Chapter 5
Balancing Sustainable Coastal Management with Development in New Zealand

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Abstract Historically in New Zealand, coastal environments were viewed as amenities for subdivision to be incorporated into town structure plans with little regard for hazards and scientific investigation. This subdivision of coastal land has led to the proliferation of developments that are increasingly vulnerable to the slow landward creep of sea level rise and increasing extreme storm events. Planning and management of vulnerable coastal communities and infrastructure could benefit from an emphasis on sustainable and resilient adaptation through managed retreat away from coastal hazards. However, it is not at all clear exactly how managed retreat can be accomplished. This chapter explores methods for analysing the interactions and manifestations of complex intersecting environmental and economic systems that are implicit in a managed retreat from coastal hazards. These complex systems can be quantifiably analysed using the principles of evolutionary economics, which enables identification of knowledge structures and information flows that can inform institutional decision-making and planning. The chapter aims to explore how policy planning, implemented through the lens of evolutionary economics, can inform sustainable land-use management and development through managed retreat in the coastal environment. It discusses Systems Thinking

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approaches to aid the decision-making process in order to reveal effective policy outcomes and financial mechanisms that enable resilient coastal management. Specific consideration is given to System Dynamics modelling, economic impact analysis and Robust Decision Making.

Keywords Managed retreat · Evolutionary economics · Coastal hazards · System Dynamics · Climate change

5.1 Introduction

New Zealand is a developed island nation where sea level rise and increasing storm events will affect its inhabitants more severely than larger and more affluent countries given its geographical location and extent. There is also a significant proportion of vulnerable assets at the coast when compared to total national capital (NIWA 2015). This makes it a good case study for other nation states to learn practical steps to enable managed retreat given the increasing risk from coastal hazards.

Coastal hazard planning in New Zealand has historically been decentralised, ad hoc and risk mitigation is largely achieved through the use of physical structures or modifications of building standards to protect vulnerable assets (Kirk et al. 1999). Relocating assets away from hazards has been employed only as a last resort after repeated failure of technical fixes (Waikato Regional Council 2006). To date, there have only been a few small-scale attempts at coastal relocation in New Zealand. For instance, between 1962 and 1965 at Mokau Spit, Waikato, eleven sections were revested with the crown following coastal erosion with compensation to property owners (Waikato Regional Council 2006). Similarly, between 1965 and 1975 at Ohiwa Spit in the Bay of Plenty, houses were lost to the sea, titles were revested with the Crown and compensation paid for residents to relocate (Waikato Regional Council 2006). In contrast to ‘forced’ relocation after disaster, there is increasing recognition internationally that managed retreat from coastal hazards will be necessary to minimise risk for communities and provide a resilient future for society (Dyckman et al. 2014; Freudenberg et al. 2016; Hino et al. 2017; Reisinger et al. 2015).

Managed retreat at the coast is a proactive, strategic and long-term management approach to eliminate exposure to the human-use system by migrating exposed assets, or vulnerable communities, inland due to threats posed by rising sea levels, coastal erosion and flooding (Reisinger et al. 2015). Managed retreat is an evolving process that demands a set of adaptive strategies over time as a single solution alone will not suffice (Owen et al. 2018). However, managed retreat is not without its issues: (1) it is currently constrained by a lack of knowledge of what it exactly is, otherwise known as a ‘black box’, (2) there is uncertainty around its implementation by government and communities, which exacerbates opposition to it, and (3) funding mechanisms for the large capital and labour costs of managed retreat do not currently exist in New Zealand (Boston 2017; Owen et al. 2018). Financial compensation is often not available and managed retreat can also be stifled by urban boundaries that concentrate development into allowable zones (Freudenberg et al. 2016). Currently retreat from areas prone to natural hazards occurs as a reactive approach to restore order to society after a disaster (Ryan 2018).

Insights from New Zealand have shown that the implementation of managed retreat will require scientifically informed decision-making on changes to the environmental system (New Zealand Government 2017), defining the extent of coastal vulnerability (New Zealand Government 2017), discovering the long-term stakeholder and community desires and expectations through co-creation (Kench et al. 2018), long-term land-use planning and financial incentives for relocation (Tombs and France-Hudson 2018). Modelling the economic impact of managed retreat through examining probable futures and policy implementations can enable scenarios for a smooth transition to resilience for populations exposed to coastal hazards. Modelled economic drivers can then provide insights into how a successful implementation of managed retreat to support hazard management would evolve. Economic drivers may include changes in business operability, value added, capital value or investment, land supply or household wealth. Whereas compensation arrangements, insurability or property taxes can also drive behavioural change (Storey et al. 2017; Tombs and France-Hudson 2018).

An analytical framework is required to assess plans through economic impact modelling of future scenarios and policy outcomes with regard to these economic drivers. This analytical framework consists of a theoretical framework derived through evolutionary economics, and a conceptual framework using System Dynamics. Evolutionary economics is analogous to that of evolutionary biology, it considers economic systems as dynamic, that they reflect historical process, and that they exhibit instinctual and habit-based behaviour (Schumpeter 1912; Veblen 1899). System Dynamics is an ontology of Systems Thinking that interprets how physical and social systems behave through modelling multi-loop nonlinear feedbacks in complex systems (Forrester 1971). Evolutionary economics considers the economic system as knowledge-based with stocks of knowledge and flows of information (Foster and Hölzl 2004). Similarly, System Dynamics facilitates knowledge creation on the drivers of change by adjusting the quantity of stocks in the system through flows between influential variables over time (Ruth and Hannon 2012). System Dynamics analysis leads to an understanding of behavioural drivers of complex systems at an aggregated level which is fundamental to evolutionary economics. System Dynamics can inform stakeholders about the possible impacts of the transition dynamics that they will pass through when implementing managed retreat. Combining this with models based on evolutionary economic theory enables us to better understand the economic consequences of coastal management and development decisions, recognising that economic considerations are a key component of decision-making.

