Opportunities to manage sediment from forestry more effectively in the Marlborough Sounds and contributing catchments

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Abstract

Soil disturbance associated with earthworks and harvesting of radiata pine *(Pinus radiata)* has caused erosion and run-off into the coastal waters of the Marlborough Sounds (the Sounds) and resulted in excessive deposition of fine sediment onto estuarine and subtidal benthic habitats. Ecological consequences have included habitat damage and species loss, alteration of ecological interaction networks and associated biogeochemical processes, and loss of resilience from ongoing disturbance. The causes and consequences of forestry's contribution to excessive sedimentation in the Sounds' coastal ecosystems are reviewed in this paper.

Despite awareness of these issues, the regulatory response over the last 45 years has been largely ineffectual. This now includes the Proposed Marlborough Environment Plan 2020 (PMEP, 2020) where greater stringency available under the National Environmental Standards for Plantation Forestry (NES-PF) has been exercised. However, this focused on the management of diffuse sources from surface processes through the provision of coastal setback controls of greater distance than required by the NES-PF. Greater stringency has not been applied to the major sources of sediment delivery, which are mass failures generated by erosion-prone gullies, gully-heads and steep side-slopes. Stricter harvesting controls and the requirement for replanting management plans that retire these source areas would significantly reduce sediment production and promote sediment retention. An update of the NZ Land Resources Inventory is also needed to improve the NES-PF Erosion Susceptibility Classification (ESC), as the predominant High ESC designation in the Sounds does not reflect the likely widespread occurrence of Very High ESC landforms.

Introduction

Ecologically healthy estuaries and inshore environments provide multiple ecosystem benefits to nature, as well as cultural, recreational, economic and social value to humans (Thrush et al., 2013). Excessive sedimentation into estuaries, harbours and nearshore areas from accelerated erosion caused by land use is a serious threat to benthic intertidal and subtidal habitats, including shellfish beds, seagrass meadows and kelp forest (Thrush et al., 2004; MacDiarmid et al., 2012). Habitats can be smothered, resulting in damage and alteration of ecological functioning, which leads to reduced ecosystem resilience to disturbance (Thrush et al., 2004).

Other adverse effects from sedimentation include:

- Increased turbidity and reduced light transmission, which affects primary productivity in the water column
- Altered biogeochemical gradients, such as inhibited nutrient cycling and reduced photosynthesis of benthic microalgae
- Clogged fish gills and the feeding parts of sediment-dwelling filter-feeders
- Chronic effects on macrofauna physiological condition and behaviour (Thrush et al., 2004).

The sheltered waters and estuaries of the Marlborough Sounds (the Sounds) are particularly vulnerable to excessive sediment deposition due to low current speeds (Johnson et al., 1981; Hadfield, 2015). For example, in slower-flowing side bays and inlets, the bottom stress from tidal current action can often be below a typical resuspension threshold of 0.1 Newton m^{-2} for clay-rich sediments resulting in settlement onto the seabed (Hadfield, 2015). Settlement can occur rapidly as clay-rich particles flocculate on contact with seawater (Thrush et al., 2004).

In the Sounds and its contributing catchments, the adverse effects of excessive fine clay-based sediment derived from extensive land clearance and disturbance have resulted in the smothering and ecological degradation of estuarine and subtidal communities over the last 160 years (e.g. Stevens & Robertson, 2014; Handley et al., 2017).

Figure 1: Relatively common issues from forestry earthworks and harvesting in the Marlborough Sounds: (a) Log-scoured runnels by inadequate lift from a cable hauler cable on a ridge top and pulling across slopes, Port Underwood, 2016; (b) Batter slump, and fill failure from logging road into Pelorus Sound, 2012; (c) Debris flow post-harvest, Pelorus Sound, 2011; (d) Post-harvest slope failure and top of debris flow, which smothered an estuary, 2015; (e) Bulldozer mishap above the shoreline Tory Channel – note sediment discoloured waters close to shore; (f) Harvesting to the shoreline, vulnerable to sediment run-off, Tory Channel, 2016; (g) Landing failure from inadequate water controls and poor construction resulted in debris flow down a forested creek, with sediment discharge into Pelorus Sound, 2017; (h) Debris flow with logs and soil after Cyclone Gita, Port Underwood, 2018. Photos: MDC – except (e) courtesy of Peter Beech

Since the 1970s, radiata pine forestry ('forestry') earthworks and harvesting have been shown to cause high sedimentation rates and ecological damage to coastal ecosystems in the Sounds (Johnston et al., 1981; Fahey & Coker, 1992; Philips et al., 1996; Urlich, 2015). Log-laden debris flows, landing and batter failures, slope runnels from insufficient deflection, and diffuse run-off from roads and harvested areas are relatively frequent occurrences (Figure 1). Many events are rapidly deposited into the Sounds due to the steep topography and short distances to the coast (Phillips et al., 1996; Urlich, 2015). Despite regulators attempting to respond to these factors over the last 45 years or so, ecological damage is continuing (Field, 1976; Planning Tribunal, 1979; Marlborough District Council (MDC), 1992; Urlich, 2015).

