures in these societies that allow the community to 'dethrone' a chief or a highly ranked decision-maker, the impacts of mismanagement are mitigated, or avoided entirely if the incentive itself is counteracted (Amanor and Ubink, 2008; Busia, 1951; Kasanga, 2002). Such structures do exist in the Northwest Coast First Nations that were used to inspire this model (Halpin and Seguin, 1990; Morrison and Wilson, 2004; Ringel, 1979), but a collective that uses a contribution system which simply *precludes* any incentive to mismanage for personal gain would ensure equity as well as efficiency in the system.

5.3 Review of assumptions and limitations

A number of assumptions that were applied to the agent-based model limited the scope of interpretation that was possible during this research and should be reconsidered in future work. These assumptions and the limitations they imposed will be briefly addressed in this section.

Firstly, we assumed that the environment was a closed system, so no external influences were built to impact the CPR. Realistically, environmental factors such as weather and disease could cause fluctuations in the available stock of resources in the environment, as could anthropogenic factors such as pollution and adjacent land-use changes. However, environmental variability was determined to be an unnecessary complexity at this initial stage of the model's design and analysis, as it could introduce too much noise into the data. Future work would benefit from simulating some set of external influences in order to determine the potlatch's robustness in the face of environmental variability.

The model also contains a condition the ends the run if total stock reaches 0. The assumption here is that total depletion is irreversible, with no hope of assisted or natural recovery from external forces. This assumption ignores the robustness created by the interconnectedness of natural ecosystems and the possibility of intervention from various agents. However, both of these processes take time and have success rates that are highly context-dependent (Bullock et al., 2011; Pocock et al., 2012). They are therefore highly unlikely to prevent depletion from recurring if *agent behaviour* does not change at the same time. Hence the focus of this research was to analyse and understand a system that works to prevent depletion in the first place, rendering the question of external recovery redundant for this model.

The rest of the model's assumptions are concerned with agent behaviour. Firstly, it was assumed that the fixed and rank-dependent extraction levels were effectively enforced a) for cooperating agents by the underlying mechanisms of the potlatch and the ranking system and b) for defecting agents by their rank-associated extractive ability.

That cooperating agents are limited to a certain extractive level should rather be understood in reverse; they are considered cooperative *because* they are adhering to the limits imposed by the potlatch system. The actual assumption here is that the potlatch system is effective at correctly identifying cooperating agents. This was deemed appropriate because of the high preferences for social status, the requirements to earn and keep it, the public nature of all actions taken to this end, and the system of governance that facilitates and monitors all of these processes (Beynon et al., 2000; Miller, 1997; Ringel, 1979).

As for defectors, the model assumes that their social status (Norank or Titleholder) is partially earned by demonstrating a certain extractive ability, so individuals of lower rank are assumed to only be able to extract at a certain level, even when defecting.

The embedded assumption that the ranking system is effective at correctly assigning rank based on ability alone is not wholly accurate in the historic context. In practice, the opportunity to earn rank was inherited (Morrison and Wilson, 2004; Ringel, 1979), thus precluding some individuals from earning a high rank *despite* their extractive and contributive ability. If such individuals decide to defect, they would most likely have a higher extraction level than this model assigns to them and would thus require higher levels of reciprocity to want to cooperate. Future work would benefit from assessing the impact of varying levels of extractive ability amongst *same-ranked* defectors on the efficacy of the potlatch system in enforcing cooperation.

The assumption that an agent's consumption is equal to 50% of their remaining resources at the end of each time-step was based on a set of statistics generated by Statistics Canada in 2014 (Statistics Canada, 2014), which summarised the results of the 2011 World Bank International Comparison Program (The World Bank, 2014). In the summary from Statistics

Canada, the average propensities to consume (defined as the ratio of total consumption per capita to total income per capita) for 25 countries ranged between 31% and 60%.

Firstly, these statistics indicate that consumption tends to increase proportionately with increases in wealth, and thus tends to be a relatively constant percentage of wealth. Secondly, with a larger skew towards 60%, it was decided that 50% was a reasonable rough estimate for the model (Statistics Canada, 2014). However, consumption-wealth trends are not fully linear, so future work should improve on the rules governing consumption, particularly looking at variations in that develop at the upper and lower extremities of wealth.

Another simplifying assumption related to consumption is that there is no survival threshold for the individual agent based on their stored resources. As explained in section 3.1.2, most First Nations communities would not allow an individual to starve just because they have exhausted their personal store of resources or wealth. Additionally, the agents in this model represent a rank or title more than an individual, and this rank is passed on from one individual to another. So even if an individual did not survive into the next time-step, the rank would survive because the chiefs would find a suitable individual to transfer the rank.

Additionally, the results were found to be highly sensitive to small changes in a draft version of a survival threshold, particularly at high levels of *%contribution*. In combination with the previous reasons, it was decided that a survival threshold was not necessary at this stage of the model's development. However, the attempts to include one did show that the concept of agent survival needs to be further developed, as it does an impact on average payoffs and therefore on agent decision-making to some degree. Including it could provide important insights into the limitations that might have to be placed on a reciprocal system in order to account for this reality.

The model further assumes that agents could not go into debt (where debt is defined as negative wealth). This is perhaps the assumption that deviated the most from actual accounts of the potlatch system and Indigenous economies in general. Debt, in fact, plays an important role in these communities, and is an important mechanism in terms of incentives and limiting agency overall (Beynon et al., 2000; Morrison and Wilson, 2004).

Firstly, more time was needed to properly understand and simulate the intricacies of how a debt system would work in the context of this model, and how it most likely worked in pre-European contexts. Additionally, without having a defined survival threshold, a required minimum contribution level, and meaningfully derived rates of repayment, interest rates, thresholds for debt forgiveness and so on, any simulation of a debt system would be unlikely to produce meaningful insights. It will be very important in future work, however, to address this facet of the potlatch system and Indigenous economies and understand the impact it has on motivating cooperation in the system.

The next assumption that must be addressed is that the apology distributions that a defecting agent would be expected to provide are equal to any potlatch gift they would have received, resulting in the rule that defecting agents receive no potlatch gifts. This assumption was based on various texts that describe these apology distributions as being approximately equal to, if not in some cases larger than, any gift the defector received at a prior potlatch (Beynon et al., 2000; Miller, 1997; Morrison and Wilson, 2004; Ringel, 1979).

The main concern with this assumption is the individual incentive mechanisms of receiving potlatch gifts and distributing apology gifts cannot be analysed and understood independently for defectors. Instead, the interpretation in this thesis is of the artificially created condition that defectors receiving no potlatch gifts, and important insights could have been lost as a result. Future modeling work should separate these mechanisms and explore their impacts on the final payoffs for defecting agents separately.

The final assumption that must be addressed is that defecting agents cannot hide that they have defected and are thus always forced to a) share a percentage of resources according the full and true extent of their expected yield or accumulated resources, and b) perform apology distributions in punishment of their defection. This assumption ensures that defecting agents contribute more than cooperating agents, and also ensures that defecting agents receive no potlatch gifts.

Essentially, what is assumed here is that the social nature of the community's economic organisation, cultural / traditional activities and daily life in general all lend themselves to fully effective monitoring of individual actions regarding resource extraction. This is a fair assumption to make, considering that individual accumulation of resources is not allowed to occur in private, but rather as one part of the larger accumulation of the house, so it would be very difficult and risky to attempt in secret (Beynon et al., 2000; Halpin and Seguin, 1990; Ringel, 1979). However, some analysis of the robustness of this system in the face of partial monitoring efficacy would improve our understanding of just how critical an effective and efficient monitoring system is. Future work will attempt to incorporate an element of varying monitoring efficacy in order to address this.

6. CONCLUSION

This thesis, using an agent-based modelling approach, draws on the structure of the potlatch tradition to understand how collective action systems motivate cooperative behaviour within the group, and which mechanisms within a reciprocal management system provide the resource-based incentives to do this. This effort illustrates how agent-based modelling can address the shortcomings of individualistic choice models in analysing collective behaviours and decision-making, particularly in the context of the decentralised management of common-pool resources.

To create the agent-based model, a set of mechanisms were identified from the literature which enforce the potlatch system and facilitate the resource flows associated with it. These were translated into rulesets and agent behaviours that governed how the 26 agents in the model interacted with a CPR and with one another over time.

The ABM was first used to produce clan-level game theoretic payoffs under two contribution rules and at 81 different combinations of *%contribution* and *%potlatch.* Here, cooperative and non-cooperative behaviours occurred at the level of each clan. We found that these results supported the findings of existing literature in that mutual cooperation is the outcome of the potlatch modification to the Prisoner's Dilemma. We additionally found that this is true at any level of reciprocity, and that the %RS contribution rule generates higher average payoffs for cooperating clans.

The ABM was also used to produce per capita payoff data for each rank in the model under six different scenarios (representing different combinations of cooperative and non-cooperative behaviours), two different contribution rules, and at 81 different combinations of *%contribution* and *%potlatch*. Here, cooperative and non-cooperative behaviours occurred at the level of the individual.

Allowing for heterogenous behaviours at the individual level allowed us to see that the rate of CPR depletion, and thus the abundance of resources in the environment and in the community, are differentially impacted by different compositions of individual behaviours. We also found that a redistribution mechanism shifts resource-based incentives from defectors to cooperators, and that this mechanism is amplified when the agents exhibiting these two behaviours are of different ranks. Furthermore, we were able to identify a scenario (Defection –

all Noranks) that, when the %Y contribution rule is in effect, could be an alternative outcome to Mutual Cooperation as a result of power asymmetries and the decoupling effect.

These are all findings that we would not be able to discover using individualistic and behavioural models such as game theory. This is because such models homogenise individual agents and force them to make decisions in isolation from any social processes. They also treat collectives as single decision-making units that override individual agency.

