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Knowing when native regeneration is for you, and what you should do about it. The Aotearoa New Zealand context

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Abstract: Forest restoration is an activity that can be readily undertaken to address both the climate and biodiversity crises. In Aotearoa New Zealand, aspirations for large-scale native forest restoration are growing across governmental and private sectors and a considerable focus to date has been on forest establishment by actively planting native trees. In contrast to actively planting trees, considerable proportions of Aotearoa New Zealand have a demonstrated potential for passive tree establishment through natural regeneration processes, subsequent to land use change away from pastoralism or exotic forestry. At a policy and land manager level, knowledge is lacking over the main considerations that should determine whether native restoration will most efficiently be achieved by active tree planting or by natural regeneration. Whether restoration follows active or passive establishment methods (or an intermediate point along the active-to-passive continuum), adequate forest management is essential to achieve high levels of native forest health, functionality, and permanence. We describe a step approach for assessing at a site scale whether forest restoration can most efficiently be achieved via active or passive methods, or combinations of the two. Our assessment covers the main biotic and abiotic factors which explain the probability of native tree establishment. These factors are mean annual rainfall, mean annual air temperature, proximity and composition of adjacent seed sources, landform type, slope aspect, slope, topographic exposure, and the presence of existing woody cover. We then describe the main management interventions that will be required to support successful natural regeneration outcomes and highlight the importance of strategic natural regeneration for achieving large scale restoration for the betterment of both our climate and biodiversity.

Keywords: biodiversity restoration, forest management, forest regeneration, landscape restoration, large-scale native forest restoration, restoration, tree planting

Introduction

Large-scale restoration of diverse native forests (hereafter restoration) is one main avenue for humans to effect positive environmental change in the face of intertwined climate and biodiversity crises (Cohen-Shacham et al. 2016; Seddon et al. 2019). While significant opportunities for restoration have been identified (Bastin et al. 2019; Fargione et al. 2021), knowledge is required to support the selection of appropriate forest establishment and management methods (Meli et al. 2017). While actively planting trees has received considerable political and economic support (Fleischman et al. 2020), uncertainty remains over the cost-effectiveness (Molin et al. 2018) and the long-term ecological outcomes of native tree planting (Smale et al. 2001; Chazdon 2008; Meli et al. 2017; Fleischman et al. 2020; Holl & Brancalion 2020). Further, the high financial costs associated with native tree planting prohibits its application at landscape scales (Crouzeilles et al. 2020). For instance, the average cost for native tree planting in Aotearoa New Zealand (ANZ) was estimated in 2021 to be NZ$23 000 ha^{-1} versus lesser (but highly variable) costs for regeneration of NZ$595–15 000 ha^{-1} (Forbes 2021a). By comparison, restoration through natural forest regeneration is regarded by some as uncertain (Brancalion et al 2016), but in favourable circumstances regeneration has been successfully demonstrated at landscape scales (Wilson et al. 1994; Sullivan et al. 2007; Holl & Aide 2011; Wiser et al. 2011) and is an approach to restoration which has even been shown to provide greater ecological services (e.g. above ground biomass, soil erosion control, and water yield; Hua et al. 2022) and be preferred over native tree planting, wherever possible (Di Sacco et al. 2021).

Native forest self-sown regeneration (hereafter regeneration) is the natural process of native forest flora establishing on land, often where forest cover has been disturbed or cleared (Parrotta 1993). Aggressive re-invasions

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by such regeneration have been seen as producing problematic agricultural weeds in ANZ (Leonard 1962, Bascand & Jowett 1981; Grigg 1986). Large-scale regeneration commonly can restore environmental conditions and native biodiversity (Carswell et al. 2012; Strassburg et al. 2016), conserve soil and protect watersheds (Yang et al. 2018), aid climate change mitigation and adaptation (Ausseil et al. 2013; Chazdon et al. 2016; O'Neill et al. 2020), and with correct policy settings, can support rural economies and livelihoods (Chazdon et al. 2020). Given Earth's changing climate, naturally regenerating forests can exhibit greater resilience compared to planted forests (Jactel et al. 2017) as they are adapted to local conditions and to other colonising taxa (Chazdon 2016).

The facilitation of mid-late successional species causes successional development which can be identified by temporal changes in species plant traits (e.g. increasing shade tolerance, slower growth rates, longer plant lifespan, and taller stature). Evidence of succession towards a pre-disturbance community can be found where species turnover results in a forest's composition, structure, and function becoming increasingly similar to local examples of mature intact native forest (Christensen & Peet 1984; Reay & Norton 1999). However, in some circumstances, regeneration and succession will be limited or unsuccessful and the passive restoration approach should be replaced, or supplemented, by active methods to achieve an intermediate level of management intensity along the active-to-passive continuum (Chazdon et al. 2021). Indeed, even passive regeneration requires some form of management and most restoration projects will operate across the spectrum from passive to active practices (Holl & Aide 2011; Norton et al. 2018; Chazdon et al. 2021; Forbes et al. 2021).