This paper provides an overview of the causes and consequences of excessive fine sediment deposition in the Sounds, drawn from Urlich (2015) and Marden and Phillips (2015). The objective is to examine whether the National Environmental Standards for Plantation Forestry (NES-PF) (NZ Government, 2017) and the Proposed Marlborough Environment Plan (PMEP, 2020) are likely to be effective in addressing these issues. Practical solutions to mitigate sediment deposition are outlined, with the aim of reversing ecological decline. This is critical to maintaining biodiversity and its associated ecological functioning, thereby safeguarding ecosystem life-supporting capacity. The outcome may also serve to help stem the erosion of the social licence of forestry to operate in steeplands (c.f. Raymond, 2015).

Methods

The technical library of journal articles and scientific reports held by the MDC (around 1,500 items) was searched for forestry references, which had also informed an earlier MDC review (Urlich, 2015). Additional referenced articles were identified following further reading. A Google Scholar search (20 web pages) was also undertaken on 9 June 2020 using the search term 'forestry Marlborough Sounds' to ensure all the relevant literature was identified. The MDC and Te Uru Rākau websites were also examined for relevant regulatory measures.

Results and discussion

Soils and erodibility

In 2018/19, forestry (predominantly radiata pine) covered about 12,311 ha in the Sounds – Queen Charlotte/Tōtaranui, Pelorus/Te Hoiere and Port Underwood (Urlich & Handley, forthcoming), and about 14,109 ha of the Pelorus/Te Hoiere, Kaituna and Cullens Creek catchments, which are coupled to Pelorus Sound (hereinafter the 'key catchments').

Most forestry is situated on land primarily zoned orange (high risk) for erosion susceptibility in the NES-PF (NZ Government, 2017). This is mostly designated as Land Use Capability (LUC) Class 7e steeplands (Urlich & Handley, forthcoming). The predominantly steepland soils are prone to slips, and sheet and rill erosion once the vegetation cover is removed (Johnson et al., 1981; Laffan & Daly, 1985). These soils are mostly derived from Greywacke and schist and are silt and silty-clay loams with up to approximately 45% clay, formed by weathering of the parent material and some loessial deposition (Laffan & Daly, 1985).

In the Sounds, soils between the shoreline and 200 m elevation are generally clay-rich, highly weathered, and therefore prone to erosion (Laffan et al., 1985). Soil mantles are thicker at these lower altitudes, and likely to yield more fine sediment than less weathered and thinner soils at altitudes above 200 m (Laffan et al., 1985; Fahey & Coker, 1992). Geomorphological advice to the MDC in 1992 to inform the development of the regional coastal plan stated (Sutherland et al., 1992, p.17):

> *The landscape below the 200 m contour [in the Sounds] is regarded as being more unstable due to the presence of deep weathering profiles, higher clay contents [with relatively low aggregate stability], colluvial deposits and re-worked loess.*

This also applies to the key catchments given shared geology, soils, topography and strong coupling of steeplands to the river network with rapid delivery to Pelorus Sound.

Under high rainfall intensity, considerable run-off into coastal waters occurs from erosion and landsliding where hillslopes are directly coupled to the coast (Johnson et al., 1981; Sutherland et al., 1992; Phillips et al., 1996). For example, Phillips et al. (1996) identified eight landslides in a recently harvested forest above Tory Channel/Kura Te Au after a storm in 1994. All landslides were below 200 m elevation in gully depressions on steep slopes (often over 30°).

Soil erosion also occurs at higher elevations under heavy rainfall. The shallow soil mantle sits over weakly weathered rocks, which can slip under high rainfall due to relatively shallow shear planes between the thin soil and bedrock (Laffan & Daly, 1985). There is increased susceptibility to erosion in recently harvested areas and risk of delivery to waterways. In the Sounds and key catchments the 'window of vulnerability' is always open somewhere, as extensive harvesting occurs across the landscape at any time (Urlich & Handley, forthcoming).