This chapter reviews a process to enable managed retreat from coastal hazards through evolutionary economics and System Dynamics within a context of coastal management in New Zealand. Section 5.2 outlines how legislation has shaped the coastal environment. Section 5.3 addresses the evolving risk and exposure from a changing climate. Section 5.4 explores the contribution that evolutionary economics can bring to the planning regime. Finally, Sects. 5.5 and 5.6 discuss possible approaches to enable managed retreat through financing and planning implementations.

5.2 Legislating New Zealand's Coast

Coastal land-use planning in New Zealand is primarily governed by the statutory documents of the Resource Management Act 1991 (RMA 1991) and the New Zealand Coastal Policy Statement 2010 (NZCPS 2010). Previously, it was under the influence of the Town and Country Planning Act (TACPA). Other legislation that influences the coastal zone includes the Local Government Act 2002 (LGA 2002), the Public Works Act 1981 (PWA 1981) and the Civil Defense and Emergency Management Act 2002 (CDEMA 2002). However, these statutory legislative acts are not well integrated and operate under differing time frames (Boston and Lawrence 2017). Table 5.1 summarises coastal legislation over the past half-century.

Many vulnerable coastal developments in New Zealand were authorised under the TACPA 1953. They were established for their proximity to coastal amenities and leisure, often with a lack of robust environmental assessment. Part 1 of the TACPA 1953 required the preparation of regional planning schemes with an accompanying survey of natural resources and their potential uses and values for conservation and economic development. The approach employed a static use of planning instruments through structure plans and focused on lands as economic 'resources' that contributed to the expansion of residential development into the coastal environment. There was little regard for hazard identification or scientific investigation in zoning, which led to the incorporation of coastal environments into structure plans. For instance, at Omaha Beach (Rodney District) the sand spit was developed for housing with a marginal seawall in 1971 (Omaha Beach Community Inc 2017). A large storm in 1978 destroyed this seawall. Groynes were subsequently constructed and beach nourishment undertaken by developers to gain further land-use consent at the end of the spit and protect homes from storms (Omaha Beach Community Inc 2017; Peart 2009). The TACPA 1977 amended this issue by introducing regulatory zoning and allowed for the identification of areas vulnerable to natural hazards (de Lange 2006). These historical planning regimes were less focussed on coastal hazards and sea level rise and more so on the subdivision of farmland, maintaining amenity values and preserving access to the coast (Peart 2009).

Currently, the RMA 1991 is the foundation legislation in New Zealand for land-use and development. It provides authorities with an assessment of environmental effects from the applicant before resource consent is given. Land-use consents are granted based on the premise that any adverse effects are mitigated, and that appropriate scientific inquiry is undertaken to reveal less than minor hazard

Table 5.1 Historical and contemporary coastal legislation in New Zealand

Act	Timeframe	Purpose	Comments
Town And Country Planning Act (TACPA)	1953–1977	State-centred spatial resource planning.	The utility of natural resources dominates. Extensive subdivision and structural development at the coast. Many devolved councils and boards with minimal interaction.
Town And Country Planning Act (TACPA)	1977–1991	Amended original act.	Introduced regulatory zoning for hazards. A new emphasis on scientific investigation.
Resource Management Act (RMA)	1991-	Effects-based resource planning and management. Preservation of environments from inappropriate development while maintaining public access and ecosystems. Implicitly applies the precautionary principle. Legislatively enables the NZCPS.	Assessment of environmental effects dominates. Good policy, poor implementation due to stakeholder contestation.
New Zealand Coastal Policy Statement (NZCPS)	1994 & 2010-	Identify coastal hazards for 100 years. Assess the risks of climate change on new and existing development. Allow for the amenity and natural character of the coast.	Historically ambiguous to local government.
Local Government Act (LGA)	2002-	Provide infrastructure. Land-use plans at the annual and decadal interval with public consultation. Building control. Meet the needs of future generations through the provision of services, roads and access.	
Public Works Act (PWA)	1981-	Provision of infrastructure. Allowance for the compulsory acquisition of land for public areas and infrastructure. Long-term planning; usually through cost-benefit analysis.	Could be useful for the provision of ecosystems and amenity values. Provides for the maintenance and protection of roads at the coast.
Civil Defence and Emergency Management Act (CDEMA)	2002-	Provision for emergency powers during a disaster. Enables the centralisation of power. Provides for the allocation of emergency funding and resources.	A reactive approach to hazard management. Provides effective short-term responses in emergencies by overriding normal legislative barriers. Lack of long-term planning.

exposure. However, development can proliferate on hazardous land under the proviso that any adverse effect is remedied, even if adverse effects are complex in time and space, or beyond quantification (Komar 2009). Developers may provide evidence only on straight-forward technical solutions, and presiding commissioners may accept these simplistic worldviews over alternative complex, high uncertainty worldviews (Komar 2009) as in the case at Omaha Beach. These single consent decisions may also be flawed in the sense that they consider one proposal with a fixed set of outcomes rather than robustly examining cascading drivers and the temporal variability of hazards.