Regeneration has led to significant expansions in forest cover at global scales, particularly following cessation of agricultural activities (e.g. in the Neotropics: Nanni et al. 2019; Brazilian Atlantic rainforest: Crouzeilles et al. 2020; in Europe: Verburg & Overmars 2009; Thers et al. 2019) or following major shifts in socio-political regimes (Camarretta et al. 2018; Song et al. 2018). Naturally regenerating woody native communities are today a prominent feature of the vegetation cover of ANZ, particularly in zones of higher soil moisture, warmer air temperatures, and closer proximity to forest cover (Mason et al. 2013). Compositions of early-successional communities are dominated by species such as mānuka (*Leptospermum scoparium*, Myrtaceae), kānuka (*Kunzea ericoides*, Myrtaceae), māhoe (*Melicytus ramiflorus*, Violaceae), putaputawētā (*Carpodetus serratus*, Rousseaceae), and pōnga (*Cyathea dealbata*, Cyatheaceae), some of which can be recruited within an initial cover of invasive exotic flora, such as gorse (*Ulex europaeus*, Fabaceae; Sullivan et al. 2007), and which collectively cover c. 1.6 M ha of ANZ's land area (Wiser et al. 2011). Taking the Wellington region as an example, 9.7% and 3.8% of the region has cover of mānuka/kānuka and broadleaved scrub respectively (Dymond & Shepherd 2004), and these communities provide sites for recruitment of tree species of greater shade tolerance and longevity.

Specific examples of regeneration have been documented over tens to hundreds of hectares on disturbed land following exotic plantation clear-fell (Lambie & Marden 2020; Forbes et al. 2021; Forbes 2021b) or on retired livestock pastures (Allen et al. 1992; Wilson 1994; Young et al. 2016). In contrast, native tree plantings have been established at comparatively small scales and often in contexts where regeneration processes are dysfunctional, such as where regeneration sites lack sufficient natural propagule sources (Overdyck & Clarkson 2012), are extremely dry (Dollery et al. 2018), are weed infested (Wallace et al. 2017), or where fundamental biotic impacts such as altered soil hydrology or soil compaction exist (Sullivan et al. 2009). While some examples of regeneration within planted native tree stands exist (Reay & Norton 1999), in many cases it appears regeneration and recruitment in native planted stands is constrained (Sullivan et al. 2009; Roberts 2018). Inevitably, planted native stands are susceptible to the same abiotic and biotic limits on regeneration and succession which occur in naturally regenerating stands. Therefore, in contexts of conditions unfavourable to regeneration, where natural recruitment is unlikely to occur, planting offers no long-term certainty regarding forest successions actually occurring.

Given most restoration opportunities in ANZ occur in agriculturally productive landscapes, and the aspiration in ANZ to significantly expand permanent native forest cover (Climate Change Commission 2021), restoration needs to involve much more than just planting trees. When enabling landscape-scale restoration through regeneration, the approach must address the full range of dimensions (ecological, social, political, and economic; Aronson et al. 2010) that led to the site being deforested, and that govern any future land use change.

From a policy perspective, common questions over regeneration include: where can it occur? How long will recovery of forest structure take? How much area can be regenerated? Will the species composition of the regenerating forest deliver the desired outcomes? (Arroyo-Rodriguez et al. 2017). We note that at a practical level in ANZ, guidance is lacking to support land managers undertaking site assessments of regeneration potential and selecting from a range of possible forest management interventions and the circumstances when they are necessary and why they are required to passively restore native forest cover (Pohatu et al. 2020). Many factors, both biotic and abiotic, contribute to both the nature and timeframes over which regeneration will occur (Hobbs & Norton 2004; Holl & Aide 2011). We acknowledge that, within natural limits, many land areas will regenerate if given enough time—possibly requiring many decades or centuries. However, in the face of our urgent and unfolding environmental crises, the focus of our paper is on the rapid expansion of natural forest cover using regeneration. We describe and illustrate the main factors which indicate the likelihood of rapid regeneration and ongoing progression within 20–30 years of land retirement. Specifically, we provide personally styled and practical guidance for land managers to make site-specific decisions regarding (1) how to identify whether regeneration is a viable forest establishment method in the immediate to short term, (2) what main management interventions can be employed to ensure adequate and timely regeneration and successional advancement, (3) when management interventions are necessary, and (4) why these interventions are required.

Knowing when native forest regeneration is for you

Where won't regeneration happen?

Regeneration will be limited in locations which experience extreme climatic conditions. Many areas of ANZ feature dryland, primarily in rain shadow regions east of the main divide (i.e. 19% of ANZ's total land area; Rogers et al. 2005; Walker et al. 2009). Periods of either hot (e.g. at sheltered and sunny microclimates lacking forest cover; Hawkins & Sweet

1989) or cold temperatures will limit tree occurrence (e.g. at higher elevations and higher latitudes; Mason et al. 2013) and periods of intense freezing will limit forest establishment (Sakai & Wardle 1978).