High rainfall events are relatively frequent in the Sounds and its contributing catchments. For example, in three sub-catchments of the Pelorus River, the minimum return period for the top 20 rainfall events over the last 20 years is about a one-in-two-year annual return interval (ARI) for all sub-catchments (Figure 2). The maximum ARI was a one-in-65-year event or greater in July 1998. This coincided with floodwater flows exceeding 2,000 cumecs calculated at Dalton's Bridge for the Pelorus River, upstream of the Whakamarino confluence. Other floods over the last 20 years that exceeded 2,000 cumecs occurred in 2008, 2010 and 2012 (Figure 2).

Environmental consequences of erosion

The MDC (1992, p.3) recorded long-term community concern about forest development in the Sounds and excessive sedimentation:

> *Land preparation clearance for planting in the early 1970s using line dozing and root raking techniques on steep hill country resulted in damaging on-site and off-site effects including increased and [sic] silt-laden run-off, soil erosion and marine sedimentation.*

Community concern was heightened by the 'unfortunate environmental spectacle [of] severe land

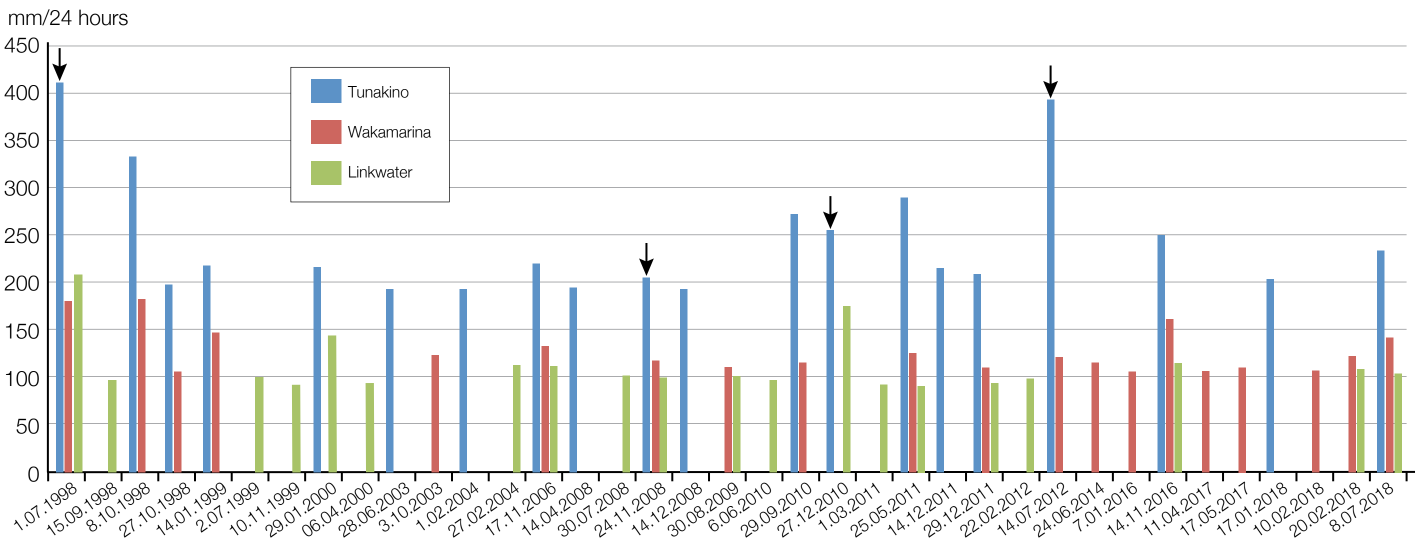

Figure 2: Twenty largest rainfall events 1998-2018 in three Pelorus/Te Hoiere sub-catchments. Arrows denote flood volumes of the Pelorus/Te Hoiere River that exceeded 2,000 cumecs, as calculated at Dalton's Bridge upstream of the Whakamarino River confluence. Data courtesy of Val Wadsworth, MDC

instability and sedimentation problems' at Farnham Forest, Queen Charlotte in the mid-late 1970s (MDC, 1992, p.4). Field (1976) refers to a complaint to the Marlborough County Council and the Minister for the Environment by the Nature Conservation Council in March 1974 about suspended sediment discolouring coastal waters.

Run-off after heavy rain also resulted in damage to the seafloor close to Farnham Forest (Johnston et al., 1981). There were few species within the fine-textured muddy sediments, which instead contained buried radiata pine bark and detritus. In contrast, in nearby seabeds unaffected by sediment run-off, coarser textured sandy sediments hosted a biodiverse array of shellfish, urchins, anemones, starfish and tubeworm colonies. There was also greater fish abundance in unaffected areas (Johnston et al., 1981).