However, individuals are inextricably embedded within societies, and their personalities and behaviours are shaped by their relationships with other individuals and the culture of their community. That models such as game theory choose to ignore these behavioural drivers makes them ill-suited to understanding how the collective guides, rather than curtails, individual decision-making via the use of individuality, relationality and socio-cultural structures.

It is therefore important to use a methodology that allows these tools of collective action systems to be examined and understood. This research has shown that agent-based modelling is capable of doing this and helping us better understand how collective action systems motivate cooperative behaviour in a CPR situation.

REFERENCES

Alchian, A.A., Demsetz, H., 1972. Production, Information Costs, and Economic Organization. The American Economic Review 62, 777-795.

Amanor, K.S., Ubink, J.M., 2008. Contesting land and custom in Ghana. State, chief and the citizen. Leiden University Press.

Andersson, K.P., Gibson, C.C., Lehoucq, F., 2006. Municipal politics and forest governance: Comparative analysis of decentralization in Bolivia and Guatemala. World Development 34, 576-595.

Asiamah, A.E.A., 2000. The mass factor in rural politics: the case of the Asafo revolution in Kwahu political history. Ghana Universities Press, Accra.

Atleo, E.R., 2011. Principles of tsawalk : an indigenous approach to global crisis. UBC Press, Vancouver.

Axelrod, R., 1980a. Effective Choice in the Prisoner's Dilemma. The Journal of Conflict Resolution 24, 3-25.

Axelrod, R., 1980b. More Effective Choice in the Prisoner's Dilemma. Journal of Conflict Resolution 24, 379-403.

Baker, J.M., 2007. The Kuhls of Kangra: community-managed irrigation in the western Himalaya. University of Washington Press.

Bakker, K., 2007. The “Commons” Versus the “Commodity”: Alter-globalization, Anti-privatization and the Human Right to Water in the Global South. Antipode 39, 430-455.

Banos, A., Lang, C., Marilleau, N., 2015. Agent-based spatial simulation with NetLogo. Volume 1, Introduction and bases. Elsevier, London.

Beynon, W., Halpin, M.M., Anderson, M., 2000. Potlatch at Gitsegukla : William Beynon's 1945 field notebooks. UBC Press, Vancouver.

Bonabeau, E., 2002. Agent-based modeling: methods and techniques for simulating human systems. Proc Natl Acad Sci U S A 99 Suppl 3, 7280-7287.

Bornstein, G., Rapoport, A., 1988. Intergroup competition for the provision of step-level public goods: Effects of preplay communication. European Journal of Social Psychology 18, 125-142.

Bowles, S., Gintis, H., 1993. The Revenge of Homo Economicus: Contested Exchange and the Revival of Political Economy. Journal OF Economic Perspectives 7, 83.

Brockington, D., 2002. Fortress conservation: the preservation of the Mkomazi Game Reserve, Tanzania. Indiana University Press.
Brockington, D., Homewood, K., 2001. Degradation debates and data deficiencies: the Mkomazi Game Reserve, Tanzania. Africa 71, 449-480.
Buccirossi, P., Immordino, G., Spagnolo, G., 2017. Whistleblower rewards, false reports, and corporate fraud.
Bullock, J.M., Aronson, J., Newton, A.C., Pywell, R.F., Rey-Benayas, J.M., 2011. Restoration of ecosystem services and biodiversity: conflicts and opportunities. Trends in ecology & evolution 26, 541-549.
Busia, K.A., 1951. The position of the chief in the modern political system of Ashanti: A study of the influence of contemporary social changes on Ashanti political institutions. Oxford University Press, Oxford.
Callahan, E.S., Dworkin, T.M., 1992. Do good and get rich: Financial incentives for whistleblowing and the False Claims Act. Vill. L. Rev. 37, 273.
Ciriacy-Wantrup, S.V., Bishop, R.C., 1975. " Common property" as a concept in natural resources policy. Natural resources journal 15, 713-727.
Coase, R.H., 1960. The Problem of Social Cost. The Journal of Law & Economics 3, 1-44.
Cooper, M.-P., 1999. The Common Fisheries Policy of the European Union - A Lesson in How Not to Make Policy. Politics 19, 61-70.
Cowell, F.A., 1985. The economic analysis of tax evasion. Bulletin of Economic Research 37, 163-193.
Dawes, R.M., McTavish, J., Shaklee, H., 1977. Behavior, communication, and assumptions about other people's behavior in a commons dilemma situation. Journal of personality and social psychology 35, 1.
de Blas, D.E., Ruiz-Pérez, M., Vermeulen, C., 2011. Management Conflicts in Cameroonian Community Forests. Ecology and Society 16.
Dubos, R., 1976. Symbiosis Between the Earth and Humankind. Science 193, 459-462.
Dutta, P.K., 1999. Strategies and games : theory and practice. MIT Press, Cambridge, Mass.
Dyck, A., Morse, A., Zingales, L., 2010. Who blows the whistle on corporate fraud? The journal of finance 65, 2213-2253.

Edney, J.J., Harper, C.S., 1978. The commons dilemma. Environmental Management 2, 491-507.
Ereshefsky, M., Pedroso, M., 2015. Rethinking evolutionary individuality. Proc Natl Acad Sci U S A 112, 10126-10132.
Eyre, E.J., 1845. Journals of Expeditions of Discovery into Central Australia, and over-land from Adelaide to King George's Sound, in the Years 1840–41. Boone, London.
Farrell, J., Ware, R., 1989. Evolutionary stability in the repeated prisoner's dilemma. Theoretical Population Biology 36, 161-166.
Gale, D., Kuhn, H.W., Tucker, A.W., 1951. Linear programming and the theory of games, Activity analysis of production and allocation : proceedings of a conference. Wiley, New York.
Gilbert, S.F., Handling Editor James, D.T., Associate Editor Stephen, C.S., Sapp, J., Tauber, A.I., 2012. A Symbiotic View of Life: We Have Never Been Individuals. The Quarterly Review of Biology 87, 325-341.
Gowdy, J.M., Polimeni, R.I., 2005. The death of homo economicus: is there life after welfare economics? International Journal of Social Economics 32, 924-938.
Graetz, M.J., Reinganum, J.F., Wilde, L.L., 1986. The Tax Compliance Game: Toward an Interactive Theory of Law Enforcement. Journal of Law, Economics, & Organization 2, 1-32.
Grey, G., 1841. Grey, George. Journals of Two Expeditions of Discovery in North-West and Western Australia During the Years 1837, 38 and 39: Describing Many Newly Discovered, Important and Feritle Districts: with Observations on the Moral and Physical Condition of the Aboriginal Inhabitants. Boone, London.
Grumet, R.S., 1975. Changes in Coast Tsimshian Redistributive Activities in the Fort Simpson Region of British Columbia, 1788-1862. Ethnohistory 22, 295-318.
Guzmán, R., Harrison, R., Abarca, N., Villena, M.G., 2020. A game-theoretic model of reciprocity and trust that incorporates personality traits. Journal of Behavioral and Experimental Economics 84.
Hackett, S., Schlager, E., Walker, J., 1994. The role of communication in resolving commons dilemmas: experimental evidence with heterogeneous appropriators. Journal of Environmental Economics and Management 27, 99-126.

Halpin, M.M., Seguin, M., 1990. Tsimshian Peoples: Southern Tsimshian, Coast Tsimshian, Nishga, and Gitksan, in: Suttles, W. (Ed.), Handbook of North American Indians. Smithsonian Institution, Washington, pp. 267-284.
Hardin, G., 1968. The Tragedy of the Commons. Science 162, 1243-1248.
Heynen, N., Robbins, P., 2005. The neoliberalization of nature: Governance, privatization, enclosure and valuation. Capitalism Nature Socialism 16, 5-8.
Hilborn, R., Walters, C.J., Ludwig, D., 1995. Sustainable Exploitation of Renewable Resources. Annual Review of Ecology and Systematics 26, 45-67.
Hird, M.J., 2010. Coevolution, Symbiosis and Sociology. Ecological Economics 69, 737-742.
Hobbes, T., [1651] 1960. Leviathan or the Matter, Forme and Power of a Commonwealth Ecclesiastical and Civil. Basil Blackwell, Oxford.
Howse, R., Daniels, R.J., 1995. Rewarding whistleblowers: the costs and benefits of an incentive-based compliance strategy. Departmental Papers (School of Law), 4.
Hulme, D., Murphree, M.W., 2001. African wildlife & livelihoods : the promise and performance of community conservation. D. Philip ;
Heinemann, Cape Town
Portsmouth, NH.
Isaac, R.M., Walker, J.M., 1988. Communication and free-riding behavior: The voluntary contribution mechanism. Economic inquiry 26, 585-608.
Johnsen, D.B., 2009. Salmon, Science, and Reciprocity on the Northwest Coast. Ecology and Society 14.
Kasanga, K., 2002. Land tenure, resource access and decentralisation in Ghana, in: C. Toulmin, Delville, P.L., Traore, S. (Eds.), The dynamics of resource tenure in West Africa. IIED, London, pp. 25-36.
Kirchler, E., Wahl, I., 2010. Tax Compliance Inventory: TAX-I Voluntary tax compliance, enforced tax compliance, tax avoidance, and tax evasion. Journal of Economic Psychology 31, 331.
Kluver, J., Frazier, R., Haidt, J., 2014. Behavioral ethics for Homo economicus, Homo heuristicus, and Homo duplex. Organizational Behavior and Human Decision Processes 123, 150-158.