Regeneration is dependent on a source of seeds, meaning regeneration will be limited in landscapes where native forest cover has been severely depleted (Overdyck & Clarkson 2012). Several biotic threats have the potential to preclude regeneration, such threats include excessive mammalian herbivory (e.g. from domestic or feral browsing mammals; Wardle et al. 2001; Wilson et al. 2003) or intense competition for light from structurally dominant plant pests, e.g. wandering Willy *Tradescantia fluminensis*, Commelinaceae (Standish et al., 2001); bramble *Rubus fruticosus* agg. Rosaceae (McAlpine et al. 2018). However, these limiting effects can usually be at least partly addressed through forest management interventions (e.g. plant or animal pest control; Standish 2002; Dodd et al. 2011). Regeneration can also be limited by physically modified (e.g. landslide, drainage; Blaschke et al. 1992) or unnatural soil properties (e.g. heavy compaction, natural chemical toxicity/mineral belt; Walls & Laffan 1986; Bassett et al. 2005).

Is native forest regeneration an option at your location?

Here we identify widely applicable factors which have been proven to affect the likelihood of regeneration over the first couple of decades following land retirement (Fig. 1). These factors are supported by national-scale predictions of where native regeneration is likely to occur (Mason et al. 2013). Before examining these factors, it is important to understand that in addition to our widely applicable factors are a myriad of additional, local, idiosyncratic aspects which might apply to your site and either help or hinder regeneration outcomes. Some examples of these additional aspects include distinctive local climate phenomena (e.g. moist coastal air flows), disturbance agents and their frequency and intensity (e.g. altered grazing regime or soil disturbance from tectonics or erosion processes), and the levels at which pollination and dispersal vectors are functioning (e.g. nectivorous and frugivorous animals). Although these aspects are important at a site scale, here we propose the main factors which form the starting point for an assessment of the likelihood of regeneration.

The first two steps should be to assess whether your land area can support forest and whether adequate tree regeneration is occurring. Where this can be confirmed then further analysis using the factors below is unnecessary. During pre-human times ANZ featured 85–90% forest cover. Unforested sites were limited to those below the alpine treeline (Ewers et al. 2006) that were regularly flooded, subjected to regular freezing, or were cliffs, sand dunes, leached shallow or ultramafic soils, or forested areas recently disturbed (McGlone 1989).

Adequate tree regeneration will be apparent where stem densities are sufficient to form a forest canopy and where the species present have the longevity and stature to form independent forest in the longer term and ultimately to facilitate the regeneration of more shade-tolerant species. Look for signs of native tree regeneration occurring at or near your site. Search locations which are most likely to support regeneration. Search steep south facing banks where climate stressors are least and browsing mammals will have had limited access and