In the late 1970s, the Marlborough Catchment and Regional Water Board considered the effects on the Brown River and the Havelock estuary from the impending pine harvest of the Rai State Forest (Bargh, 1977). Increased stream turbidity and possible effects on recreation, wildlife and commercial wet fish catches were identified. Adverse effects of fine sediment on mussel spat were inferred, with reference made to a 'massive sedimentation' event in 1976 suggested as affecting spat production (Clarke, 1977 cited in Bargh, 1977).

Bargh (1977) commented that sedimentation was a natural process, but acknowledged that how much sediment was too much was unknown. It was accepted then that: 'Sediment loads increase significantly in all streams draining logged catchments' (Bargh, 1977, p.3). The Catchment Board were also clear that: 'Sediment originating from forest harvesting operations needs to be strictly controlled … as they may cause detrimental changes to life in the river system or in Pelorus Sound' (Bargh, 1977, pp.4–5).

There are currently multiple adverse effects from forestry in the Marlborough Sounds and the key catchments (Figure 1). The consequences of mass failures associated with harvesting and earthworks, and ongoing diffuse flow from clearfell areas and roads, include the smothering of habitats assessed as ecologically sustainable under Section 6c of the Resource Management Act (RMA) 1991, such as shellfish beds and seagrass meadows in estuarine and shallow subtidal areas (Urlich, 2015 and references therein).

Estuaries in the inner Pelorus Sound are now amongst the muddiest in the country (Stevens & Robertson, 2014), with seagrass reduced in extent and in some areas observed with fine sediment coating on the leaves. Handley et al. (2017) identified that sediment accumulation rates are elevated five to 20 times above pre-European levels in Pelorus Sound. Sediment derived from forestry is disproportionately represented in the top 2 cm of seabed samples within Pelorus Sound, including near the entrance about 40-50 km from Havelock (Handley et al., 2017).

Regulatory responses over time

In 1975, forestry was notified as a conditional use for soil conservation reasons in the Marlborough County Council District Planning Scheme under the Town and Country Planning Act (Field, 1976). The District Scheme reserved control to the County Council due to the recognition that environmental and landscape effects of forestry had the potential to conflict with other uses of the Sounds. Field (1976) noted that this arose from a multi-agency meeting, which included environmental groups, following public concern in 1974 at run-off discolouring coastal waters caused by forestry earthworks and harvesting at Farnham Forest.

The District Scheme drew its own adverse reaction from forestry interests and hastened, according to Field, the formation of the Marlborough Forest Owners Association (MFOA). Thus began the often fraught relationship between the industry and local authority regulators. At its heart is an ongoing tension between different ideas about the use of the commons that is the Sounds, with its myriad waterways, diverse ecology and scenic values.

This has played out in different ways within succeeding planning instruments over the last 45 years and has included other activities, such as marine farming and fast-ferry operations. These conflicts were compounded by a general lack of ecological understanding of the nature and seriousness of effects within both the planning and land use communities. More latterly, as the effects on ecological functioning and seabed health are becoming more widely known, the debate is starting to shift to the proportional contribution by forestry of sediment into Sounds waterways compared with other land uses. An industry representative has publicly expressed that they share the public's concern about sedimentation in the Sounds (Vern Harris, Marlborough Forestry Industry Association, Stuff Business website, 27 December 2017).

The MFOA objected to the conditional use in the District Scheme as 'bad stewardship' (Field, 1976). They argued forestry could provide the economic base to support communities in the Sounds, as the pastoral sector was struggling, and tourism and recreation were too small. The NZ Forest Service also argued for forestry to be a predominant (permitted) use. Their vision was for tourism and recreation around the coastal margins and forestry on the hills above. There was also an existing public investment in forestry encouragement loans (Field, 1976).

The Planning Tribunal heard a series of appeals to the District Scheme in 1979. The Scheme allowed forestry in two rural zones, with the Marlborough Sounds zone (Zone B) proposed to restrict forestry to a conditional use, and only farming and passive recreation as permitted uses 'to preserve the unique Marlborough Sounds Coastal environment and to protect it from unnecessary subdivision and development' (Planning Tribunal, 1979, p.170). The MFOA wanted Zone B abolished or, failing that, forestry to be recognised as a permitted use.