Kokorsch, M., Benediktsson, K., 2018. Prosper or perish? The development of Icelandic fishing villages after the privatisation of fishing rights. Maritime Studies 17, 69-83.
Lee, R., 1969. !Kung Bushman Subsistance: An Input-Output Analysis, in: Lee, R., DeVore, I. (Eds.), Environment and Cultural Behavior. Natural History Press, Garden City, NY.
Leyton-Brown, K., Shoham, Y., 2008. Essentials of game theory : a concise, multidisciplinary introduction. Morgan & Claypool Publishers, [San Rafael, Calif.].
Margulis, L., 1998. Symbiotic planet : a new look at evolution, 1st ed. ed. Basic Books, New York.
Marwell, G., Oliver, P., 1993. The critical mass in collective action. Cambridge University Press.
Maynard Smith, J., 1982. Evolution and the theory of games. Cambridge University Press, Cambridge ;.
McCloskey, D., 1998. The So-Called Coase Theorem. Eastern Economic Journal 24, 367-371.
McKean, M.A., 1992. Management of Traditional Common Lands (Iriaichi) in Japan, in: Bromley, D.W. (Ed.), Making the commons work : theory, practice, and policy. ICS Press, San Francisco, Calif.
Miceli, M.P., Near, J.P., 1994. Whistleblowing: Reaping the Benefits. The Academy of Management Executive (1993-2005) 8, 65-72.
Miller, J., 1997. Tsimshian culture : a light through the ages. University of Nebraska Press, Lincoln.
Morrison, R.B., Wilson, C.R., 2004. Native peoples : the Canadian experience, 3rd ed. ed. Oxford University Press, Toronto.
Nash, J., 1951. Non-cooperative games. Annals of mathematics, 286-295.
Nelson, A., Schneider, F.o., 2018. Housing for Degrowth : Principles, Models, Challenges and Opportunities. Routledge, Milton.
Nelson, F., 2010. Community rights, conservation and contested land : the politics of natural resource governance in Africa. Earthscan, London ;.
Okali, C., 1983. Cocoa and Kinship in Ghana: the matrilineal Akan of Ghana. Routledge.
Okasha, S., 2006. The Levels of Selection Debate: Philosophical Issues. Philosophy Compass 1, 74-85.
Oliver, D., 1949. Studies in the Anthropology of Bougainville, Solomon Islands. Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University. 29.

Oliver, P., Marwell, G., Teixeira, R., 1985. A theory of the critical mass. I. Interdependence, group heterogeneity, and the production of collective action. American journal of Sociology 91, 522-556.
Orbell, J.M., Van de Kragt, A.J., Dawes, R.M., 1988. Explaining discussion-induced cooperation. Journal of Personality and Social Psychology 54, 811-819.
Ostrom, E., 1990. Governing the commons : the evolution of institutions for collective action. Cambridge University Press, Cambridge ;.
Ostrom, E., 2012. Future of the commons : beyond market failure and government regulation. Institute of Economic Affairs, London.
Ostrom, E., Gardner, R., Walker, J., 1994. Rules, games, and common-pool resources. University of Michigan Press, Ann Arbor.
Pocock, M.J.O., Evans, D.M., Memmott, J., 2012. The Robustness and Restoration of a Network of Ecological Networks. Science 335, 973-977.
Ringel, G., 1979. The Kawkiutl Potlatch: History, Economics, and Symbols. Ethnohistory 26, 347.
Robbins, P., 2001. Fixed categories in a portable landscape: the causes and consequences of land-cover categorization. Environment and planning A 33, 161-179.
Rutten, M.M.E.M., 1992. Selling wealth to buy poverty : the process of the individualization of landownership among the Maasai pastoralists of Kajiado District, Kenya, 1890-1990. Verlag breitenbach Publishers, Saarbrücken ;.
Ryan, F., 2002. Darwin's blind spot : evolution beyond natural selection. Houghton Mifflin Company, Boston.
Sahlins, M., 2017. Stone age economics. Routledge Classics, Milton Park, Abingdon, Oxon ;.
Sen, A.K., 1977. Rational Fools: A Critique of the Behavioral Foundations of Economic Theory. Philosophy & Public Affairs 6, 317-344.
Simensen, J., 1975. Nationalism from below: the Akyem Abuakwa example, in: Addo-Fening, R. (Ed.), Akyem Abuakwa and the Politics of the Inter-war Period in Ghana. Basler Afrika-Bibliographien, Basel.
Siy, R.Y., 2011. Community Resource Management: Lessons from the Zanjera. University of the Philippines Press.
Smith, A., 1759. The Theory of Moral Sentiments. .

Smith, A., Haakonssen, K., 2002. The theory of moral sentiments. Cambridge University Press, Cambridge, U.K. .
Sober, E., Wilson, D.S., 1998. Unto others : the evolution and psychology of unselfish behavior. Harvard University Press, Cambridge, Mass.
Statistics Canada, 2014. The World Bank International Comparison Program for purchasing power: Overall ranking of countries, 2011. Statistics Canada, Ottawa.
Steltzer, U., 1984. A Haida potlatch. University of Washington Press, Seattle.
Sumaila, U.R., 2001. Achieving sustainable fisheries: The economic dimension, in: Sumaila, U.R. (Ed.), UNEP Workshop on Fisheries Subsidies and Sustainable Fisheries Management, p. 27.
Taylor, F., Mackenzie, F., 1992. Development from within: survival in rural Africa.
The World Bank, 2014. Purchasing Power Parities and Real Expenditures of World Economies: Summary of Results and Findings of the 2011 International Comparison Program. The World Bank, Washington DC.
Trosper, R.L., 2009. Resilience, reciprocity and ecological economics: Northwest Coast sustainability, 1st ed. Routledge, London.
Ubink, J.M., Quan, J.F., 2008. How to combine tradition and modernity? Regulating customary land management in Ghana. Land use policy 25, 198-213.
Wade, R., 1988. The management of irrigation systems: How to evoke trust and avoid prisoner's dilemma. World Development 16, 489-500.
Walens, S., 1981. Feasting with cannibals : an essay on Kwakiutl cosmology. Princeton University Press, Princeton, N.J.
Wilensky, U., 1999. NetLogo. Center for Connected Learning and Computer-based Modeling, Northwestern University. Evanston, IL.
Woodburn, J., 1968. An Introduction to Hadza Ecology, in: Lee, R., DeVore, I. (Eds.), Man the Hunter. Aldine, Chicago.

APPENDIX 1

Tables I and II show the payoffs that each clan might receive for all 81 combinations of *%contribution and %potlatch,* under the four scenarios described in section 3.3.1. They additionally show the final decision that each clan would take in a single-iteration game using best response principles. Table I shows data generated under the %RS contribution rule, and Table II shows data generated under the %Y contribution rule.

The four columns under each clan show the four different payoffs that would be available to that clan in game theory matrices. The column labels correspond as follows:

- MC: the payoff expected for clan X when both clans cooperate (mutual cooperation)
- MD: the payoff expected for clan X when both clans defect (mutual defection)
- C: the payoff expected for clan X when clan X cooperates and their opponent in the game defects
- D: the payoff expected for clan X when clan X defects and their opponent in the game cooperates

Finally, the color gradients in the payoff columns are an indicator of how high (green) or low (red) the payoff is relative to the other payoffs in that column. This provides a quick assessment of how changes in the level of reciprocity affect the payoff for a particular behavioral decision.