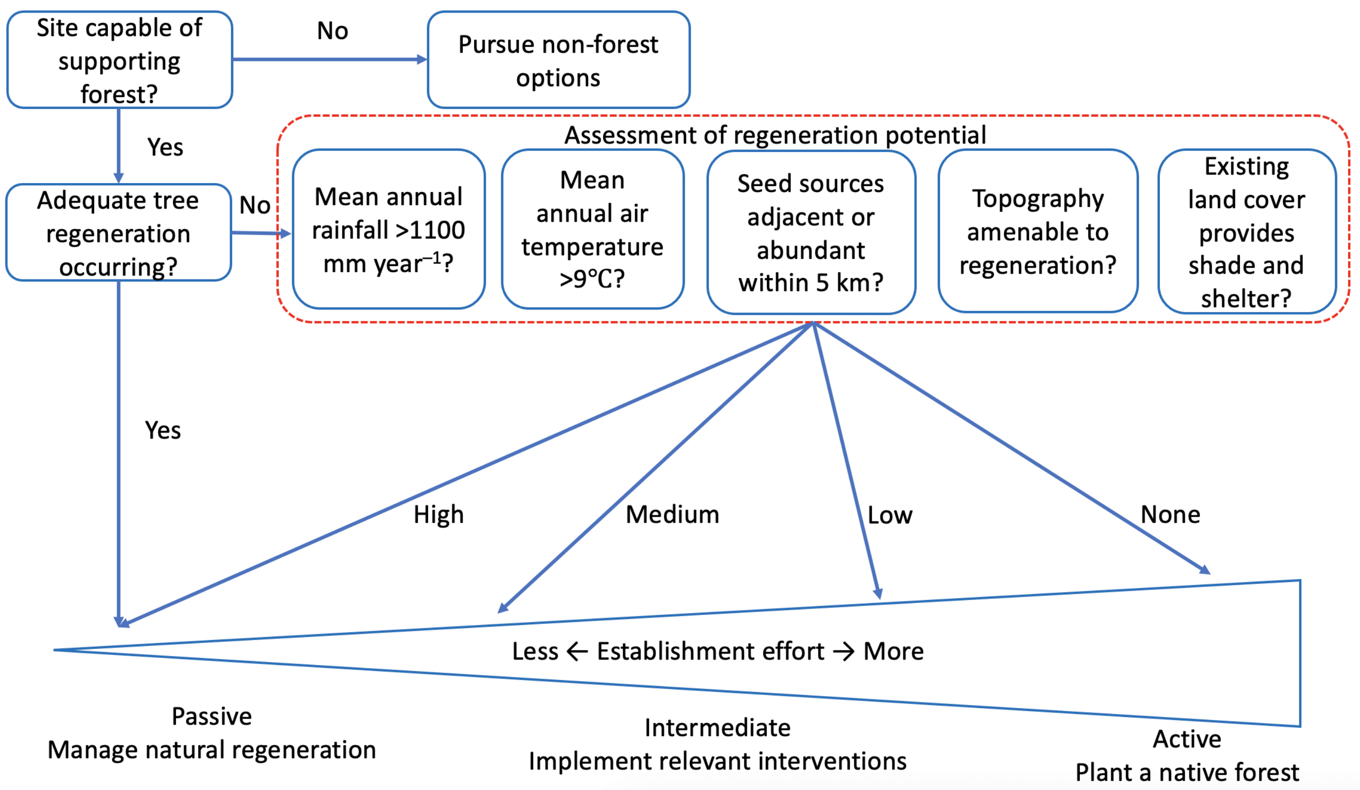

Figure 1. A stepped approach for determining active or passive restoration mode at the site scale in Aotearoa New Zealand. The assessment of regeneration potential clarifies the level of effort required for successful restoration based on a continuum from active-to-passive approaches.

less influence on regenerating vegetation. Search gullies where soil moisture and topographic shelter might aid regeneration, and other sites where disturbance of regenerating vegetation is infrequent (e.g. inaccessible portions of road verges).

Consider the influence that plant or animal pests are currently having on regeneration and how the distribution and rate of regeneration might be improved with pest management. Determine whether, and in which areas, native shrub and tree species are establishing at densities that will form a closed canopy when mature (e.g. > 1111 stems ha^{-1} at < 3 × 3 m spacing; Bergin 2012). You can be most optimistic where you already have regeneration in gullies on your property that is spreading onto adjacent slopes, especially where the species regenerating are those that will grow to a reasonable height (e.g. tree species of the genera *Fuscospora*, *Lophozonia*, *Griselinia*, *Kunzea*, *Melicytus*, *Pittosporum*, *Podocarpus*, and *Pseudopanax*).

Where your site is capable of supporting forest and showing abundant regeneration you can be confident that forest establishment by regeneration is a good option on your land. However, where regeneration is only patchy or non-existent, the following factors (Fig. 1) can be examined to clarify where along a continuum from active-to-passive management a site is positioned for successful forest establishment.

Assess your site's mean annual rainfall and air temperature. While there are no absolute climate thresholds, regeneration at unforested sites with mean annual rainfall of < 1100 mm $year^{-1}$ is likely to be at least seasonally constrained (Mason et al. 2013). In cool climates (e.g. mean annual temperature < 9°C) forest tree establishment and regeneration will be slow and is unlikely to meet management objectives (Mason et al. 2013). Determine whether rainfall at your site is greater or less than 1100 mm $year^{-1}$ and whether your site's mean annual temperature is greater or less than 9°C.

Next, consider the wider landscape and whether there are sources of forest seed, and the composition of those seed sources. The ability of seeds to reach your site will have a big influence on the composition and structure of the regeneration. Proximal and floristically diverse seed sources are optimal, and tree regeneration is likely to be supported where natural forests occur within a c. 5 km radius of your site (with closer seed sources being more effective; Mason et al. 2013). Determine what proportion of the landscape surrounding your site supports indigenous forest cover and whether those seed sources are diverse or homogeneous in their species composition. Sites devoid of native forest for multiple years are unlikely to have substantial native soil seed banks but might contain considerable exotic seed loads (Overdyck & Clarkson 2012; Broadfield & McHenry 2019).

Now, consider the types of landforms (e.g. ridge, face, terrace, or gully), the aspect of sloping sites (e.g. cardinal direction: N, E, S, W), slope (Carswell et al. 2013; Murphy et al. 2015; Forbes et al. 2021), and the level of topographic exposure (e.g. the angle to the horizon on eight cardinal directions from the location of your assessment; McNab 1993). This step provides a within-site assessment of the finer-grain processes among landforms, microclimates, soil properties, and regeneration (Cheesman et al. 2018; Jucker et al. 2018). Regeneration tends to commence sooner in gullies and on lower portions of faces compared to ridges and upper slope landforms (Wilson 1994). Microclimates will be warmer and drier on northern aspects compared to southern (De Frenne et al. 2021), meaning southern aspects are likely to regenerate faster than northern aspects (Carswell et al. 2013). Shelter afforded by surrounding topography affects microclimate, such as modifying the influence of the predominant wind, regulating the drainage of cool air, and controlling the duration of incoming solar radiation throughout each day and season which in combination affects site productivity (McNab 1993).

