**Chapter 3**

**Section A (conservation investment)**

**Introduction**

Global conservation funding is currently inadequate to eliminate biodiversity loss (Echols et al., 2019; Waldron et al., 2013). Previous estimates suggest that in 2010 only 12% of the required $0.875 billion – $1.23 billion was being spent on conservation, leaving the global conservation funding shortfall in the order of $0.77 billion - $1.08 billion (McCarthy et al 2012). Although global estimates such as these are unlikely to be accurate, the order of magnitude conveys the scale of the funding challenge. Therefore, to have the greatest positive effect on the conservation of biodiversity as possible, managers and conservationists need to ensure the investment of scarce resources is strategic and efficient, and they must strive to maximise the biodiversity outcomes of each dollar spent (Bruner et al., 2004; McBride et al., 2007; Waldron et al., 2013).

Investing conservation funds strategically over time is made difficult by the dominant funding model that exists in conservation which is based on short-term grants that generally last between one and five years (Hodge and Adams, 2016). Most conservation projects or initiatives, even in wealthy countries with relatively well-funded protected area networks, rely on such short-term grants to launch programmes, conduct research, and implement key activities such as training, engagement, enforcement, and outreach. This funding model results in long-term budgets that are non-linear, often unpredictable, and do not necessarily track changes in threat levels. The financial stability of a conservation project or organisation is therefore reliant on the ability to leverage external funding through grant applications, which are inherently competitive and have low success rates. This funding mechanism means that conservation projects go through periods of relative affluence when conservation activities (such as enforcement, policy interventions, community engagement) can increase in scope and scale, ultimately leading to net benefits for nature. The same projects will inevitably go through periods of financial hardship, which often occur between grants. During these periods financial expenditure is restricted to minimal core activities, project activities wind down, staff redundancies occur, and initiatives end. These periods can have serious negative effects on conservation projects. Organisations lose talented staff and thus institutional knowledge, trust between stakeholders and the project or organisation can be lost as commitments may not be met, and stakeholders may view the project as unreliable due to inconsistent support. In many parts of the world where unregulated or illegal activities such as forest clearance and hunting of wildlife threaten conservation landscapes, periods of financial hardship can cause increases in these activities as project support for enforcement, engagement, outreach, and overall project visibility decreases.

The long-term cycle of organisations applying for grants to maintain budgets leads to ‘projectification’, whereby control over conservation activities, interventions, and strategic direction is ceded to funders, as conservation organisations adapt to funding trends and specific funder interests in an effort to remain competitive and maintain project funding (Hodge and Adams, 2016). Nevertheless, many conservation projects are unable to fund activities through other means. Grants for conservation activities vary in size and duration, with larger, long-term grants (between three and five years) often requiring significant investments in staff time for the development of applications, and substantial administrative capacity to manage the grant if it is awarded. Such grants are often awarded by international financial institutions (e.g, the World Bank) or international development agencies (e.g., the United States Agency for International Development), and often come with complex rules governing procurement, accounting, reporting, and attribution (e.g., branding). These requirements often preclude smaller organisations that do not have in-house fundraising teams or large financial management and administrative capacity. Alternatively, conservation organisations can apply for smaller, short-term grants (between one and three years) which are often targeted towards specific species, habitats, or activities (e.g., the United States Fish and Wildlife Service Asian Elephant Conservation Fund, and the UK government’s Darwin Initiative). The smaller grants require less staff time for the application process and subsequent grant management yet can be limited in the amount of the award that can be spent on overheads, fixed costs, and other core project expenditure such as salaries, fuel, office space, and utilities. This results in the core operational budgets of smaller projects or organisations comprising small percentages of multiple short-term grants, leading to insecure and unstable core budgets that can fluctuate from year to year. Budgets such as this prohibit long-term strategic planning for investment of funds and conservation action (Emerton et al., 2006).

Reliance on limited duration grants rather than permanent core funding is one cause of the global conservation funding shortfall. Protected areas are the cornerstones of landscape-level conservation, yet up to 75% are severely underfunded (Coad et al., 2019). Insufficient funding of protected land- and seascapes leads to poor management, ecological damage, and the loss of species and habitats (Kearney et al., 2020; Pringle, 2017). It is difficult to design and implement effective conservation action that targets the correct drivers at the correct spatial and temporal scales when available funding is consistently below what is required (Tulloch et al., 2020). In landscapes where harvesting of wildlife occurs, weak management and regulation, which is a common symptom of chronic underfunding, can increase the probability of population collapse of the harvested species (Fryxell et al., 2010). In the absence of dramatic increases in funding and resources available to landscape managers, studies that explore the trade-offs between different strategies for investing existing resources will be critical. Site-level assessments of investment priorities are relatively common, and form an important part of a manager’s toolkit for developing strategy (see Ervin, 2003; Utami et al., 2020). Yet studies that provide broader theoretical insights into long-term investment strategies in the context of finite resources are lacking. There is a large body of literature that explores prioritising conservation investment over space, or the ‘conservation resource allocation problem’ (Wilson et al., 2006), with approaches including return on investment (Armsworth et al., 2018; Murdoch et al., 2010), heuristic algorithms (Meir et al., 2004; Wilson et al., 2006), regression models (Fishburn et al., 2013), and impact mapping (Tulloch et al., 2020). The next question, which is equally important yet largely unanswered, is once land has been selected or acquired for conservation, how should the authority responsible for its management invest finite conservation resources over the next five, ten, thirty, or fifty years to minimise biodiversity loss?