		Clan 1					Clan 2				
%C	%P	MC	MD	C	D	Choice of clan 1	MC	MD	C	D	Choice of clan 2
10	10	574.721776	128.364853	175.548328	116.299222	Cooperate	601.547268	126.696262	167.979584	116.266777	Cooperate
10	20	732.62602	126.16501	211.88064	113.773619	Cooperate	733.125568	126.538062	217.232473	114.641463	Cooperate
10	30	798.426192	124.711822	255.850699	115.235715	Cooperate	799.020032	129.139756	232.401237	114.720408	Cooperate
10	40	835.902041	128.669269	282.315311	118.678781	Cooperate	839.829926	126.615643	264.805935	117.663375	Cooperate
10	50	858.85042	128.189829	274.363063	117.496798	Cooperate	857.418504	124.033549	261.202691	117.482241	Cooperate
10	60	869.476917	124.532747	285.679835	119.746156	Cooperate	879.913922	128.206055	286.088618	116.402199	Cooperate
10	70	879.872162	125.538252	307.240127	112.296116	Cooperate	891.649158	128.100451	307.524019	112.015653	Cooperate
10	80	895.615702	128.356694	298.634229	116.022512	Cooperate	892.498301	125.828138	313.748229	120.985816	Cooperate
10	90	905.460399	126.841233	318.969661	112.774388	Cooperate	903.596158	124.824241	304.342106	117.417627	Cooperate
20	10	1026.50596	103.832902	176.816844	95.4641804	Cooperate	1067.45274	104.035784	211.40761	94.4089409	Cooperate
20	20	1409.51133	102.382983	328.593264	92.416915	Cooperate	1356.4759	102.98739	286.016321	94.9506593	Cooperate
20	30	1537.19767	104.676896	378.775716	96.3627488	Cooperate	1553.1123	103.652964	288.407041	95.2730201	Cooperate
20	40	1643.91835	104.274199	396.094925	92.6909456	Cooperate	1645.83516	103.009927	398.170596	99.1289641	Cooperate
20	50	1708.14279	103.425378	430.839366	93.7568594	Cooperate	1675.10417	104.075172	424.448588	94.803183	Cooperate
20	60	1743.49318	105.201008	401.045655	95.956009	Cooperate	1746.94164	102.190127	426.316461	92.3512083	Cooperate
20	70	1757.96586	102.190228	441.665642	95.4421429	Cooperate	1758.75546	102.899097	417.849563	98.5761851	Cooperate
20	80	1803.14701	105.110825	445.562306	92.3796313	Cooperate	1785.52252	100.754031	435.720662	95.9572486	Cooperate
20	90	1801.81346	103.724901	465.702192	93.9124293	Cooperate	1805.20055	103.808379	444.611151	94.024066	Cooperate
30	10	1361.40123	82.4902833	245.294844	76.1177508	Cooperate	1574.26542	84.9020832	246.795002	73.6109181	Cooperate
30	20	2073.93625	83.1476786	359.111887	77.2860983	Cooperate	2069.37444	85.0714169	347.135365	75.0567608	Cooperate
30	30	2386.31255	82.9587049	410.294212	76.3480464	Cooperate	2393.63154	84.2378364	387.186673	78.0112782	Cooperate
30	40	2570.23507	83.2660162	462.554228	74.0056827	Cooperate	2576.97545	84.5094083	473.719211	77.5994381	Cooperate
30	50	2664.50792	82.5441744	514.571879	77.7859929	Cooperate	2699.92185	84.505066	434.084927	77.2126542	Cooperate
30	60	2745.28084	83.3767567	513.095251	75.6373481	Cooperate	2731.11761	83.8963004	563.504112	77.9238477	Cooperate
30	70	2805.96577	84.7857175	554.042316	77.8662528	Cooperate	2807.15746	80.7458492	588.578781	79.2886269	Cooperate
30	80	2846.23894	83.503058	529.816183	75.1953096	Cooperate	2846.61688	84.4669808	556.762104	78.6019062	Cooperate
30	90	2885.28895	84.3800791	571.12778	77.1851454	Cooperate	2872.07027	83.3614821	552.812653	75.6111952	Cooperate
40	10	1878.14104	67.0793096	280.282346	60.4375551	Cooperate	2021.67869	66.2592359	228.517132	60.2326211	Cooperate
40	20	2875.93864	66.7539788	429.703151	62.0110443	Cooperate	2857.52628	67.3497077	449.223522	59.2339051	Cooperate
40	30	3373.86984	67.0051356	501.501046	60.0717902	Cooperate	3328.86154	67.3077261	482.0667	59.3166346	Cooperate
40	40	3532.19899	67.4235939	502.577242	61.5005962	Cooperate	3590.39727	66.1285704	551.044678	61.8550054	Cooperate
40	50	3773.25275	65.1256402	627.343434	61.8411115	Cooperate	3818.65019	67.0850195	580.695556	62.8221465	Cooperate
40	60	3958.10629	66.5030108	635.87015	61.5544094	Cooperate	3939.95621	66.0458829	577.706445	59.9165731	Cooperate
40	70	4090.2786	68.0118135	648.476143	63.861445	Cooperate	4100.06625	64.1335156	589.705948	60.0609329	Cooperate
40	80	4177.70183	67.3034173	668.158562	61.9804911	Cooperate	4171.33267	66.2546781	642.14367	59.8220964	Cooperate
40	90	4197.93444	67.1655658	656.620362	61.5333737	Cooperate	4196.56897	65.9515536	668.976081	60.899806	Cooperate
50	10	2482.85386	52.2107862	299.084696	46.3933663	Cooperate	2324.20365	51.3553805	277.634038	47.5269219	Cooperate
50	20	3626.70116	51.2877874	472.776518	47.1187467	Cooperate	3605.57309	52.3422078	510.805995	49.2927697	Cooperate
50	30	4391.35798	52.1694122	606.178912	48.0139457	Cooperate	4314.18926	50.6916699	450.053415	47.2129973	Cooperate
50	40	4812.92678	52.1275149	635.162375	46.4369189	Cooperate	4776.12725	52.0735474	593.026781	47.3725178	Cooperate
50	50	5237.79488	52.4039225	681.459451	47.6555562	Cooperate	5109.87539	51.9722561	659.690249	46.4705924	Cooperate
50	60	5319.22942	52.3144324	661.593916	45.7385092	Cooperate	5345.91406	50.532226	662.57653	47.8389963	Cooperate
50	70	5595.58484	50.9571153	658.727687	46.3690777	Cooperate	5612.44463	52.5152594	773.265766	47.4085688	Cooperate
50	80	5709.2013	52.6872018	764.929982	47.5831048	Cooperate	5717.44404	51.2239679	711.801284	46.3553923	Cooperate
50	90	5858.69898	52.4289261	730.762989	49.2266114	Cooperate	5861.19275	50.1197545	757.539069	45.8385161	Cooperate
60	10	2855.3388	38.3785118	327.347049	34.7455546	Cooperate	2805.39248	39.5506913	266.127174	34.9823487	Cooperate
60	20	4534.77494	38.5861114	468.186358	35.3651567	Cooperate	4609.97548	39.4060075	424.600211	36.4952128	Cooperate
60	30	5791.55973	39.444242	562.158434	35.313392	Cooperate	5622.84948	38.1110527	655.318041	33.8468119	Cooperate
60	40	6323.07033	38.6107973	616.24947	35.5436428	Cooperate	6408.33647	39.2867531	633.193229	35.8674505	Cooperate
60	50	6741.68065	39.0561629	671.858542	35.0082506	Cooperate	6874.6326	38.9511067	725.657724	36.8148171	Cooperate
60	60	7120.82174	39.0060531	774.890351	35.8947342	Cooperate	7112.64763	39.2268017	721.562114	34.5748083	Cooperate
60	70	7483.72415	38.1928516	793.960572	35.3431167	Cooperate	7494.31497	39.3754384	785.072823	34.7526605	Cooperate
60	80	7528.28197	38.7322298	825.393725	33.8232449	Cooperate	7588.35311	39.0167993	745.241315	35.2331591	Cooperate
60	90	7767.52555	39.1575321	845.169604	34.7375889	Cooperate	7839.69715	38.9639675	759.476121	35.1942767	Cooperate
70	10	3282.63273	27.8043258	345.688803	24.4128643	Cooperate	3185.42275	26.5768197	345.176553	25.6006521	Cooperate
70	20	5403.85524	27.2792048	577.031161	24.45693	Cooperate	5513.04538	27.808996	545.055166	24.5594938	Cooperate
70	30	6904.64915	27.4012686	652.942195	23.8869155	Cooperate	6784.77478	27.4944631	594.068759	25.0715725	Cooperate
70	40	8060.80697	27.2229956	703.005517	25.343967	Cooperate	8019.67182	27.8273278	638.895538	25.6876104	Cooperate
70	50	8909.36144	27.7516296	755.080248	25.4013811	Cooperate	8838.53272	27.8757532	741.429026	24.7600693	Cooperate
70	60	9429.69832	27.2498622	845.570053	24.9799611	Cooperate	9493.34181	27.5948544	794.97197	25.7307668	Cooperate
70	70	9998.24808	26.848277	754.380129	24.9828354	Cooperate	9923.96105	27.5876784	815.325546	25.1159648	Cooperate
70	80	10200.3802	27.2766949	847.616491	25.6247911	Cooperate	10206.8148	27.600236	820.919563	25.1503622	Cooperate
70	90	10669.0309	27.3327823	908.796334	25.4972203	Cooperate	10730.2851	27.6307659	866.693155	25.9060233	Cooperate
80	10	3804.67194	16.9556799	288.15897	16.0284202	Cooperate	3590.22494	17.5654378	393.7379	15.9943289	Cooperate
80	20	6554.52049	17.4736454	432.544374	15.8462988	Cooperate	6479.34956	17.2707731	519.210091	15.6777474	Cooperate
80	30	8652.89633	17.3755352	577.710456	16.0292366	Cooperate	8634.35591	17.2507013	595.096123	15.7902501	Cooperate
80	40	9909.16671	17.3480809	761.905889	15.7066493	Cooperate	10254.6751	17.2985831	720.176169	15.9492093	Cooperate
80	50	11093.9044	17.5814276	697.424902	15.7177192	Cooperate	10915.8097	17.0939604	786.449283	16.105697	Cooperate
80	60	11715.8071	16.5673295	870.622396	15.6161119	Cooperate	11818.8896	17.4865938	847.97055	15.8564246	Cooperate
80	70	13255.4879	17.4446998	889.416394	15.8359017	Cooperate	13196.1451	17.4249388	867.425612	15.7947564	Cooperate
80	80	13050.4883	17.5102123	960.512861	15.3485344	Cooperate	13123.4556	17.0471667	922.494297	15.7136354	Cooperate
80	90	15191.2634	17.5628739	953.35296	15.7508691	Cooperate	15235.0508	17.0816822	876.27436	15.757518	Cooperate
90	10	4031.77385	8.29993942	369.843184	7.53126022	Cooperate	4150.48518	7.9147233	304.68969	7.75410543	Cooperate
90	20	7425.84603	8.19163052	519.142299	7.46352542	Cooperate	7571.34067	8.11835342	524.507002	7.26162021	Cooperate
90	30	9806.2357	7.99897927	729.943432	7.6847204	Cooperate	9918.11595	8.32011061	647.539745	7.65307321	Cooperate
90	40	12240.2447	8.15143052	731.462916	7.24162634	Cooperate	12131.8146	8.20476125	829.310696	7.51255574	Cooperate
90	50	14701.8829	8.14599179	775.021981	7.44257632	Cooperate	14466.0278	8.31667123	923.1952	7.45718299	Cooperate
90	60	16150.1524	8.07008078	819.092695	7.4702502	Cooperate	16220.6685	8.22644668	816.117507	7.49525848	Cooperate
90	70	16393.0514	7.96102469	898.565691	7.61333198	Cooperate	16598.4615	8.28408364	837.128697	7.89510047	Cooperate
90	80	18027.603	8.26229387	936.211924	7.60413231	Cooperate	18125.5393	8.15421968	981.406136	7.70443836	Cooperate
90	90	19756.2325	8.043654	953.049642	7.57374931	Cooperate	19820.1606	8.27261467	1020.49514	7.27273265	Cooperate