Lastly, assess the presence and level of cover of woody species. The presence of existing woody cover, even if exotic, e.g. Scotch broom *Cytisus scoparius*, Fabaceae, or gorse (Sullivan et al. 2007; Burrows et al. 2015), can facilitate regeneration of shade-tolerant native species by ameliorating the climate and reducing competitive interactions with other light-demanding species, e.g. dense swards of invasive or rank pasture exotic grasses (Sullivan et al. 2009) through canopy shading (McIntire & Fajardo 2014).

Assessing these factors will help to identify the main limitations on regeneration at your site. If few or no factors are assessed positively (Fig. 2a; Table 1), then a more active approach to restoration will be required and expert advice should be sought on how best to more actively establish native forest cover (e.g. seek advice on species choice, planting spacing, planting scale and timing, and other management interventions required at your site). Where one or more factors are assessed as negative (Fig. 2b–d; Table 1), further investigate the most appropriate restoration mode and whether management interventions can be used to achieve passive restoration. Where all factors are assessed as positive (i.e. climate thresholds are exceeded, abundant local seed sources are present, signs of adequate regeneration exist), with adequate management of biotic threats, your site has a high likelihood for successful passive restoration (Fig. 2e, f; Table 1).

Our guidance assumes that management aims to achieve forest cover by regeneration within several decades. It is possible that drier and cooler sites with fewer or more distant seed sources will also regenerate; however, this process would occur over longer timeframes. Where a likelihood for passive restoration through regeneration is indicated the next step is to determine any specific biotic threats (i.e. animal, e.g. Allen et al. 1984; or plant pests, e.g. Wotton & McAlpine 2013) or other barriers to regeneration (e.g. rank exotic grassland; Miller & Wells 2003) and the need for other supportive management interventions, e.g. canopy disturbance (Tulod & Norton 2020), enrichment planting (Forbes et al. 2020), a limited period of strategic grazing to reduce ground cover competition (Miller & Wells 2003), at your site.

The what, when, and why of native forestry interventions

In the context of ANZ's current landscapes, a gradient of management approaches exists (Fig. 3). Approaches range from (1) directly planting a diverse canopy in deforested landscapes (Fig. 1. Active restoration mode, high establishment effort required, plant to establish a native forest), (2) planting a homogeneous canopy of early successional woody species to shade out grass and kick-start natural regeneration in landscapes with native seed sources, (3) augmenting natural regeneration with enrichment interventions to facilitate the return of rare or absent species (Fig. 1. Intermediate restoration mode, moderate establishment effort required, enrichment plant and address competition), (4) to just managing the worst pests while letting a site naturally regenerate (Fig. 1. Passive restoration mode, low establishment effort, manage natural