The decision-making process around land-use planning by governments often results from balancing the environmental, social and economic costs of resource allocations within an adversarial legal setting of competing stakeholders until a consensus is reached (Gibbs 2015) or a ruling made. When local government seeks to implement planning rules to manage sea level rise, it can be challenged by development interests, and the Environment Court then evaluates between competing interests (Campbell 2017). This approach to land-use planning through ad hoc mediated outcomes by the weighting of incomplete information to enable zoning changes for managed retreat becomes cumbersome and litigious. For example, in *Foreworld Developments v Napier City Council* [1998] 5 ELRNZ69 zoning changes consistent with adaptation to coastal hazards were imposed by Napier City Council on a resource consent applied for by Foreworld Developments which were counteracted with mitigation measures. Napier City Council imposed the principle of managed retreat through s106 of the RMA 1991 on new coastal development: a requirement for mitigating adverse effects through the vesting of vulnerable land with the council because of their liability given future coastal hazards. Donating land was not palatable for Foreworld, and therefore inundation mitigation measures to protect the development were put forward by Foreworld to maintain the spatial extent which was subsequently accepted by the Environment Court based on information supplied by the applicant (Foreworld Developments Ltd v Napier City Council 1998).

5.3 Evolving Risk and Hazard Exposure Due to a Changing Climate

Governments in New Zealand are often focussed on relatively short-term issues (Boston 2017). By contrast, the dynamics of climate change require that we focus on coastal hazards over decades as a result of the slow creep of sea level rise and changing intensity and frequency of extreme storms (IPCC 2014b; Komar et al. 2013; Williams and Micallef 2009). This dichotomy is exacerbated by temporal unpredictability in societal uses and values in the coastal environment that influence trade-offs between conservation and development (Kwakkel et al. 2015). Consequently, there is an urgent need to develop methods that allow government planning and decision making to occur over timeframes reflective of the diverse impacts that will be experienced at the coast (New Zealand Government 2017) and their flow-on effects to the wider economic system.

At the national scale, an assessment of vulnerability in New Zealand identified 9000 properties within 0.5 m of mean high water springs that can be directly impacted by coastal inundation (Parliamentary Commissioner for the Environment 2015). The estimated total building replacement cost of at-risk structures is NZD$19.3B (2011) for the 0–1.5 m elevation zone (NIWA 2015).[1] Insured losses for extreme weather events were NZD$240 M in 2017 from 25,000 claims of homes and businesses (Insurance Council of New Zealand 2018).[2] In the last decade, annual costs of repairing weather-related damages to land transport networks have increased from NZD$20 to NZD$90 M (Boston and Lawrence, 2017). Static, cost-based methods such as these are useful, but likely underestimate vulnerability as they do not consider how disruptions to markets influence the socio-economic systems, account for spillover trade effects or account for price changes due to changes in supply and demand that may impact an economy (Sugiyama et al. 2008). At the close of 2018, New Zealand has experienced 2 years in a row of the three most expensive years on record for insurance claims in history indicating the increasing frequency and intensity of storms (Radio New Zealand 2018). The impact of repeated disruption to the economy from flooding needs further exploration as they are one of the catalysts for social change (Okada et al. 2014). Therefore, these direct impacts from coastal hazards are exacerbated by the influence of indirect flow-on impacts (here referred to as ‘higher-order impacts’). Integrating these higher-order impacts into the economic analysis of coastal vulnerability provides a more robust understanding of system tolerance, thresholds and feedbacks to hazards. Higher-order impacts are not considered deeply in the current approach to coastal vulnerability assessment in New Zealand which recommends estimating the loss in value-added and the loss of income (Reese and Ramsay 2010). To date, higher-order impacts have been derived statistically from the Annual Enterprise Survey for industries and sectors published by Statistics New Zealand (Reese and Ramsay 2010).

Both direct and higher-order economic impacts can be modelled through Systems Dynamics (McDonald et al. 2018; Smith et al. 2016). Hughes et al. (2017) describe how positive system feedbacks associated with higher-order impacts can precipitate a threshold response that can lead to a flow-on cyclical effect, hysteresis, or produce a catastrophic system collapse. Alternatively, they note that multiple weak feedbacks that act simultaneously may induce a regime shift. Figure 5.1, a causal loop diagram, provides an example of system drivers in the coastal environment and the associated reinforcing (positive) and balancing (negative) feedbacks. Many critical relationships exist between the environmental and economic systems. The relationships of concern are the reinforcing feedback loops that de-stabilise the complex system

[1] NZD$1 = US$0.83 as at 31 March 2011 (Reserve Bank of New Zealand, 2018).

[2] NZD$1 = US$0.69 as at 31 March 2017 (Reserve Bank of New Zealand, 2018).