Table I Payoffs experienced by Clan 1 and Clan 2 under the %RS contribution rule. *Data was produced at all possible combinations of %contribution and %potlatch.*

		Clan 1					Clan 2				
%C	%P	MC	MD	C (vs. D)	D (vs. C)	Choice of clan 1	MC	MD	C (vs. D)	D (vs. C)	Choice of clan 2
10	10	347.946193	137.125459	170.351124	121.387614	Cooperate	379.701536	132.941124	160.790289	119.48164	Cooperate
10	20	433.505145	138.372369	200.082066	125.15875	Cooperate	421.672953	134.606676	202.06688	122.106014	Cooperate
10	30	455.603764	137.589396	200.799032	119.64529	Cooperate	450.987835	131.659954	217.049038	129.807771	Cooperate
10	40	469.929248	135.18115	218.505802	120.56167	Cooperate	468.222342	135.416774	236.588259	121.744047	Cooperate
10	50	482.28699	135.980314	229.8031	121.419532	Cooperate	472.217829	137.642655	232.925603	126.316414	Cooperate
10	60	481.954081	137.069288	244.194026	121.787097	Cooperate	482.720371	134.369136	242.112847	124.310734	Cooperate
10	70	487.316326	133.050207	246.636257	121.033655	Cooperate	488.910898	136.810343	258.217796	123.09957	Cooperate
10	80	489.739111	133.471568	254.083585	123.301156	Cooperate	488.556373	136.07844	254.819256	119.990301	Cooperate
10	90	494.010954	134.781386	249.891295	116.660847	Cooperate	488.821613	136.733081	252.467582	122.488978	Cooperate
20	10	602.744675	117.646566	203.723122	105.70365	Cooperate	575.972687	115.812659	180.325834	104.230504	Cooperate
20	20	722.505861	116.217903	279.751513	108.014216	Cooperate	710.046387	114.671387	281.423111	107.475121	Cooperate
20	30	769.572087	117.29236	301.074827	107.923135	Cooperate	766.918223	116.040859	261.692268	105.671904	Cooperate
20	40	795.15776	117.042219	326.7604	103.415616	Cooperate	799.139442	118.164403	326.348607	104.341741	Cooperate
20	50	813.012091	117.88598	329.080505	100.618357	Cooperate	816.299582	115.716063	327.230165	103.364919	Cooperate
20	60	830.606037	117.066668	354.30172	104.538882	Cooperate	819.000342	115.744888	358.971341	104.116475	Cooperate
20	70	832.869796	114.546195	371.464398	109.043507	Cooperate	836.510833	117.585165	355.145236	106.294722	Cooperate
20	80	844.753113	117.418461	378.730668	105.150585	Cooperate	838.100436	115.645989	389.544464	104.5175	Cooperate
20	90	843.989307	116.638438	362.254932	107.365894	Cooperate	846.754204	115.585728	383.247992	108.947259	Cooperate
30	10	838.200676	98.1603427	224.949369	90.5469324	Cooperate	787.239458	96.4561296	227.194055	89.3580372	Cooperate
30	20	1002.94085	95.1071324	311.903033	87.4951108	Cooperate	1013.47247	98.1288538	329.051654	87.7794806	Cooperate
30	30	1056.8391	97.9053377	373.353045	90.1659825	Cooperate	1103.41592	96.7237572	380.809715	83.575285	Cooperate
30	40	1107.30858	98.7601817	399.144014	89.3022613	Cooperate	1135.2391	98.125368	431.786493	88.7826385	Cooperate
30	50	1144.81032	96.4022769	435.493881	86.1745013	Cooperate	1155.6371	98.3391722	457.648533	90.3742809	Cooperate
30	60	1165.36749	98.2864078	466.995714	92.6090502	Cooperate	1174.18508	97.6883421	444.653385	82.6081738	Cooperate
30	70	1187.82188	96.6260656	479.342511	86.1359735	Cooperate	1179.6284	96.8243374	483.513908	89.1800138	Cooperate
30	80	1192.21671	97.6818442	474.335284	85.4948965	Cooperate	1190.56192	97.741507	502.536438	83.7088032	Cooperate
30	90	1193.39383	97.8722778	481.330344	90.3981971	Cooperate	1203.45445	98.2575649	474.99496	85.2427197	Cooperate
40	10	1021.41832	79.1520209	235.603351	75.4676455	Cooperate	1058.2956	79.8953957	288.364256	70.2724492	Cooperate
40	20	1287.2388	77.7725885	359.195117	69.4548985	Cooperate	1285.11372	78.6956278	384.048747	69.5599129	Cooperate
40	30	1396.90566	77.6650393	442.985332	76.0942189	Cooperate	1404.36668	79.3974306	472.073753	68.6777046	Cooperate
40	40	1448.19199	78.1300406	486.274986	72.8219271	Cooperate	1453.25473	78.9777889	512.169835	71.8435785	Cooperate
40	50	1472.61265	78.9209191	579.375379	73.4052616	Cooperate	1497.91062	78.6493597	550.817094	70.6673895	Cooperate
40	60	1515.32099	77.8358823	573.13616	70.2002013	Cooperate	1503.865	78.8411675	598.54401	70.3004598	Cooperate
40	70	1525.58978	76.7371662	621.088536	70.8458751	Cooperate	1530.74282	79.0024768	587.760169	70.2864891	Cooperate
40	80	1555.61887	76.1494066	589.354331	71.5173687	Cooperate	1533.06711	77.1206502	631.329978	72.3198495	Cooperate
40	90	1556.00669	78.1505904	598.144931	73.2836581	Cooperate	1551.73574	79.5601003	607.610003	69.3071522	Cooperate
50	10	1271.17112	59.4515198	323.143809	56.1436849	Cooperate	1249.6216	60.6566182	316.33843	53.3516431	Cooperate
50	20	1551.90479	60.7915009	439.774035	55.4596957	Cooperate	1589.54553	60.4941743	424.287061	53.3680485	Cooperate
50	30	1685.001	59.5741186	479.253909	53.0541597	Cooperate	1731.29801	61.1521586	482.58757	54.9856591	Cooperate
50	40	1781.91534	59.6871809	537.059211	52.3111824	Cooperate	1777.89935	60.1895799	631.048046	54.7806513	Cooperate
50	50	1785.98912	59.1849426	638.62868	53.684548	Cooperate	1854.55427	60.5376365	667.199179	55.0448398	Cooperate
50	60	1862.43015	61.3049184	686.248619	54.6659256	Cooperate	1825.93709	60.2516429	673.79188	53.0511501	Cooperate
50	70	1880.2804	60.3758948	692.917524	53.7070939	Cooperate	1857.61127	60.886642	732.101848	55.7393008	Cooperate
50	80	1902.01119	60.0935732	706.213211	53.8325057	Cooperate	1873.41838	60.3148799	723.282257	53.4072693	Cooperate
50	90	1908.58018	61.1433661	726.344666	55.4874063	Cooperate	1909.17661	60.0686808	746.768383	53.6372308	Cooperate
60	10	1420.80765	43.5120605	251.888708	39.3699319	Cooperate	1555.03854	45.0151366	319.255193	37.7239046	Cooperate
60	20	1911.19883	44.1734969	452.915637	39.551089	Cooperate	1795.93408	44.7478396	435.243337	38.2092814	Cooperate
60	30	2040.44491	44.8569607	571.163483	38.7564311	Cooperate	1999.15387	45.1354427	675.429997	39.753194	Cooperate
60	40	2123.33651	44.2837118	679.180826	39.0472759	Cooperate	2108.06244	45.131929	748.115145	38.1348352	Cooperate
60	50	2155.55262	44.2508593	591.72314	39.9797665	Cooperate	2160.66313	43.43612	736.705585	38.1494241	Cooperate
60	60	2209.10572	44.9646448	832.971357	38.1743164	Cooperate	2158.84029	44.0419489	784.410162	38.1136996	Cooperate
60	70	2194.74389	44.0876411	786.820996	38.4021252	Cooperate	2234.02957	44.858222	804.88192	40.3551531	Cooperate
60	80	2249.23319	44.5008016	862.491243	38.6553239	Cooperate	2230.54659	44.7954131	804.926614	37.1192943	Cooperate
60	90	2260.59239	44.9569944	837.512134	37.602975	Cooperate	2272.47177	44.0696066	834.156482	40.0500338	Cooperate
70	10	1716.85559	30.7486105	437.321119	27.0271161	Cooperate	1714.91404	30.2898421	361.46987	27.0195973	Cooperate
70	20	2178.24314	31.1243428	569.84534	25.8850136	Cooperate	2138.22845	30.4823378	588.52749	25.8101747	Cooperate
70	30	2343.87383	30.2385384	735.004796	26.5311925	Cooperate	2340.31456	30.6162014	645.124144	25.5823262	Cooperate
70	40	2436.0486	30.5191089	812.686486	26.2720543	Cooperate	2431.73527	30.971605	723.472812	25.1679915	Cooperate
70	50	2480.10287	30.0268805	813.07013	26.9226745	Cooperate	2505.47497	30.9982021	775.298832	25.7427283	Cooperate
70	60	2547.76431	30.5084109	943.0045	26.9063303	Cooperate	2540.46038	30.8933702	865.544374	25.441305	Cooperate
70	70	2541.41611	29.8324677	895.907296	26.2762336	Cooperate	2586.22651	31.0444456	831.805966	26.091465	Cooperate
70	80	2585.65444	30.1656098	916.001502	25.8635966	Cooperate	2599.18576	30.2932991	878.771407	25.9380727	Cooperate
70	90	2612.51336	29.1214929	985.219951	25.1545963	Cooperate	2602.03673	30.7418011	923.94748	26.5071988	Cooperate
80	10	1996.81387	19.1386036	376.091745	16.0943596	Cooperate	1900.63221	19.2836375	271.588099	16.4247193	Cooperate
80	20	2435.91342	18.5179928	622.988854	16.6020732	Cooperate	2451.71913	19.190456	611.149831	15.9225804	Cooperate
80	30	2622.61002	19.085641	816.913446	16.1618095	Cooperate	2684.64366	18.9366579	616.262627	16.6263023	Cooperate
80	40	2781.19244	18.4080025	848.27317	16.1188025	Cooperate	2753.66472	19.1273083	821.967006	16.1904208	Cooperate
80	50	2834.49552	19.3489808	900.705316	16.2268865	Cooperate	2846.96292	18.9331096	845.355207	15.7969681	Cooperate
80	60	2888.82449	18.9727548	994.170057	16.3446744	Cooperate	2897.44438	19.0324261	930.316942	16.7813396	Cooperate
80	70	2896.07504	18.9874166	948.817807	15.873083	Cooperate	2938.37806	18.6393084	975.729082	15.9996429	Cooperate
80	80	2913.86683	18.8700903	1045.66214	15.6139687	Cooperate	2958.18006	18.8765383	943.627832	16.0191309	Cooperate
80	90	2962.94817	19.0258037	1036.04684	15.738561	Cooperate	2929.51381	18.8074639	998.402882	16.4291668	Cooperate
90	10	2148.22518	8.70156621	288.372344	8.1039872	Cooperate	2200.66811	8.96306829	285.962741	7.37257358	Cooperate
90	20	2752.62678	8.78410433	546.773495	7.66295398	Cooperate	2713.21718	8.9448759	630.918842	7.72307824	Cooperate
90	30	3014.10889	8.93333554	760.222981	7.75927107	Cooperate	2910.17429	8.98006417	688.768226	7.56336504	Cooperate
90	40	3070.09586	9.04515017	850.670586	7.88668897	Cooperate	3108.46004	8.94765988	981.849186	7.62115318	Cooperate
90	50	3215.81956	8.87489787	970.142785	7.69693191	Cooperate	3126.07835	8.90754569	949.790732	7.86306239	Cooperate
90	60	3235.7154	8.63106636	1004.86879	7.87654643	Cooperate	3230.73485	9.04820709	906.362936	7.22736491	Cooperate
90	70	3269.64277	8.89267342	1035.63255	7.52980217	Cooperate	3261.79261	8.87992936	1025.15898	7.93687283	Cooperate
90	80	3324.28164	8.81728096	915.591902	7.89879221	Cooperate	3276.97128	8.8805949	1099.90208	7.70877538	Cooperate
90	90	3333.87213	8.47076331	1049.07744	7.61329098	Cooperate	3323.3175	8.73082671	1010.97237	7.16255029	Cooperate