The Tribunal considered the appeals to be of '… considerable significance to the future development of the Marlborough Sounds in particular' [para 1.2]. At that time, 6,146 ha of radiata pine was established within the Marlborough Sounds. In considering the environmental effects of enabling forestry to expand under controls in the Marlborough Sounds, the Planning Tribunal heard evidence from Dr Colin O'Loughlin, a Senior Scientist with the Forest Research Institute. Despite forestry activities causing increased turbidity near the shoreline, he assessed that the seawater was able to:

> *… clear itself quite quickly after contamination … He concluded that there was no reason why forestry cannot be practised without adverse consequences to the marine environment. In the past, some practices with regard to these matters have been unsatisfactory. He considered, however, with changing technology and proper practices, such problems could be overcome. He thought the land was stable; there was unlikely to be much problem from landslides; and that overall, taking into account the fact that the whole forestry cycle is something like 25 to 30 years, the cumulative sedimentary effect on the sea bottoms would be less than for other land uses. [at 5.1]*

Subsequent research on landsliding and debris flows has run counter to the idea that the land is stable (e.g. Phillips et al., 1996). Adverse consequences have also occurred, and continue to occur, to the marine environment from forestry (Figure 1), and there has been a demonstrable cumulative sedimentary effect on the seabed (Johnson et al., 1981; Handley et al., 2017).

The Tribunal did not hear evidence from a marine biologist, nor from iwi. Rather, in contrast to the evidence called in support of the appellants, which placed faith in technological developments to minimise run-off, the Nature Conservation Council witness urged that thought be given to avoiding future issues before trees were planted [at 5.16].

The Tribunal dismissed the MFOA appeals due to the need 'to protect the unique Coastal environment' as a matter of national importance (p.183). However, it also rebuffed conservationists who were opposed to an expansion of forestry and had argued that significant regeneration of native bush within the Sounds should continue to expand. The Tribunal placed production ahead of natural values '… in the interests of the national economy, we think there needs to be a balance' (p.183). This overall balancing approach or 'broad judgment' presumption has carried through to the Resource Management Act 1991 (RMA), but the Supreme Court in 2014 determined that to be incorrect (SC82/2013 [2014] NZSC 38). The court found that there are environmental bottom-lines around the need to protect certain values, which had been articulated within the New Zealand Coastal Policy Statement (NZCPS, 2010).

The 1990s saw an increase in public concern at the environmental effects of forestry as harvesting got underway above Tory Channel. A number of studies on environmental effects resulted (reviewed in Urlich, 2015). In 1995, the Marlborough Regional Policy Statement required under the RMA was made operative.

Example along the lines of what a replanting management plan aims to achieve. Note the retention of mature indigenous forest in steep erosion-prone gullies and faces and careful placement of roads and landings, Havelock, 2016. This operation had issues with woody debris left in a waterway out of view

This identified that forestry run-off was an adverse threat to coastal marine and freshwater ecosystems. The maintenance of marine water quality was a specific objective, given its acknowledged importance to the health of the marine ecosystem.

The method was to put controls into resource management plans to avoid, remedy or mitigate sediment entering coastal waters from land, and educate those undertaking land use practices. The Marlborough Sounds Resource Management Plan came into full effect in 2011. It stated:

Rigid controls are necessary in the coastal marine area as this is the 'environmental sink' where the effects of all coastal and land-based activities impact. Coastal marine ecosystems depend on uncontaminated seawater, undisturbed seabed or foreshore and healthy land and freshwater ecosystems adjacent to the coast. Environmental effects in the coastal marine area are felt in essentially two ways: Degradation of coastal water quality; and alteration to the foreshore or seabed. (Volume 1, 9-8A & 9)

Resource consent was required for land disturbance associated with forestry earthworks, but not harvesting or for replanting to retire erosion-prone areas. From personal observation between 2011 and 2018, replanting was prohibited within 30 m of the coastal marine area but was not actively monitored for compliance. The question of whether plan provisions and resource consent conditions were adequate is now moot, given the advent of the NES-PF and PMEP.

The MDC review of environmental effects in 2015 did, however, identify gaps in the regulatory regime and suggest a range of solutions (Table 1). The key recommendation was for a property-specific replanting management plan to control future erosion and sedimentation. This would require the identification of areas for retirement to prevent debris flows, exacerbated by slash left in gully-heads, steep gullies and faces (see example in the photo). Discretion would be reserved to the MDC for replanting approval. Native regeneration under the high rainfall of the Sounds would be swift, but wildings would need management.

These recommendations could have been addressed within the Marlborough Environment Plan notified for public consultation in June 2016. The release of the draft NES-PF for public consultation the previous year meant that the MDC chose not to undertake policy work for the notified plan around greater coastal setbacks or replanting management controls. However, this would have benefited the MDC's Hearings Panel in February 2020 when they were considering greater stringency in the PMEP in response to numerous public submissions. The Panel chose to control replanting between 30–200 m from the shoreline, and reserve restricted discretion over earthworks to require a higher standard of design and implementation (MDC Hearings Panel, 2020). They ignored mass failures which deliver the most sediment to the Sounds (Marden & Phillips, 2015) by being silent on the need to control replanting in erosion-prone steep landforms, except for woodlots on farms.