One of the main challenges associated with assessing future conservation implementation and predicting outcomes is the inherent uncertainty surrounding future conditions (McBride et al., 2007). Previous studies have investigated the effects of investment uncertainty (transaction uncertainty and performance uncertainty) on the optimal allocation of conservation funds to land acquisition (McBride et al., 2007), and uncertainty surrounding future site conditions (availability and ecological condition) and how this influences the optimal combination of short- and long-term conservation contracts with private landowners (Lennox and Armsworth, 2011). Yet the uncertainty surrounding changing social-ecological conditions within a single site or landscape over time, and how this may affect biological resources given different investment strategies by the management authority, has yet to be investigated. The global human population is increasing, particularly around protected areas and other ecologically rich landscapes (Wittemyer et al., 2008), and increasing human populations within these areas increase pressure on natural resources (Lindsey et al., 2014). Therefore, understanding how investment decisions by landscape managers affect system dynamics in the context of increasing human pressure and uncertainty, will be critical for developing strategies that maximise conservation gains. Lessons can be learnt from empirical studies that examine past strategies and the subsequent observed outcomes (Santana et al., 2014), but using such data to project future social-ecological conditions and system dynamics is at best challenging, and at worst misleading (Mouquet et al., 2015). In contrast to empirical studies, simulation modelling offers an analytical environment within which system dynamics can be stress tested without any real-world consequences.

Conservationists have for many years relied on both theory and empirical generalisations to make urgent decisions when appropriate data have been lacking (Doak and Mills, 1994). Perhaps borne out of necessity in the past, theoretical models are now seen as important tools for ecologists and conservation biologists to improve understanding of their study systems (Green et al., 2005). Mathematical models offer the opportunity to take the well-studied component parts of a complex system and reassemble them in ways that capture their fundamental properties whilst allowing for the interrogation of system dynamics (Wilson, 1999). Such models require complex systems to be carefully simplified so that theories can be tested within a manageable environment whilst ensuring fundamental processes are honoured. The simplification of models to develop and test theory has been seen as an important approach for decades, with the understanding that building models that are all at once manageable, general, realistic, and precise is impossible (Levins, 1966). The importance and utility of simple theoretical models is easily forgotten in this age of exponentially increasing computing power and advanced statistical techniques, which allow researchers to move towards increasingly complex models and analyses. However, adding complexity and detail to models is not always the best approach as increases in complexity require more data and computation time, analysis and interpretation become more difficult, and the ability to generalise is lost (Green et al., 2005). Social-ecological systems (SES) are fundamentally complex, dynamic systems which are characterised by non-linear relationships and feedbacks between multiple social and ecological sub-systems (Berkes et al., 2000). It is not feasible to build a model that captures all components of a SES, and therefore simplified models that simulate the fundamental dynamics are required to test social-ecological theory. Generalised Management Strategy Evaluation (GMSE) is a modelling framework that allows the construction of simplified social-ecological systems that are comprised of four fundamental sub-systems, allowing for a huge variety of theoretical investigations (Bunnefeld et al., 2011; Duthie et al., 2018).

In this study, we build a widely applicable mechanistic model of a generic conservation landscape and use it to investigate the dynamics between different conservation investment strategies and forest loss, in the context of increasing human populations over a period of 50 years. To disentangle and emphasise potential effects of the different investment strategies on forest loss, we simplify the system so that the actions of the human stakeholders are the only factors influencing forest loss, and we push the investment scenarios to their extremes. We use the GMSE modelling framework (Duthie et al., 2018) to test the effects of five investment scenarios available to the landscape management authority that are designed to reflect real-world conservation funding scenarios: 1) a uniform management budget that does not increase or decrease over the study period, 2) a management budget that increases linearly over time, 3) a management budget that fluctuates in a predictable and regular way, reflecting short-term grant cycles, 4) a management budget that fluctuates randomly and unpredictably, but with only minor variation from the starting value, reflecting a core budget that increases or decreases via short-term grants, and 5) a management budget that fluctuates randomly and unpredictably with high variation from the starting value, reflecting a highly variable budget that has no core quantity, and is influenced by short-term grants of varying sizes and durations. This modelling framework in generalised in such a way as to be of interest to landscape managers and conservationists around the world who are reliant on non-linear and unpredictable funding cycles, and offers theoretical insights into the consequences of the business-as-usual conservation funding mechanisms.