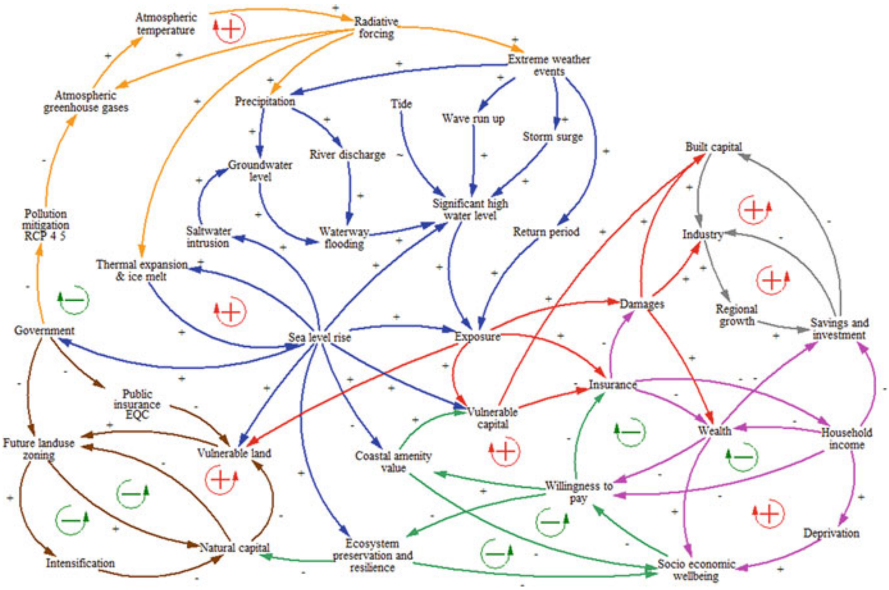

Fig. 5.1 The causal loop diagram illustrating the influencing variables within the environmental and economic systems and where there are reinforcing (positive) or balancing (negative) feedbacks. Climate change exacerbates reinforcing system feedbacks within the environmental system that can spill over into the socio-economic system. Resilience aims to moderate reinforcing system feedbacks by enabling sustainable balancing feedback loops

(Ford 2010). For example in Fig. 5.1, exposure to sea level rise creates vulnerable capital which in turn increases the insurance premium on that capital. Household income is then diminished, which reduces society's willingness to pay for coastal amenity values. A lower willingness to pay leads to a further reduction in the value of vulnerable capital through reduced demand. This example demonstrates how evolutionary economic analyses, supported with Systems Dynamics modelling, can help identify and potentially reduce, through effective policy intervention, system drivers of threshold-crossing reinforcing feedbacks and promote drivers that stimulate social change toward sustainability (Hughes et al. 2017).

The following sections will now address how society can move forward by developing and implementing long-term resilient policies and plans that enable dynamic adaptation in the form of managed retreat through evolutionary economic analysis.

5.4 Economic Planning in Systems Adapting to Knowledge and Information

Globally, adaptation to climate change is one of the least explored areas of climate economics when compared with the economics of mitigation, risk analysis or impact assessments (Burke et al. 2016). There are currently few techniques available describing how to incorporate inundation damage functions into adaptation (Burke et al. 2016). Most analyses of adaptation options have followed traditional approaches that emphasise market solutions, efficiency and cost-benefit analysis (CBA) (IPCC 2014b). It is now prudent to consider risks, inequalities, behavioural biases, non-market and non-monetary measures, limits and barriers, and ancillary costs and benefits (IPCC 2014b) over the long-term. The current approach in New Zealand to socio-economic decision-making typically utilises a mixture of econometric, CBA, multi-criteria analysis, real options analysis and economic impact modelling (e.g. Input-Output Analysis, Computable General Equilibrium) (Infometrics Consulting Limited 2017; Maven Consulting Ltd 2017; Tonkin and Taylor 2017), whereas fiscal impact analysis is popular in the USA (Freudenberg et al. 2016). These techniques are generally focused on the short-term or capture dynamics poorly through time. Economic assessments that are based on CBA do not typically assess wider environmental and social issues (Losada and Diaz-Simal 2014) and have no accepted institutional mechanism for assessing who pays for adaptation (Tonkin and Taylor 2017).

Traditionally in many developed countries, environmental policy theory has been based on applying neo-classical welfare theory to adaptation options, which strives to maximise welfare through a competitive equilibrium (van den Bergh 2004). This neo-classical economic theory of the utility maximisation of stakeholders is borne out of the microeconomic analysis of preferential consumption (Mas-Colell et al. 1995). Therefore, the neo-classical general equilibrium approach applies demand-supply relationships to estimate price changes through market redistribution based on rational responses (Sugiyama et al. 2008). It seeks to derive where the equilibrium is located rather than where it is tending toward or deviating to (Nelson and Winter 2002). This approach fails to accommodate the behavioural response (Sugiyama et al. 2008), or a dynamic equilibrium (Nelson and Winter 2002). Both of which are useful for long-term planning for managed retreat. Evolutionary economics can fulfil this role given its aggregated population approach to accommodate behaviour and its evolutionary tendencies which are driven by the systemic change brought on by continual economic development (Foster and Hölzl 2004). It can also assess the economic effects on society of various funding options for managed retreat. Box 5.1 provides an overview of evolutionary economics as an analytical tool for adaptive coastal management.

Box 5.1. Evolutionary Economic Analysis

Evolutionary economics provides a useful analytical framework for adaptive coastal management. Foster and Hölzl (2004) recognise three fundamental principles of evolutionary economics: (1) economic systems are knowledge-based systems in which knowledge and information are represented as stocks and flows; (2) it adopts an aggregated population approach based on behavioural variation instead of a typological approach based on representative agents; and (3) inertia, selection and development are the primary drivers of systemic change which enables a dynamic equilibrium.

Evolutionary economics has been compared to ecological economics and environmental economics (Christensen 1989; Rosser 2011; van den Bergh 2004). It is similar in spirit to ecological economics, as both are concerned with sustainable economic development (Van Den Bergh (2004), but it differs from environmental economics, which focuses on natural resource management and managing environmental externalities (Munda 1997).