Table II Payoffs experienced by Clan 1 and Clan 2 under the %Y contribution rule. *Data was produced at all possible combinations of %contribution and %potlatch.*

Tables III and IV show sample run data for each individual-level scenario from years 0-11, a range that shows the period leading up to and including the first potlatch. The *pot* of both chiefs, as well as the *res-stored* of each Norank and Titleholder are shown at every time step. Note that although potlatch distributions and gift reception were programmed to occur within the same time-step, a quirk of NetLogo is that the distribution is subtracted from the chief's *pot* when *n*=10, but gifts are only added to the guests' *res-stored* when *n*=11. *%contribution* and *%potlatch* are both set at 50%, and the contribution rule in effect is %RS.

YEAR	Mutual cooperation																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	70.00	8.75	8.75	8.75	8.75	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	35.00	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
2	172.90	7.44	7.44	7.44	7.44	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	122.50	6.56	6.56	6.56	6.56	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19
3	268.63	7.11	7.11	7.11	7.11	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	214.38	6.89	6.89	6.89	6.89	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30
4	362.56	7.03	7.03	7.03	7.03	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36	307.34	6.97	6.97	6.97	6.97	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32
5	456.04	7.01	7.01	7.01	7.01	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	400.59	6.99	6.99	6.99	6.99	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
6	549.41	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	493.90	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
7	642.75	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	587.22	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
8	736.09	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	680.56	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
9	829.42	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	773.89	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
10	922.76	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	867.22	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
11	1016.09	55.03	55.03	55.03	55.03	31.15	31.15	31.15	31.15	31.15	31.15	31.15	31.15	480.28	7.00	7.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
	Defection - half noranks																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	38.00	5.25	5.25	5.25	5.25	2.50	2.50	1.75	2.50	2.50	1.75	1.75	1.75	85.12	9.05	9.05	9.05	9.05	2.50	4.03	4.03	2.50	2.50	4.03	4.03	2.50
2	133.00	6.56	6.56	6.56	6.56	3.13	3.13	2.19	3.13	3.13	2.19	2.19	2.19	192.28	7.51	7.51	7.51	7.51	3.13	2.76	2.76	3.13	3.13	2.76	2.76	3.13
3	232.75	6.89	6.89	6.89	6.89	3.28	3.28	2.30	3.28	3.28	2.30	2.30	2.30	295.07	7.13	7.13	7.13	7.13	3.28	2.44	2.44	3.28	3.28	2.44	2.44	3.28
4	333.69	6.97	6.97	6.97	6.97	3.32	3.32	2.32	3.32	3.32	2.32	2.32	2.32	396.77	7.03	7.03	7.03	7.03	3.32	2.36	2.36	3.32	3.32	2.36	2.36	3.32
5	434.92	6.99	6.99	6.99	6.99	3.33	3.33	2.33	3.33	3.33	2.33	2.33	2.33	498.19	7.01	7.01	7.01	7.01	3.33	2.34	2.34	3.33	3.33	2.34	2.34	3.33
6	536.23	7.00	7.00	7.00	7.00	3.33	3.33	2.33	3.33	3.33	2.33	2.33	2.33	599.55	7.00	7.00	7.00	7.00	3.33	2.33	2.33	3.33	3.33	2.33	2.33	3.33
7	637.56	7.00	7.00	7.00	7.00	3.33	3.33	2.33	3.33	3.33	2.33	2.33	2.33	700.89	7.00	7.00	7.00	7.00	3.33	2.33	2.33	3.33	3.33	2.33	2.33	3.33
8	738.89	7.00	7.00	7.00	7.00	3.33	3.33	2.33	3.33	3.33	2.33	2.33	2.33	802.22	7.00	7.00	7.00	7.00	3.33	2.33	2.33	3.33	3.33	2.33	2.33	3.33
9	840.22	7.00	7.00	7.00	7.00	3.33	3.33	2.33	3.33	3.33	2.33	2.33	2.33	903.56	7.00	7.00	7.00	7.00	3.33	2.33	2.33	3.33	3.33	2.33	2.33	3.33
10	941.56	7.00	7.00	7.00	7.00	3.33	3.33	2.33	3.33	3.33	2.33	2.33	2.33	1004.89	7.00	7.00	7.00	7.00	3.33	2.33	2.33	3.33	3.33	2.33	2.33	3.33
11	521.44	7.00	7.00	7.00	7.00	3.33	3.33	2.33	3.33	3.33	2.33	2.33	2.33	1231.37	59.14	59.14	59.14	59.14	3.33	33.62	33.62	3.33	3.33	33.62	33.62	3.33
	Defection - half titleholders																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	47.40	5.25	7.50	7.50	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	79.00	7.50	7.50	9.20	9.20	4.12	4.12	4.12	4.12	4.12	4.12	4.12	4.12
2	146.15	6.56	9.38	9.38	6.56	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	191.18	9.38	9.38	7.55	7.55	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78
3	249.84	6.89	9.84	9.84	6.89	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	298.23	9.84	9.84	7.14	7.14	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
4	354.76	6.97	9.96	9.96	6.97	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32	403.99	9.96	9.96	7.03	7.03	2.36	2.36	2.36	2.36	2.36	2.36	2.36	2.36
5	459.99	6.99	9.99	9.99	6.99	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	509.43	9.99	9.99	7.01	7.01	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
6	565.30	7.00	10.00	10.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	614.79	10.00	10.00	7.00	7.00	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
7	670.62	7.00	10.00	10.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	720.13	10.00	10.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
8	775.96	7.00	10.00	10.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	825.46	10.00	10.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
9	881.29	7.00	10.00	10.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	930.80	10.00	10.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
10	986.62	7.00	10.00	10.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	1036.13	10.00	10.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
11	1091.96	64.07	10.00	10.00	64.07	36.58	36.58	36.58	36.58	36.58	36.58	36.58	36.58	684.88	10.00	10.00	7.00	7.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33

Table III Sample run data from the raw Netlogo output is shown for the "Mutual Cooperation", "Defection – half Noranks" and "Defection – half Titleholders" scenarios. *Contribution rule = %RS; %contribution = 50; %potlatch = 50.*