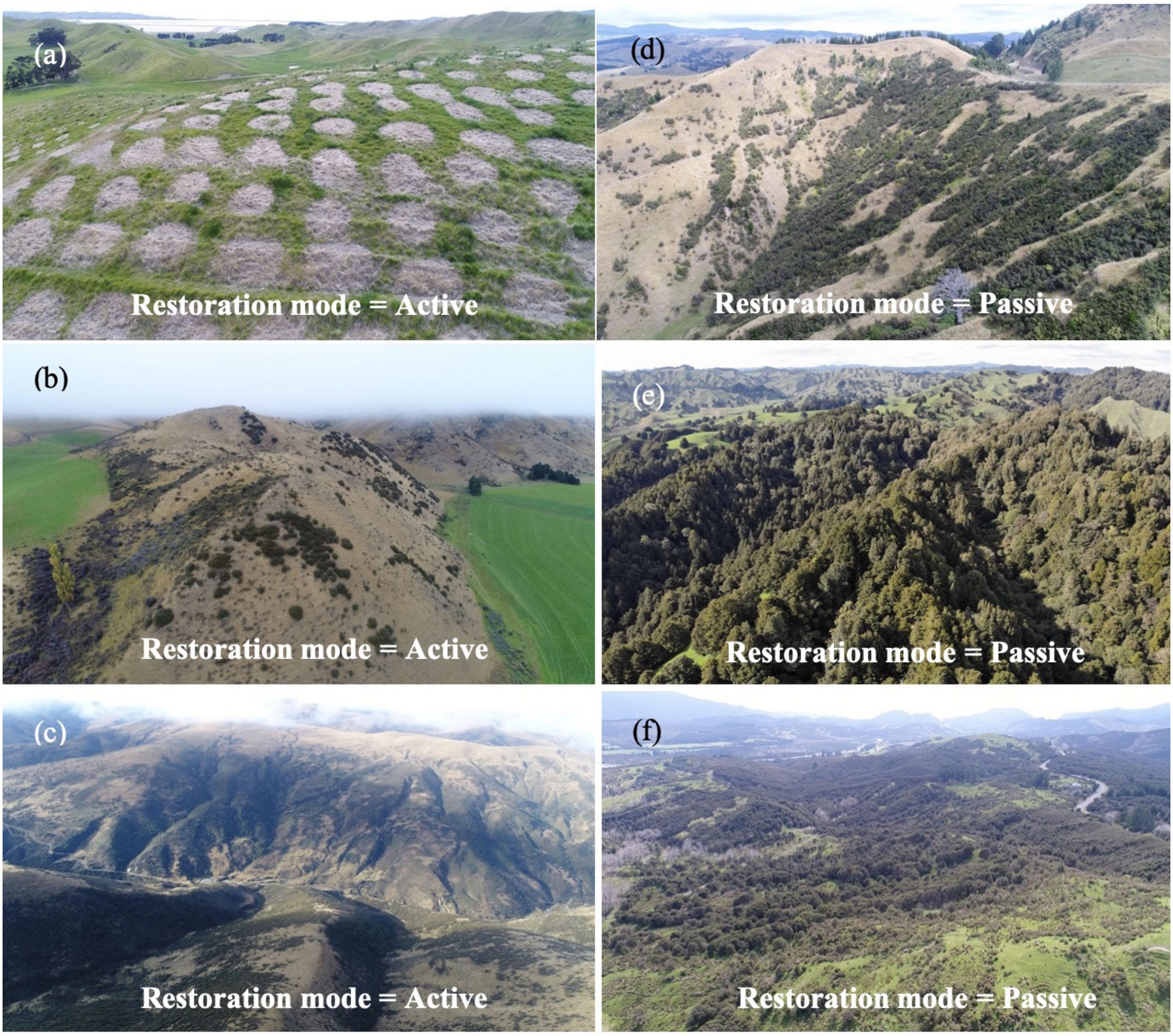

Figure 2. Site examples of restoration mode determined by the stepped approach shown in Fig. 1. Site locations and data for the factors which underpin the restoration mode assessment are given in Table 1. Sites (a) and (b) require fencing and restoration planting. Sites (c) and (d) require animal pest control/fencing and enrichment planting. Options (e) and (f) require animal pest control and would benefit from enrichment planting coupled with competition treatments.

regeneration). Even passive forest establishment requires the support of management interventions to address the effects of pests or altered ecological processes on the developing forest composition and structure.

If regeneration projects are being considered as biological carbon sinks such management interventions support the concept of additionality. Additionality is a core aspect of quality assurance of greenhouse gas emissions reduction and sequestration activities. It is used in a climate change context to mean net atmospheric carbon reduction or removal needs to be over and above that which would have arisen anyway in the absence of the given activity or project (Valatin 2011). Determination of additionality is not simple but can have a legal/ regulatory, financial, or environmental basis whereby the test indicates that there is a net benefit from a land use change that would not have happened under business-as-usual conditions.

Enrichment treatments aim to subsidise deficits in natural forest establishment and build representativeness and diversity through either in-fill planting of seedlings, seed sowing (Cole et al. 2011), or stimulating establishment from the seedbank (Forbes et al. 2020). In addition to enrichment using tree species, enrichment of other vegetation lifeforms may assist restoration goals, such as restoring rongoā (medicinal) species, epiphytes (Hall 2020), or threatened non-tree flora. Enrichment interventions should be timed and executed when the regenerating forest provides suitable structural and microclimatic conditions for the enrichment species to thrive. Forest restoration planting to thicken sparse native vegetation cover can increase a stand's suitability for enrichment planting. Very dense or tall stands of regenerating forest might require manipulation of the vegetation structure to reduce competition from the existing stand thereby ensuring growth of enrichment

Table 1. Location, climate and seed source data underpinning the stepped assessment of restoration mode for six sites across Aotearoa New Zealand (Fig. 2 a–f).

Ref	Location	Coordinates (WGS84)	Capable of supporting forest?	Regeneration occurring?	Rainfall (mm year^{-1})	Temperature (°C)	Seed source (ha; % Cover)	Topographic character (Landforms, slope aspects, topographic shelter)	Existing landcover provides shade and shelter?	Restoration mode (Active/ Passive)
a	Grassmere, Marlborough	41°45’ S 174°07’ W	Yes	No	556 ± 121	13.5 ± 0.9	45 (<1)	Landform homogenous, NW aspect, little shelter	No	Active
b	Culverden, Canterbury	42°43’ S 172°50 W	Yes	No	609 ± 115	11.4 ± 0.3	0 (<1)	Landform homogenous, NW aspect, little shelter	No	Active
c	Black Umbrella Range, Otago	45°43’ S 169°03’ W	Yes	Yes	c. 1100	c. 7.5	1400 (18)	Diverse range of landforms, aspects and levels of shelter	Yes	Active
d	Matahorua, Hawke’s Bay	39°08’ S 176°55’ W	Yes	Yes	c. 1250	c. 13.5	175 (2)	Landform homogenous, SE aspect, moderate shelter	Yes	Passive
e	Matiere, Manawatu-Whanganui	38°46’ S 175°07’ W	Yes	Yes	c. 1450	c. 12.5	2020(26)	Diversity of landforms, aspects and shelter	Yes	Passive
f	Kiwinui, Tairāwhiti	37°42’ S 178°20’ W	Yes	Yes	c. 1900	c. 14.5	4304 (55)	Moderate variably of landforms and aspects, little shelter	Yes	Passive