Evolutionary economists view the economy as a domain characterised by dynamic equilibrium processes rather than a system transforming from shocks toward a stable equilibrium state (Foster and Hölzl 2004). They attempt to represent economics as a system of processes of consolidation and development, rather than resource or utility optimisation (Foster and Hölzl 2004). Evolutionary economics utilises a more behavioural and temporal approach for analysing the tendencies of populations displayed in complex systems (Foster and Hölzl 2004). The aggregated behavioural approach is in contrast to the incentive-based utilitarianism of representative agents commonly used as a guiding ethical principle in the economic decision-making process (Gorddard et al. 2012; Pyka and Hanusch 2006). The long-time horizons and the continuous selection and mutation processes inherent in evolutionary economic analysis are also complementary with the attributes of sustainable development and the slow-creep of climate change (van den Bergh 2004).

Evolutionary economics analyses stochastic fluctuations that are inherent in all complex systems. Fluctuations are imposed on the system through extreme flooding, or where water levels breach a threshold through slow-creeping sea level rise. System fluctuations are then accommodated through perturbation, saltation or bifurcation before finally coming to rest at a new dynamic equilibrium. Saltation (abrupt evolutionary change or mutation) creates the catalyst for societal change and bifurcation (path separation into divergent branches) drives the acceptance of the 'new normal' conditions (Foster and Hölzl 2004). Saltation and bifurcation can then manifest as trigger and tipping points for when society needs to make plans or take action.

Path dependency is a characteristic of evolutionary economics that can prove problematic for analysing multiple dynamic adaptation responses with

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reversibility (van den Bergh 2004). Unfortunately, Rosser (2011) describes very low reversibility of industrial, residential and transportation processes due to the long duration for a response. It is therefore crucial when analysing future options to discover if there are any potential for significant pathway dependencies such as substantial up-front costs, technological commitments, or environmental degradation that will reduce long-term well-being (Boston 2017). However, managed retreat is irreversible and path dependant if the original site no longer exists due to sea level rise.

Finally, evolutionary economics relies on the bounded rationality of individuals (van den Bergh 2004). The decision-making processes at the individual and policy levels are constrained by this imperfect knowledge, cognitive limitation and the time constraints of bounded rationality (van den Bergh 2004). Knowledge dissemination of the long-term benefits of managed retreat that result from evolutionary economic analysis helps to broaden this bounded rationality of limited information on which to base decisions.

Unfortunately, neo-classical economics or evolutionary economic solutions for planning alone do not guarantee socially optimum outcomes (van den Bergh 2004). Policy integration, stakeholder participation, funding initiatives and land-use zoning are also critical (van den Bergh 2004). Evolutionary economics does give society a new perspective to view a pertinent problem, by allowing decision-makers to be more informed of economic interdependencies and causalities. It incorporates knowledge over time for multiple stakeholders, and it allows for the changing demand and supply of land, capital, and populations. Evolutionary economic analysis can then test plans and policies ahead of implementation. It accounts for the rational behaviour of informed communities, the unpredictable manifestations of the environment and the counter-intuitive behaviour of institutions and markets. Thereby deriving a pragmatic balance between sustainable market prices, speculative investment, market uncertainty and aggregated behavioural variation.

In this chapter, we argue that evolutionary economics can be used in a coastal context to enhance long-term societal welfare by analysing coastal vulnerability, socio-economic dynamics and future policy options to enable managed retreat. A framework is suggested in which policy goals are set that align with the long-term needs of society. Modelling tools such as System Dynamics and Geographic Information Systems (GIS) can analyse dynamic economic impacts and spatial vulnerabilities based on the robust science of coastal hazards. These tools provide for the analysis of environmental-economic system interdependencies, thresholds and feedbacks (Dearing et al. 2010). Multiple plausible futures and their economic impacts can be explored and stress-tested through Robust Decision Making (RDM) to provide authorities with opportunities for managed retreat based on policy interventions with enhanced outcomes (Lempert et al. 2013). RDM is a method of probabilistic statistical analysis which seeks to minimise regret and uncertainty