YEAR	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
	Defection - all noranks																									
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	41.00	5.25	5.25	5.25	5.25	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	101.68	9.35	9.35	9.35	9.35	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
2	143.50	6.56	6.56	6.56	6.56	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	212.38	7.59	7.59	7.59	7.59	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
3	251.13	6.89	6.89	6.89	6.89	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28	322.06	7.15	7.15	7.15	7.15	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28
4	360.03	6.97	6.97	6.97	6.97	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	431.47	7.04	7.04	7.04	7.04	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32
5	469.26	6.99	6.99	6.99	6.99	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	540.83	7.01	7.01	7.01	7.01	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
6	578.56	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	650.17	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
7	687.89	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	759.50	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
8	797.22	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	868.84	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
9	906.56	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	978.17	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
10	1015.89	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	1087.50	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
11	1412.46	66.84	66.84	66.84	66.84	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	598.42	7.00	7.00	7.00	7.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
	Defection - all titleholders																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	88.00	7.50	7.50	7.50	7.50	4.39	4.39	4.39	4.39	4.39	4.39	4.39	4.39	61.60	7.50	7.50	7.50	7.50	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
2	208.56	9.38	9.38	9.38	9.38	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	171.60	9.38	9.38	9.38	9.38	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19
3	326.70	9.84	9.84	9.84	9.84	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46	287.10	9.84	9.84	9.84	9.84	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30
4	444.23	9.96	9.96	9.96	9.96	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	403.98	9.96	9.96	9.96	9.96	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32
5	561.62	9.99	9.99	9.99	9.99	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	521.19	9.99	9.99	9.99	9.99	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
6	678.96	10.00	10.00	10.00	10.00	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	638.50	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
7	796.30	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	755.82	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
8	913.64	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	873.16	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
9	1030.97	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	990.49	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
10	1148.30	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	1107.82	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
11	885.94	10.00	10.00	10.00	10.00	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	1225.16	10.00	10.00	10.00	10.00	40.30	40.30	40.30	40.30	40.30	40.30	40.30	40.30
	Mutual defection																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	124.00	7.50	7.50	7.50	7.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	70.00	7.50	7.50	7.50	7.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
2	249.00	9.38	9.38	9.38	9.38	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	195.00	9.38	9.38	9.38	9.38	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13
3	380.25	9.84	9.84	9.84	9.84	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28	326.25	9.84	9.84	9.84	9.84	3.28	3.28	3.28	3.28	3.28	3.28	3.28	3.28
4	513.06	9.96	9.96	9.96	9.96	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	459.06	9.96	9.96	9.96	9.96	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32
5	646.27	9.99	9.99	9.99	9.99	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	592.27	9.99	9.99	9.99	9.99	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
6	779.57	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	725.57	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
7	912.89	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	858.89	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
8	1046.22	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	992.22	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
9	1179.56	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	1125.56	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
10	1312.89	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	1258.89	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
11	1780.36	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	974.56	10.00	10.00	10.00	10.00	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33

Table IV Sample run data from the raw Netlogo output is shown for the "Defection – all Noranks", "Defection all Titleholders" and "Mutual Defection" scenarios.
Contribution rule = %RS; %contribution = 50; %potlatch = 50.

Tables V and VI show sample run data for the mutual cooperation scenario to illustrate the savings effect in both contribution rules. Data is shown for the years 0-11, 21, 31 and 41, at three intervals of *%contribution*, and *%potlatch* is kept constant at 50%. The *pot* of both chiefs, as well as the *res-stored* of each Norank and Titleholder are shown at every given time step.

YEAR	%contribution = 30% | %RS																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	42.00	9.45	9.45	9.45	9.45	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71	21.00	7.35	7.35	7.35	7.35	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
2	104.24	10.66	10.66	10.66	10.66	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	77.70	9.92	9.92	9.92	9.92	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31
3	168.03	11.08	11.08	11.08	11.08	3.76	3.76	3.76	3.76	3.76	3.76	3.76	3.76	139.55	10.82	10.82	10.82	10.82	3.61	3.61	3.61	3.61	3.61	3.61	3.61	3.61
4	232.35	11.23	11.23	11.23	11.23	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	203.19	11.14	11.14	11.14	11.14	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71
5	296.87	11.28	11.28	11.28	11.28	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	267.47	11.25	11.25	11.25	11.25	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
6	361.45	11.30	11.30	11.30	11.30	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	331.96	11.29	11.29	11.29	11.29	3.76	3.76	3.76	3.76	3.76	3.76	3.76	3.76
7	426.05	11.30	11.30	11.30	11.30	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	396.54	11.30	11.30	11.30	11.30	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77
8	490.66	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	461.14	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77
9	555.28	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	525.75	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77
10	619.89	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	590.36	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77
11	342.25	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	654.98	45.53	45.53	45.53	45.53	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30
21	984.14	84.28	84.28	84.28	84.28	47.55	47.55	47.55	47.55	47.55	47.55	47.55	47.55	729.70	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77
31	963.33	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77	1375.86	107.64	107.64	107.64	107.64	61.57	61.57	61.57	61.57	61.57	61.57	61.57	61.57
41	1609.49	131.97	131.97	131.97	131.97	76.17	76.17	76.17	76.17	76.17	76.17	76.17	76.17	1206.63	11.31	11.31	11.31	11.31	3.77	3.77	3.77	3.77	3.77	3.77	3.77	3.77
	%contribution = 60% | %RS																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	42.00	4.20	4.20	4.20	4.20	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	84.00	8.40	8.40	8.40	8.40	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92
2	142.80	5.04	5.04	5.04	5.04	1.68	1.68	1.68	1.68	1.68	1.68	1.68	1.68	206.98	5.88	5.88	5.88	5.88	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18
3	246.96	5.21	5.21	5.21	5.21	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74	315.57	5.38	5.38	5.38	5.38	1.84	1.84	1.84	1.84	1.84	1.84	1.84	1.84
4	351.79	5.24	5.24	5.24	5.24	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	421.29	5.28	5.28	5.28	5.28	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
5	456.76	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	526.43	5.26	5.26	5.26	5.26	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
6	561.75	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	631.46	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
7	666.75	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	736.47	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
8	771.75	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	841.47	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
9	876.75	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	946.47	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
10	981.75	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1051.47	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
11	1086.75	63.07	63.07	63.07	63.07	36.44	36.44	36.44	36.44	36.44	36.44	36.44	36.44	578.23	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
21	1614.37	132.81	132.81	132.81	132.81	78.29	78.29	78.29	78.29	78.29	78.29	78.29	78.29	1275.62	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
31	1753.14	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	2325.62	180.56	180.56	180.56	180.56	106.94	106.94	106.94	106.94	106.94	106.94	106.94	106.94
41	2803.14	231.88	231.88	231.88	231.88	137.73	137.73	137.73	137.73	137.73	137.73	137.73	137.73	2266.35	5.25	5.25	5.25	5.25	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
	%contribution = 90% | %RS																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	126.00	7.35	7.35	7.35	7.35	4.13	4.13	4.13	4.13	4.13	4.13	4.13	4.13	63.00	1.05	1.05	1.05	1.05	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
2	308.20	1.42	1.42	1.42	1.42	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	195.30	1.10	1.10	1.10	1.10	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
3	443.31	1.12	1.12	1.12	1.12	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	327.92	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
4	576.06	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	460.55	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
5	708.70	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	593.18	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
6	841.33	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	725.81	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
7	973.96	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	858.44	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
8	1106.59	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	991.07	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
9	1239.23	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	1123.70	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
10	1371.86	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	1256.34	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
11	1504.49	70.55	70.55	70.55	70.55	42.04	42.04	42.04	42.04	42.04	42.04	42.04	42.04	694.48	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
21	2052.30	170.28	170.28	170.28	170.28	101.87	101.87	101.87	101.87	101.87	101.87	101.87	101.87	1691.76	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
31	2394.50	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	3018.08	240.56	240.56	240.56	240.56	144.04	144.04	144.04	144.04	144.04	144.04	144.04	144.04
41	3720.82	318.14	318.14	318.14	318.14	190.59	190.59	190.59	190.59	190.59	190.59	190.59	190.59	3170.33	1.11	1.11	1.11	1.11	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37

Table V Sample run data from the raw Netlogo output is shown for three given levels of %contribution under the %RS rule. *The scenario in place is "Mutual Cooperation", and %potlatch = 50.*