Opportunities for better management

Replanting in the NES-PF is controlled with reference to the underlying Erosion Susceptibility Classification (ESC) for the Marlborough Sounds and contributing catchments. The ESC oscillated between orange and red in the years leading to the finalisation of the NES-PF (Figure 3), reflecting the coarseness of underlying soil and land use capability mapping, as well as the subjectivity of expert assessment of the potential for soil erosion underpinning the ESC. The MDC's submission on the draft NES-PF said that the ESC did not fairly or accurately represent erosion risk (Figure 3 centre), and expressed concern about potential adverse effects being effectively managed under permitted activity conditions. While initially appearing to address the MDC's concern in the third reiteration of the ESC,

Table 1: Regulatory options from Urlich (2015) after analysis of scientific studies on forestry effects in the Marlborough Sounds, with review by Marden & Phillips (2015)

Regulatory options	NES-PF	PMEP	Comment
Replanting setbacks from shoreline 30 m, 100 m or 200 m	Replanting setback 30 m	30–200 m controlled to manage erosion	PMEP criteria for control not defined. High transaction costs, little certainty, compliance issues. Highest erodible soils from sea-level to 200 m. Also 200 m setback supported by available soils evidence
Replanting setbacks for permanently flowing streams coupled to sea	Replanting within 5 m of perennial rivers <3 m width, 10 m >3 m width	Not applied	NES-PF reflects regulatory option
Replanting control on steep slopes: mandatory replanting management plan to retire erosion-prone slopes	No discretion as all forestry land zoned as orange in ESC	Not applied	Mass failures greatest source of sediment delivery to coast. Replanting plan enables property-specific solution. Discretion to replant over 200 m and ESC revision options needed (see *Opportunities for better management* above)

Note: NES-PF = National Environmental Standards for Plantation Forestry (2017); PMEP = Proposed Marlborough Environment Plan (2020). MEP column is where the MDC applied greater stringency under the NES-PF to address the NZ Coastal Policy Statement (NZCPS, 2010)

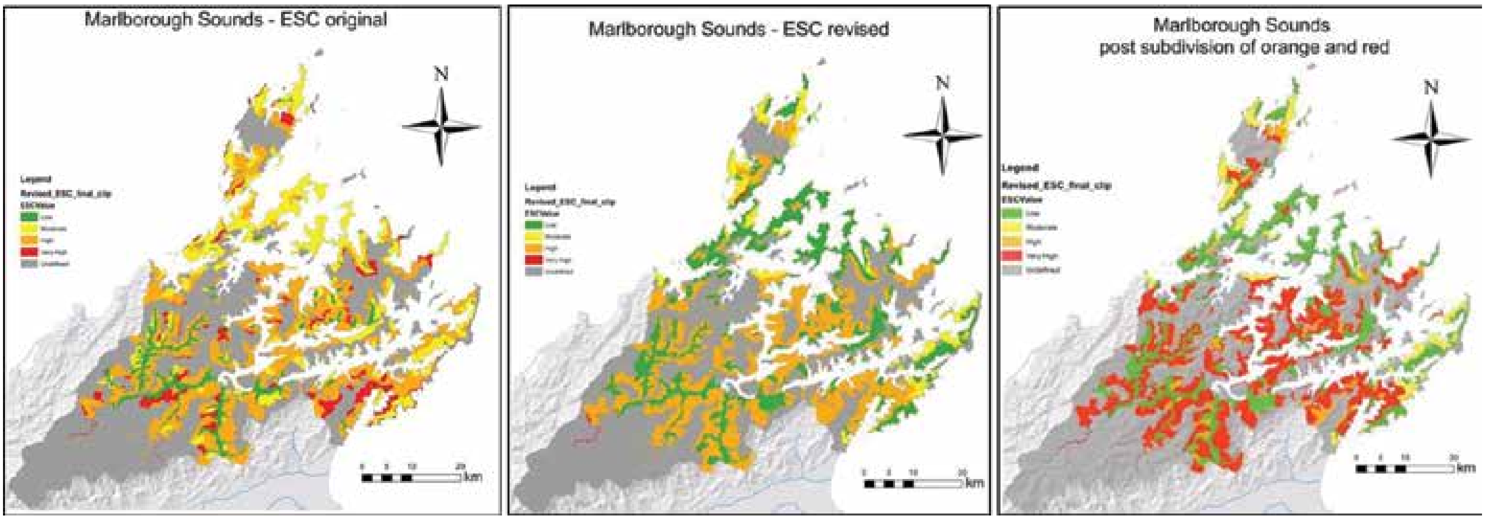

Figure 3: Variations of the ESC for the Marlborough Sounds and contributing catchments, from Basher (2016). Left: Original ESC from Bloomberg et al., 2011. Centre: First revision by Basher et al., 2015 and third (final) revision by Basher & Barringer, 2017. Right: Second revision by Basher et al., 2016. See the NES-PF for full references. The centre image is the current ESC

with large areas becoming red (Figure 3), the ESC reverted back to its second iteration (Figure 3 centre).