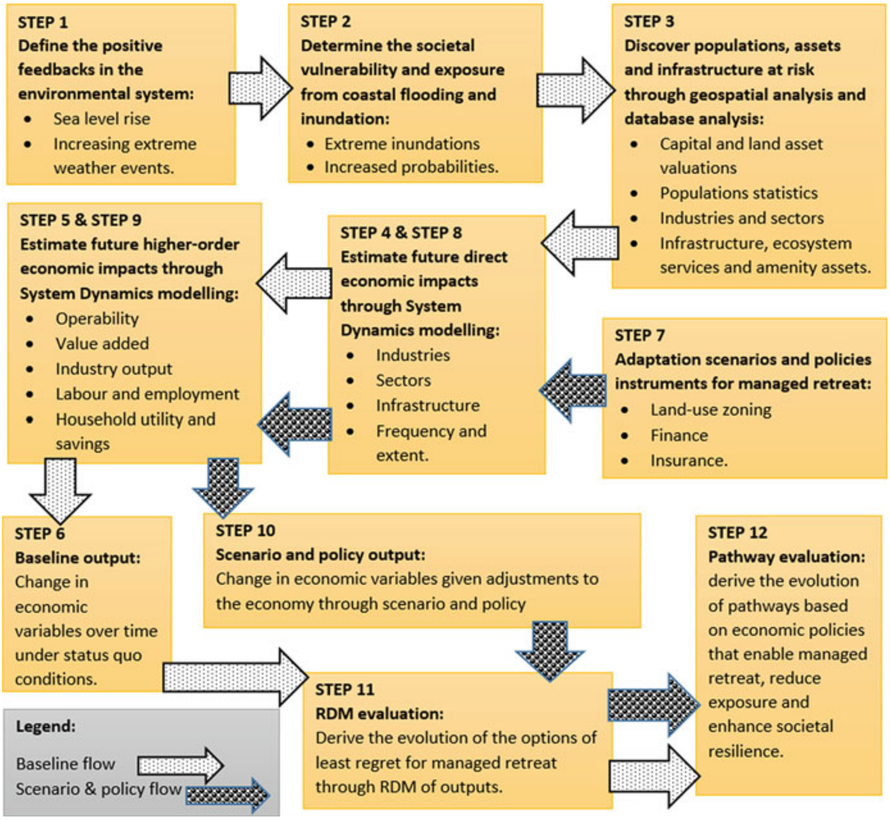

Fig. 5.2 The conceptual flow of the analysis of knowledge and information to enable long-term planning for managed retreat away from coastal hazards. Evolutionary economics and System Dynamics enable economic impact analysis over time that is then statistically tested through Robust Decision Making to define pathways toward managed retreat and societal resilience

when assessing local planning options before implementation (Lempert et al. 2013). Evolutionary economics then allows for the inclusion of a gradual and reflective dynamism of complex systems over the long term to allow knowledge and information-based preferential adaptation to occur (Foster and Hölzl 2004). Vulnerable areas can then implement strategic, individually-styled long-term plans for managed retreat that achieve greater integration for managing coastal risks in land-use management (Manning et al. 2015) when exposure becomes critical. Figure 5.2 illustrates this conceptual framework to enable long-term planning for managed retreat away from coastal hazards.

5.5 A Managed Hazard Response: Dynamic Adaptation and Financing Large-Scale Manage Retreat

The notion of 'managed' retreat implies a process of dynamic adaptation in which vulnerable communities and exposed assets can be relocated as new information on coastal hazards becomes available (Haasnoot et al. 2012a). Planning for dynamic adaptation requires the assessment of multiple plausible future scenarios (Haasnoot et al. 2012b; Kwakkel et al. 2015). It requires long-term planning across multiple pathways to guide future decisions (Barnett et al. 2014) because it is highly unlikely that one single action will eliminate all risk. Managed retreat can be viewed as a combination of dynamic adaptation plans and policies, such as integrated risk-reduction plans, land-use development restrictions, financial incentives, rezoning land-use, and accommodating affected parties (Abel et al. 2011). Its implementation is influenced by the cost of asset relocation, the ongoing costs of maintaining the existing situation, the cost of alternative actions, the effectiveness of current practice, and societal acceptance (Abel et al. 2011; Hino et al. 2017).

Currently, in New Zealand, unfavourable risk assessments for households and firms negatively affect welfare through declining valuations of exposed assets (Christchurch City Council 2015) inhibiting managed retreat. This is because the cumulative costs of relocation outweigh the perceived benefits of remaining in situ which maintains behavioural entrenchment. Globally, declining capital values are detrimental to the vulnerable, but a more risk-informed capital market is driven by, and beneficial to, society as it provides a more objective market valuation inclusive of any expected flood damage (McNamara and Keeler 2013). In order to reduce this loss of equity through declining capital values, central government administered financial compensation to the vulnerable at a fair market price would incentivise managed retreat (Freudenberg et al. 2016) sooner rather than later. Government compensation is unavoidable where state decisions impose restrictions, or eliminate, existing property rights (Tombs and France-Hudson 2018).

Enabling compensation requires new types and combinations of funding instruments in New Zealand to overcome the increasing exposure to coastal hazards (Local Government New Zealand 2015). Alongside new funding instruments are discussions around who inevitably pays for implemented strategies. Funding adaptation will be the critical enabler and needs to be addressed across scales of government (Lawrence et al. 2013). Current policy in New Zealand is devoid of practical guidelines on how managed retreat should be financed (Boston and Lawrence 2018). There is also the issue of investment decisions having non-simultaneous exchanges of immediate costs with distant benefits (Boston 2017). The greater the temporal gap between costs and the realisation of benefits, there tends to be a greater reluctance from governments to invest (Boston 2017). This uncertainty makes for a difficult task for governments who may have communities requiring expensive relocation strategies when they are socio-economically disadvantaged or facing a dramatic loss in equity (Hayward 2008).

System Dynamics modelling enables the assessment of alternative funding options ahead of implementation. It allows the economy to evolve and accommodate this new financial information as it becomes available with each iteration. Box 5.2 illustrates how differing levels of investment in managed retreat away from hazardous land can be modelled using Vensim® by Ventana Systems. Relocation costs and investment funding can be analysed to determine the appropriate level and timing of funding given the supply of new information with every model iteration. Box 5.2 shows four hypothetical simulations to discover the effectiveness of these different amounts of capital investment funding to cover relocation costs over time. The 'investment effectiveness' illustrates the long-term balance of increasing relocation costs offset by future investments in managed retreat. Discovering the dynamic equilibrium of investment effectiveness through System Dynamics allows economists to determine how much investment capital is required while simultaneously minimising the financial cost of borrowing.

Box 5.2 System Dynamics to Assess Evolving Funding Options for Managed Retreat

This Vensim® System Dynamics model based on evolutionary economics principles illustrates how differing levels of investment might be used to relocate communities from 200 ha of hazardous land to new land. Graph A illustrates the temporal investments of four simulations (Sim1, 2, 3, 4) for initial investments of USD$1, 2, 3 and 4 M respectively. Graph B illustrates the relocation from hazardous land to new land. Graph C shows the increasing cost of relocation over time for Sim 3 only as all simulations returned the same relocation cost. Graph D shows the 'Investment effectiveness', or the investment in managed retreat less the relocation cost. This illustrates the viability of the investment over time. An initial delay of 10 years, a 6% p.a. growth rate and a 3% discount rate were used. This example demonstrates that a dynamic equilibrium in investment effectiveness occurs under Sim3 around 2055, in which an investment of USD$3 M is enough to offset the relocation cost for managed retreat over this period. Dynamic equilibrium is achieved under Sim 3 where the investment covers relocation costs and the costs of borrowing are minimised.