YEAR	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
	%contribution = 30% | %Y																									
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	21.00	7.35	7.35	7.35	7.35	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	42.00	9.45	9.45	9.45	9.45	3.71	3.71	3.71	3.71	3.71	3.71	3.71	3.71
2	63.00	11.03	11.03	11.03	11.03	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	84.00	12.08	12.08	12.08	12.08	4.31	4.31	4.31	4.31	4.31	4.31	4.31	4.31
3	105.00	12.86	12.86	12.86	12.86	4.29	4.29	4.29	4.29	4.29	4.29	4.29	4.29	126.00	13.39	13.39	13.39	13.39	4.60	4.60	4.60	4.60	4.60	4.60	4.60	4.60
4	147.00	13.78	13.78	13.78	13.78	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59	168.00	14.04	14.04	14.04	14.04	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75
5	189.00	14.24	14.24	14.24	14.24	4.75	4.75	4.75	4.75	4.75	4.75	4.75	4.75	210.00	14.37	14.37	14.37	14.37	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
6	231.00	14.47	14.47	14.47	14.47	4.82	4.82	4.82	4.82	4.82	4.82	4.82	4.82	252.00	14.54	14.54	14.54	14.54	4.86	4.86	4.86	4.86	4.86	4.86	4.86	4.86
7	273.00	14.59	14.59	14.59	14.59	4.86	4.86	4.86	4.86	4.86	4.86	4.86	4.86	294.00	14.62	14.62	14.62	14.62	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88
8	315.00	14.64	14.64	14.64	14.64	4.88	4.88	4.88	4.88	4.88	4.88	4.88	4.88	336.00	14.66	14.66	14.66	14.66	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89
9	357.00	14.67	14.67	14.67	14.67	4.89	4.89	4.89	4.89	4.89	4.89	4.89	4.89	378.00	14.68	14.68	14.68	14.68	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
10	399.00	14.69	14.69	14.69	14.69	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	420.00	14.69	14.69	14.69	14.69	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90
11	220.50	14.69	14.69	14.69	14.69	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.90	462.00	36.74	36.74	36.74	36.74	18.13	18.13	18.13	18.13	18.13	18.13	18.13	18.13
21	651.00	58.80	58.80	58.80	58.80	31.36	31.36	31.36	31.36	31.36	31.36	31.36	31.36	441.00	14.72	14.72	14.72	14.72	4.91	4.91	4.91	4.91	4.91	4.91	4.91	4.91
31	535.50	14.74	14.74	14.74	14.74	4.93	4.93	4.93	4.93	4.93	4.93	4.93	4.93	861.00	68.25	68.25	68.25	68.25	37.03	37.03	37.03	37.03	37.03	37.03	37.03	37.03
41	955.50	78.75	78.75	78.75	78.75	43.33	43.33	43.33	43.33	43.33	43.33	43.33	43.33	640.50	14.75	14.75	14.75	14.75	4.93	4.93	4.93	4.93	4.93	4.93	4.93	4.93
	%contribution = 60% | %Y																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	84.00	8.40	8.40	8.40	8.40	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92	42.00	4.20	4.20	4.20	4.20	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
2	168.00	8.40	8.40	8.40	8.40	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	126.00	6.30	6.30	6.30	6.30	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
3	252.00	8.40	8.40	8.40	8.40	3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08	210.00	7.35	7.35	7.35	7.35	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
4	336.00	8.40	8.40	8.40	8.40	2.94	2.94	2.94	2.94	2.94	2.94	2.94	2.94	294.00	7.88	7.88	7.88	7.88	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
5	420.00	8.40	8.40	8.40	8.40	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87	378.00	8.14	8.14	8.14	8.14	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71
6	504.00	8.40	8.40	8.40	8.40	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83	462.00	8.27	8.27	8.27	8.27	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76
7	588.00	8.40	8.40	8.40	8.40	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	546.00	8.33	8.33	8.33	8.33	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78
8	672.00	8.40	8.40	8.40	8.40	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	630.00	8.37	8.37	8.37	8.37	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79
9	756.00	8.40	8.40	8.40	8.40	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	714.00	8.38	8.38	8.38	8.38	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79
10	840.00	8.40	8.40	8.40	8.40	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	798.00	8.39	8.39	8.39	8.39	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
11	462.00	8.40	8.40	8.40	8.40	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	882.00	54.60	54.60	54.60	54.60	30.52	30.52	30.52	30.52	30.52	30.52	30.52	30.52
21	1302.00	96.60	96.60	96.60	96.60	55.72	55.72	55.72	55.72	55.72	55.72	55.72	55.72	882.00	8.45	8.45	8.45	8.45	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
31	1071.00	8.49	8.49	8.49	8.49	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	1722.00	115.50	115.50	115.50	115.50	67.06	67.06	67.06	67.06	67.06	67.06	67.06	67.06
41	1911.00	136.50	136.50	136.50	136.50	79.66	79.66	79.66	79.66	79.66	79.66	79.66	79.66	1281.00	8.50	8.50	8.50	8.50	2.86	2.86	2.86	2.86	2.86	2.86	2.86	2.86
	%contribution = 90% | %Y																									
	Chief 1	T 1-1	T 1-2	T 1-3	T 1-4	N 1-1	N 1-2	N 1-3	N 1-4	N 1-5	N 1-6	N 1-7	N 1-8	Chief 2	T 2-1	T 2-2	T 2-3	T 2-4	N 2-1	N 2-2	N 2-3	N 2-4	N 2-5	N 2-6	N 2-7	N 2-8
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	63.00	1.05	1.05	1.05	1.05	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	126.00	7.35	7.35	7.35	7.35	4.13	4.13	4.13	4.13	4.13	4.13	4.13	4.13
2	189.00	1.57	1.57	1.57	1.57	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	252.00	4.73	4.73	4.73	4.73	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
3	315.00	1.84	1.84	1.84	1.84	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	378.00	3.41	3.41	3.41	3.41	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56
4	441.00	1.97	1.97	1.97	1.97	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	504.00	2.76	2.76	2.76	2.76	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
5	567.00	2.03	2.03	2.03	2.03	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	630.00	2.43	2.43	2.43	2.43	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
6	693.00	2.07	2.07	2.07	2.07	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	756.00	2.26	2.26	2.26	2.26	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
7	819.00	2.08	2.08	2.08	2.08	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	882.00	2.18	2.18	2.18	2.18	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
8	945.00	2.09	2.09	2.09	2.09	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1008.00	2.14	2.14	2.14	2.14	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
9	1071.00	2.10	2.10	2.10	2.10	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1134.00	2.12	2.12	2.12	2.12	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
10	1197.00	2.10	2.10	2.10	2.10	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1260.00	2.11	2.11	2.11	2.11	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
11	661.50	2.10	2.10	2.10	2.10	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	1386.00	68.26	68.26	68.26	68.26	40.39	40.39	40.39	40.39	40.39	40.39	40.39	40.39
21	1953.00	134.40	134.40	134.40	134.40	80.08	80.08	80.08	80.08	80.08	80.08	80.08	80.08	1323.00	2.17	2.17	2.17	2.17	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
31	1606.50	2.23	2.23	2.23	2.23	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	2583.00	162.75	162.75	162.75	162.75	97.09	97.09	97.09	97.09	97.09	97.09	97.09	97.09
41	2866.50	194.25	194.25	194.25	194.25	115.99	115.99	115.99	115.99	115.99	115.99	115.99	115.99	1921.50	2.26	2.26	2.26	2.26	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79

Table VI Table V Sample run data from the raw Netlogo output is shown for three given levels of %contribution under the %Y rule. *The scenario in place is "Mutual Cooperation", and %potlatch = 50.*

APPENDIX 2

Figure I shows a set of screenshots of the model visualisation in Netlogo. The screenshots were taken during one run of the model with the "Defection – half Noranks" scenario selected, so that the impact of having some defectors in the system could be seen.

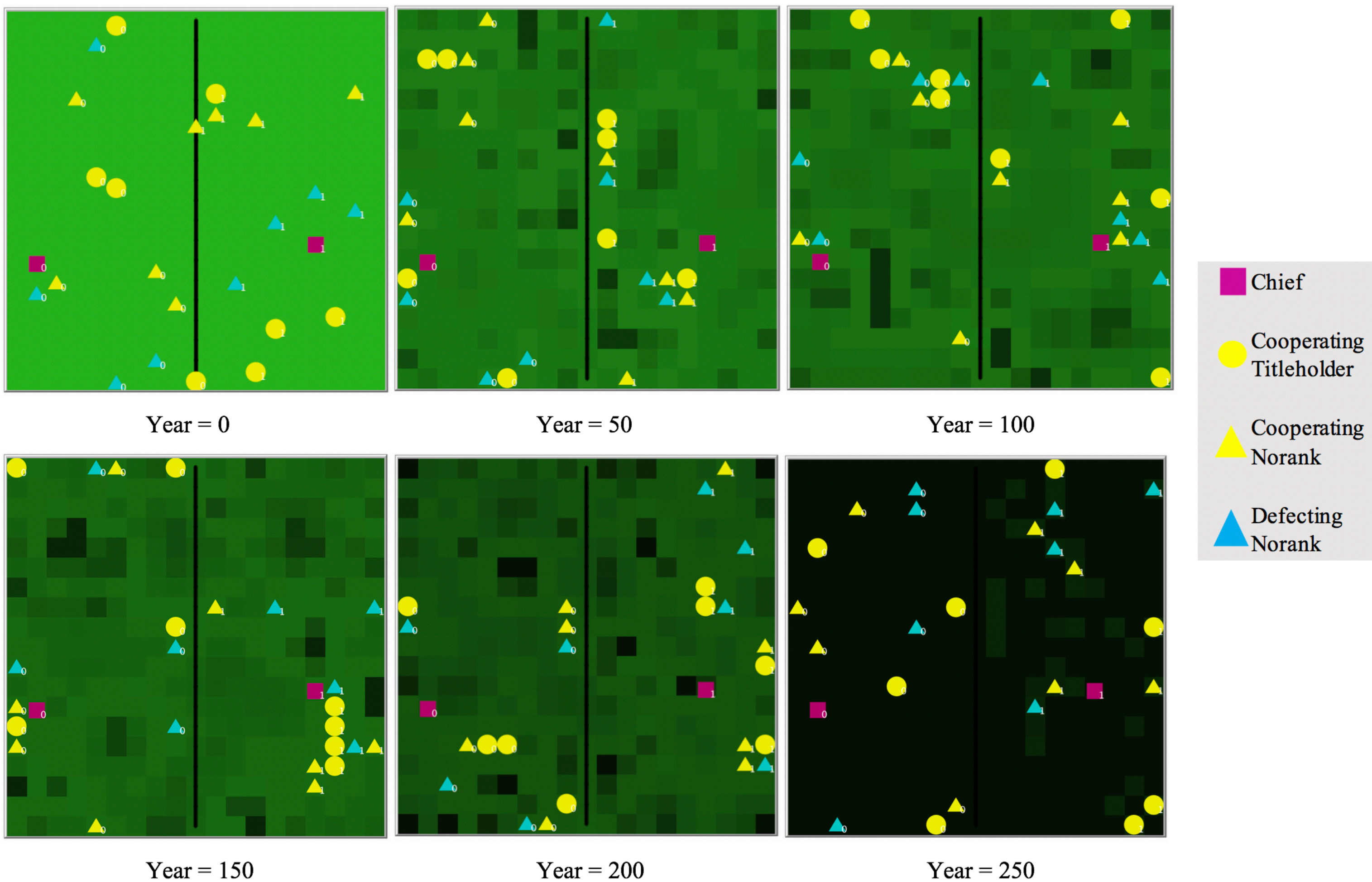

Figure I Examples of the Netlogo model visualization tool from one run. *Screenshots were taken every 50 years from year 0 to 250. The stop condition was triggered at year 256 during this run. The greyscale value of the green color on each patch shows how depleted it is; the darker the patch, the fewer resources are stocked in it.*