The MDC was advised that the NZLRI mapping of the Sounds was too coarse at 1:50,000 scale for the ESC, and remapping should be undertaken to the property scale 1:10,000 (Basher, 2016), but this has not yet occurred. The MDC has commissioned LiDAR across the region, which will be available in 2021. The elevation data can be combined with an analysis of radiometric isotopic data, collected from an aeromagnetic survey flown in 2015/16, to identify areas of mass wasting, erosion pathways and inherent erosion susceptibility on different geologies (Basher, 2016; Clint Rissman, pers. comm.). Along with improved underlying soil mapping, the information may also improve terrain stability zoning at an operational scale to better match harvesting methods with slope stability, hazard and risk management (Phillips et al., 2018).

Any future improvement to the ESC should lead to the identification of areas within different landforms that would meet the NES-PF threshold of Very High ESC (Mark Bloomberg, pers. comm.), triggering resource consents for forestry activities. If harvesting consent conditions are strong enough, landowners may be compelled to replant forests in a way that reflects land use capability, or even let the land revert to native forest or adventive species (Mark Bloomberg, pers. comm.). It could also result in trees within some areas being unharvestable and therefore left standing.

However, these developments may take years to be operationalised, and there are no barriers to practical controls on replanting, which are needed now (see photo). This is the subject of appeal on the PMEP by environmental groups, with community support. Replanting controls will also assist forest owners in the long term to meet the stringent water quality standards set in the NES-PF. In the Sounds and contributing catchments, it would be extremely difficult for clearfell harvesting to meet NES-PF Regulations 26 or 65 to prevent any conspicuous change in colour or visual clarity or any significant adverse effects on aquatic life. The clock is ticking for compliance and enforcement of the PMEP and NES-PF in the Sounds.

New and refined tools are a step in the right direction if they lead back to the salient words of noted explorer and conservationist Sir Holmes Miller, Deputy Chairman of the Nature Conservation Council, before the Planning Tribunal in 1979: '… that the problems be given some thought before trees were planted.' The challenge before the industry is to embrace the need for change and lead on developing replanting guidelines for retiring erosion-prone landforms on steeplands, thereby mitigating the erosion of its social licence (Raymond, 2015).

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References

Bargh, B.J. 1977. *Possible Effects of Forest Harvesting Operations in the Brown River Catchment on Water Quality and Implications for Downstream Wildlife, Recreation and Other Uses*. Blenheim, NZ: Marlborough Catchment and Regional Water Board Report.

Basher, L. 2016. *Summary Notes from Meeting and Field Trip on Land Resource Data and Forestry Issues in the Marlborough Sounds*. Envirolink Advice Grant: 1704-MLDC118 prepared for the Marlborough District Council. Auckland, NZ: Landcare Research.

Basher. L. and Barringer, J. 2017. *Erosion Susceptibility Classification (ESC) for the NES for Plantation Forestry, Landcare – March 2017*. Landcare Research Report 2744 prepared for the Ministry for Primary Industries. MPI Technical Paper No. 2017/47. Wellington, NZ: MPI.

Basher. L., Barringer, J. and Lynn, I. 2016. *Update of the Erosion Susceptibility Classification (ESC) for the proposed*

NES for Plantation Forestry: Subdividing the High and Very High ESC Classes. Landcare Research Report 2472 prepared for the Ministry for Primary Industries. MPI Technical Paper No. 2016/12. Wellington, NZ: MPI.

Basher, L., Lynn, I. and Page, M. 2015. *Update of the Erosion Susceptibility Classification (ESC) for the Proposed National Environmental Standard for Plantation Forestry – Revision of the ESC*. Landcare Research Report LC2196 prepared for the Ministry for Primary Industries. MPI Technical Paper No. 2015/13. Wellington, NZ: MPI.

Bloomberg. M., Davies, T., Visser, R. and Morgenroth, J. 2011. *Erosion Susceptibility Classification and Analysis of Erosion Risks for Plantation Forestry*. Prepared for the Ministry for the Environment. Christchurch, NZ: University of Canterbury.

Fahey, B.D. and Coker, R.J. 1992. Sediment Production from Forest Roads in Queen Charlotte Forest and Potential Impact on Marine Water Quality, Marlborough Sounds, New Zealand. *NZ Journal of Marine and Freshwater Research*, 26(2): 187–195.