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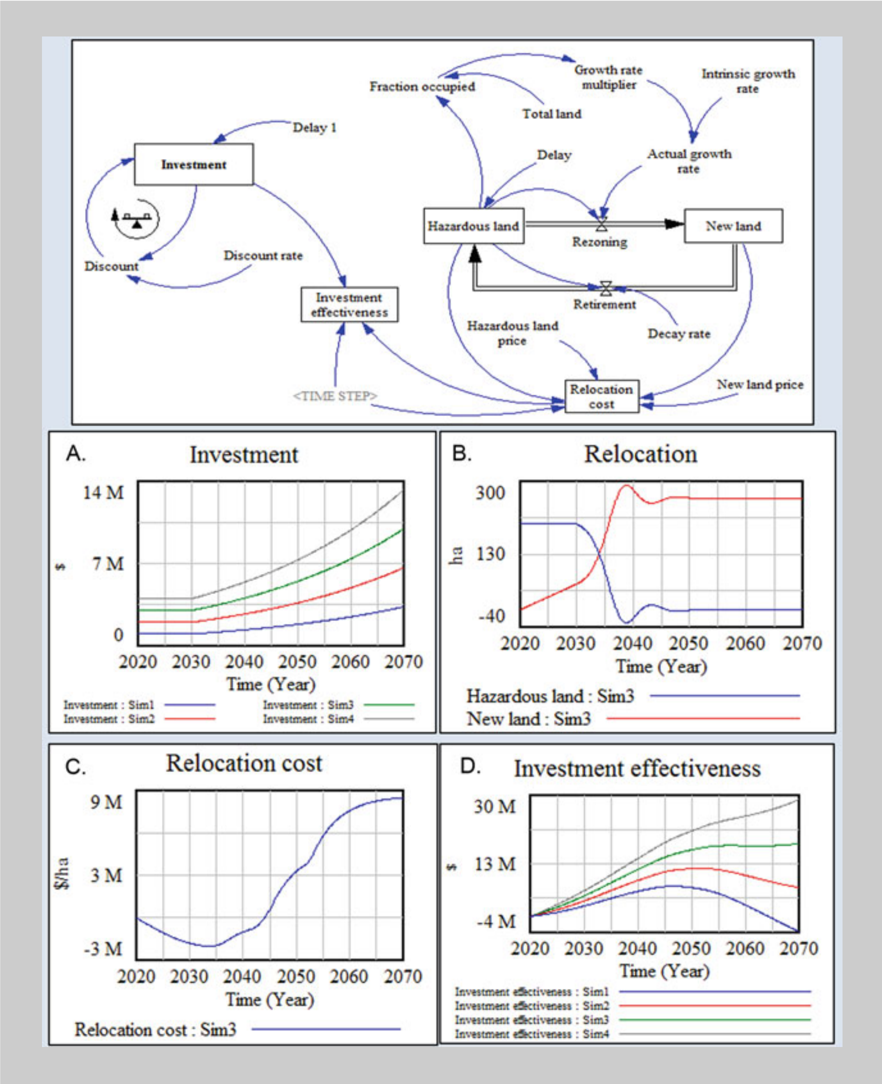

To date there have not been any direct climate change funding instruments for coastal hazards in New Zealand (Boston and Lawrence 2018). Although, the New Zealand Government recently announced the New Zealand Green Investment Finance Fund as it wishes to become a global leader in response to climate change (Herd 2018). This fund aims to manage the financial risk to the economy from climate change and unlock economic opportunities for emission mitigation (Herd 2018).

The range of possible funding instruments that can enable managed retreat include: public-private partnership (PPP) finance, loans, taxes, charges and subsidies, general or targeted rates, central government grants and funding, resilience bonds, improved resource pricing, risk transfer mechanisms, and insurance (Boston and Lawrence 2017; Cunniff and Meyers 2017; IPCC 2014b; Kartez and Merrill 2016; van den Bergh 2004). The insurance industry by default becomes the key driver in reducing potential human exposure and the financial costs of disaster (Murray et al. 2015). It can indirectly drive an 'unmanaged retreat' where policies are cancelled when the coastal risk becomes unacceptable, or when the fortuitous nature of insurance is no longer apparent (Storey et al. 2017). Insurance companies are requiring the use of these risk-based premiums and for preventative measures as a precondition for cover in hazardous zones to incentivise awareness, prepare for and adapt to future risk (Murray et al. 2015). Unfavourable insurance excesses and premiums can also discourage development in high-risk areas (Storey et al. 2017). Conversely, extreme excesses and premiums can become unpalatable for consumers which can lead to voluntary withdrawal from the insurance market. New insurance mechanisms are required to manage the evolving risk over the long term and provide for asset relocation rather than replacement.

Public insurance is also available to New Zealand households and firms through a compulsory levy on property payable to the government entity, The Earthquake Commission (EQC). EQC provides contingency funding and long-term financial resilience against natural disaster. It covers lands affected by flood disasters through the Natural Disaster Fund (Boston and Lawrence 2017). New Zealand is fortunate to have a Crown entity solely mandated to provide relief to parties affected by natural disaster. Public insurance through EQC has facilitated greater insurance penetration in New Zealand than other countries in order to avoid a socially unacceptable level of distress and loss caused by natural disaster (New Zealand Treasury 2015).