Notes: Mean annual temperature and rainfall records represent: (a) temperature = 17 years over 1983–2008 and rainfall = 11 years over 1984–2003 at the Grassmere Salt Works; (b) temperature = 17 years over 1984–2008 and rainfall = 11 years over 1983–2004 at the Culverden climate station; (c–f) statistics inferred from NIWA’s modelled climate surfaces (Chappell 2013, 2015, 2016).

species (Tulod & Norton 2020). Enrichment provides a means of accelerating aspects of forest development and is particularly important in contexts where regeneration is homogenous or where natural seed sources are scarce, are missing target species, or where pollination or dispersal functions are impaired meaning natural establishment is limited. Enrichment treatments are well suited to passive restoration in so far as enrichment species can be introduced into forest contexts where their future natural spread is plausible. There are potential risks associated with enrichment planting, especially when conducted at landscape scales. Such risks include introduction of genetic material from maladapted local ecotypes, propagation and spread of disease via nursery stock, and inappropriate species choice affecting natural species distributions (Forbes et al. 2020).

Competition treatments are interventions which aim to optimise the availability of light for growth of planted seedlings to promote their recruitment to higher forest tiers. Interventions can focus on creating small-scale canopy gaps (McAlpine & Drake 2003; Forbes 2017) or on addressing competition from excessive weed growth (McAlpine et al. 2018). Management should aim where possible to eliminate shade tolerant or structurally dominant weed species, particularly in the early stages of invasion when control is more achievable (Harris et al. 2001). Competition treatments are most likely to be needed when planting into dense stands where light transmission to the forest understorey is strongly limited by heavy shade.

Preservation treatments (i.e. treatments that support regeneration through preservation of existing processes or attributes) aim to protect regeneration and successional processes from biotic (e.g. excessive herbivory or weed competition) and abiotic (e.g. wildfire) threats and preserve existing ecosystem attributes which support regeneration processes (e.g. legal protection and management of adjacent forest seed sources; carnivorous predator control to build and maintain avian pollinator and disperser communities; Kelly et al. 2010). Specifically, domestic stock should be excluded from regenerating forests and feral mammalian pests (e.g. ungulates, possums, pigs, rabbits and hares) should be excluded by fencing or at larger scales by culling feral populations. Threats to regeneration need to be addressed early in the project and often these interventions must be ongoing, as without an adequate level of ongoing management, threats can seriously limit forest restoration outcomes irrespective of the climate and seed source contexts.

Scaling-up regeneration

Scaling-up regeneration requires a strategic approach where various avenues of advice and support are stacked for landowners in geographical areas where regeneration is most likely (i.e. regeneration zones). Rainfall and temperature gradients indicate broad regions of ANZ which are most amenable to restoration by passive means (Mason et al. 2013). These broad regions will contain existing examples and evidence of regeneration (e.g. Fig. 2d–f) and this approach

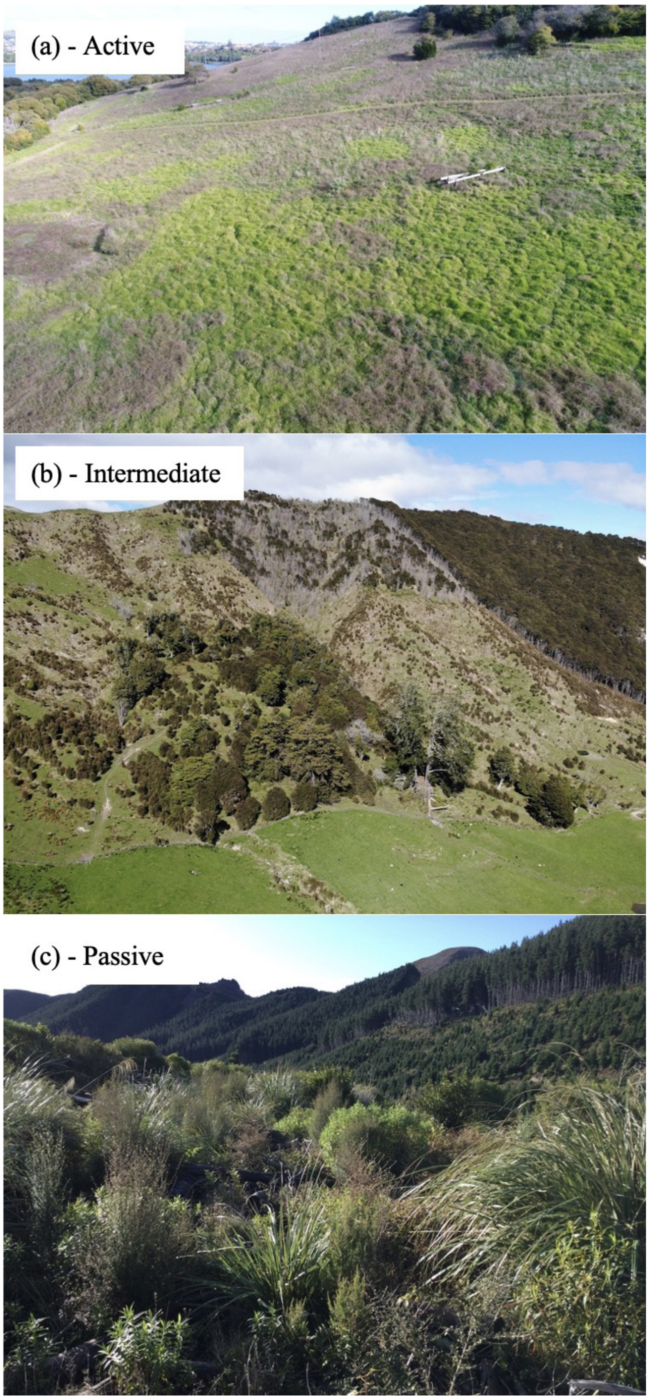

Figure 3. Examples of appropriate management interventions required to support forest establishment in three circumstances along a gradient from active to passive. (a) Pasture grassland containing high levels of cover of the aggressive exotic kikuyu grass (*Cenchrus clandes*). Key management interventions are to retire domestic grazing animals, clear exotic grass at planting sites to reduce competition, and plant seedlings of early successional species to outcompete exotic grasses and create microsites where seedlings can establish from natural seed rain (b) Hill country with a history of both prolific kānuka (*Kunzea* ericoides) regeneration and herbicide applied to maintain pasture grassland. Key management interventions are to exclude stock and eradicate feral ungulates and possums, enrich the regeneration with representative species which are missing from the surrounding secondary forests, protect the regenerating forest by ceasing herbicide application, protect surrounding forests as future seed sources, and remove weed sources from the surrounding landscape. (c) Land cleared of an exotic conifer plantation and retired for conservation. Key management interventions are to remove competing wilding conifer regeneration and protect regeneration by eradicating feral ungulates and possums.

allows a focus on multiple large-scale regeneration projects aggregated in favourable climate contexts.

Within regeneration zones, ecological threats need to be identified and addressed (e.g. mammalian browsers or serious plant pests) at landscape scales in a collaborative and coordinated manner which alleviates the burden of addressing threats on any one landowner. This coordinated and landscape scale approach would remove barriers that an individual landowner faces when having to address landscape scale threats at a farm or site scale in isolation from the surrounding landscape. Community-led catchment care groups located in regeneration zones should be developed and resourced to support and connect landowners with their regeneration project and to cultivate a community culture supportive of forest regeneration and associated management interventions (e.g. landscape-scale ungulate control; Maseyk et al. 2021).

Central government can make significant steps towards achieving their emissions budgets (under the Climate Change Response Act 2002) through financial incentives (e.g. grants schemes, rates relief working with local government) for marginal land retirement and regeneration projects in the regeneration zones. Financial support should be structured to fund native forest enrichment, competition, preservation treatments, and fencing where required. Region-specific economic analyses of income streams (e.g. carbon sinks, native timber markets, medicinal, cultural products, ecotourism) and costs of land use changes from agriculture on marginal land to native forestry need to be available to landowners (Walsh et al. 2017; Lambie et al. 2021). In addition to adequate financial support, landowners might be motivated by a wide array of advantages from environmental (e.g. protecting flora and fauna, managing the environment, water quality), economic (e.g. farm value), social (e.g. intergenerational equity, feel-good factor, aesthetics), and practical on-farm management (e.g. animal wellbeing, land use change) perspectives (Maseyk et al. 2021). Lastly, to assist with technical aspects of their regeneration project, landowners require access to free expert independent restoration advice (e.g. Restoration Ambassadors/Restoration Rangers; Norton et al. 2020).

Conclusions

We describe a process for site-scale assessment of the likelihood of natural forest establishment through regeneration processes. We frame our assessment in the context and timeframes of urgent climate and biodiversity crises and the corresponding need to achieve large-scale restoration within several decades. On sites that can support forest, and where adequate regeneration is not yet occurring, we identify a combination of climate and physical factors that landowners can use to determine where on a continuum from active-to-passive forest establishment sites or parts of sites relate.

Natural regeneration processes will, to differing degrees, require management support, such as interventions to enrich the diversity of native species, address adverse competition, or preserve important processes or attributes which underpin regeneration. Scaling-up regeneration requires a strategic approach which focuses forest management and support in geographical regions which are environmentally and economically amendable to regeneration. This consolidated regional approach would focus threat management and financial and technical support to land areas where co-ordinated action among neighbouring landowners can promote the processes necessary for landscape-scale recreation of native forest ecosystems.

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