5.6 Mechanisms for Change

New approaches to technological economic impact analysis, regulatory policies on land-use, investment in new locations, and the formation of new governance structures need an avenue for proactive analysis and subsequent implementation into the hazard management practice (IPCC 2014b). These new approaches to hazard management can enable sustainable development (IPCC 2014b) through coastal managed retreat. For success, implementation needs to reflect a cohesive national vision and a drive for long-term sustainability (IPCC 2014b). However, sustainable development through managed retreat is not always economically favourable for society given expensive labour and capital requirements for relocation (IPCC 2014a).

Managed retreat may not be a rational adaptation measure under a neo-classical framework due to the key determinant of present cost but must go beyond this by incorporating a long-term behavioural aspect to solve this problem (Sugiyama et al. 2008). Compounding the issue is that the cost of land to relocate to is more expensive than the hazardous land, which can often leave some residents needing to re-mortgage their homes (Fleming 2017). The investigation into options for the compulsory acquisition of hazardous land where behavioural entrenchment is apparent also needs to take place, as well as discussion around how suitable land for urban development can be obtained affordably. Similarly, acquisition of land is required for coastal dynamics, ecosystem services and habitats, public access and amenity values as outlined in the NZCPS 2010. Local government is therefore required to amend plans to rezone rural, residential and industrial boundaries to mitigate run-away property prices brought on by land supply scarcity.

Governments can utilise strategic spatial planning instruments that are responsive to dynamic climate changes, social values (Manning et al. 2015) and population and trade dynamics through regular allowances for the rezoning and intensification of land-use. Structure plans that outline land-use zoning and areas for development can then give markets confidence in new developments and accommodate future development fairly, reduce uncertainty for future resource management and minimise exposure to risk. Accurate and updated national asset geodatabases are also essential to quantify vulnerable capital on a regular basis for physical changes in stock, value and extent, and accommodate new hazard information as it comes to light. These geodatabases enable spatial planning, modelling and statistical analysis. Ideally, planning instruments should be accompanied by integrated impact assessments, long-term monitoring of the physical environment, public participation (New Zealand Government 2017), risk management plans and economic impact modelling of adaptation and worst-case scenarios (Jevrejeva et al. 2014).

Finally, Van den Bergh (2004) claims that in the future, sustainable development will be built on an evolutionary perspective based on the relationship between economic evolution and environmental resources. Sustainable development will involve the integration of disparate knowledge on technology and innovations, coevolution and environmental history (van den Bergh 2004). Integration will give rise to a hybrid of social, biological, technological and economic processes that are dependent on specific problems and time horizons (van den Bergh 2004). The socio-economic and the biophysical systems can be analysed as one complex system to enable sustainable development through managed retreat. The overall patterns that lead to sustainable development can be tested over time and space to discover causal drivers and interdependencies of variables under multiple plausible futures. The very nature of evolutionary economic modelling is to find a dynamic equilibrium amongst multiple non-linear interactions. This dynamic equilibrium may fluctuate between a steady state (stable equilibrium), a dynamic state brought on by a sudden system shock, or positive reinforcement bought about by a chaotic perturbation (unstable equilibrium), or a disturbed state where shocks and perturbations lead to a new quasi-stable state (neutral equilibrium) (Ford 2010). Often bifurcation can arise in the unstable equilibrium (Rosser 2011) leading to dendritic divergent future pathways with or without human intervention. Even if the climate system were in a steady state, its interaction with the economy could drive chaotic dynamics (Rosser 2011). By modelling multiple futures and policies, resilient economic states can be discovered within the complex system. This modelling would enable robust institutional decision-making toward effective policy outcomes through minimising loss, disruption or chaotic perturbation. Scenarios and policies can then be implemented with the likelihood of the success of managed retreat vastly enhanced. Adaptation trigger points for planning and action emerge once system thresholds are breached (saltation), or new systems arise (bifurcation) allowing organisations to reconsider their operations through rational action (Stam 2006). Analysis of dynamic complex systems can then give an informed understanding of the interactions between all these influential elements (Tobin 1999) on which to base decisions and policy outcomes.

5.7 Conclusion

Changes to planning and policy are required to introduce new land-use practices and funding models that enable dynamic adaptation to coastal hazards through managed retreat. Policies and plans need to be modelled ahead of implementation to test their effectiveness to provide sustainable development within the complex and evolving environment-economic system. Modelled scenarios can then inform society of where change is needed to achieve policy outcomes. Risks and exposure of assets and infrastructure are evolving due to the slow creep of sea level rise and changes in extreme weather events which exacerbates the direct impacts of coastal flooding or inundation. Higher-order impacts such as economic disruption from flooding or inundation events also need analytical consideration. Evolutionary economics and System Dynamics have emerged as key tools to support decision-making in the presence of new knowledge and information. System Dynamics modelling provides a powerful framework for applying evolutionary economics through economic impact modelling, quantitative spatial risk assessment, and RDM for analysing multiple scenarios in a thorough statistical manner. Collectively these approaches allow exploration of future scenarios and policies for land-use and finance that can support effective coastal managed retreat. Analysing complex systems in this way facilitates knowledge creation of system relationships, discovers information flows that can modify behavioural drivers and provide insights that can enable institutional change. Successful policy outcomes can then be integrated into planning documents and development practices. Sustainable coastal management through managed retreat can then lead to more resilient coastal societies in an uncertain and changing world.

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