Field, D.A. 1976. *Implications of Exotic Forestry for Other Resource Uses in the Marlborough Sounds*. MSc thesis. Canterbury, NZ: University of Canterbury.

Hadfield, M. 2015. *An Assessment of Potential for Resuspension of Fine Sediments in Marlborough Sounds*. NIWA Report WLG2015-053 prepared for the Marlborough District Council. Wellington, NZ: NIWA.

Handley, S. Gibbs, M. Swales, A. Olsen, G. Ovenden, R. and Bradley, A. 2017. *A 1,000 Year History of Seabed Change in Pelorus Sound/Te Hoiere, Marlborough*. NIWA Report 2016119NE prepared for the Marlborough District Council, Ministry for Primary Industries and the Marine Farming Association. Nelson, NZ: NIWA.

Johnston, A. Mace, J. and Laffan, M. 1981. The Saw, the Soil, and the Sounds. *Soil & Water*, (Aug/Oct): 4–8.

Laffan, M.D. and Daly, B.K. 1985. Soil Resources of the Marlborough Sounds and Implications for Exotic Production Forestry. 1. Soil Resources and Limitations to Exotic Forest Growth. *New Zealand Journal of Forestry*, 30: 54–69.

Laffan, M.D., McQueen, D.J., Churchman, G.J. and Joe, E.N. 1985. Soil Resources of the Marlborough Sounds and Implications for Exotic Production Forestry. 2. Potential Site Disturbance and Fine Sediment Production from Various Forest Management Practices. *NZ Journal of Forestry*, 30: 70–86.

MacDiarmid, A., McKenzie, A., Sturman, J., Beaumont, J., Mikaloff-Fletcher, S. and Dunne, J. 2012. *Assessment of Anthropogenic Threats to New Zealand Marine Habitats*. New Zealand Aquatic Environment and Biodiversity Report No. 93. Wellington, NZ: Ministry of Agriculture and Forestry.

Marden, M. and Phillips C. 2015. *A Review of Mitigating Fine Sediment from Forestry in Coastal Waters of the Marlborough Sounds: Options for Determining Plan Rules*. Landcare Research report 2414 prepared for the Marlborough District Council. Gisborne, NZ: Landcare Research.

Marlborough District Council. 1992. *Issues and Options for Forestry and Farming in the Marlborough Sounds*. Blenheim, NZ: MDC.

Marlborough District Council Hearings Panel. 2020. *Proposed Marlborough Environment Plan. Decision on Topic 22: Forestry*. Blenheim, NZ: MDC.

NZ Government. 2017. *Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017*. Wellington, NZ: NZ Government.

Phillips, C., Marden, M. and Basher, L. 2018. Geomorphology and Forest Management in New Zealand's Erodible Steeplands: An Overview. *Geomorphology*, 307: 107–121.

Phillips, C., Pruden, C. and Coker, R. 1996. Forest Harvesting in the Marlborough Sounds – Flying in the Face of a Storm? *New Zealand Journal of Forestry*, 41(1): 27–31.

Planning Tribunal. 1979. *In the Matter of the Town and Country Planning Act 1977 Between the Marlborough Forest Owners Association and the Minister of Works and Development (Appellants) and the Marlborough County Council (Respondent). Appeals 750/77 and 818/77. Decision No C55/80*. Wellington, NZ: Planning Tribunal.

Raymond, K. 2015. Crisis. What Crisis? Maintaining Our Social Licence to Harvest Steepland Forests. *New Zealand Journal of Forestry*, 60(2): 43–45.

Stevens, L.M. and Robertson, B.M. 2014. *Havelock Estuary 2014. Broad Scale Habitat Mapping*. Prepared for the Marlborough District Council. Nelson, NZ: Wriggle Coastal Management.

Sutherland, R.D. Kirk, R.M. and Bell, D. 1992. *Natural Processes and Environmental Hazards in the Marlborough Sounds: Issues and Options*. A report to Marlborough District Council in connection with preparation of the combined Sounds/Coastal Plan. Blenheim, NZ: MDC.

Thrush, S.F., Hewitt, J.E., Cummings, V.J., Ellis, J.I., Hatton, C., Lohrer, A. and Norkko, A. 2004. Muddy Waters: Elevating Sediment Input to Coastal and Estuarine Habitats. *Frontiers in Ecology & Environment*, 2(6): 299–306.

Thrush, S.F., Townsend, M., Hewitt, J.E., Davies, K., Lohrer, A.M., Lundquist, C. and Cartner, K. 2013. The Many Uses and Values of Estuarine Ecosystems (pp.226-237). In Dymond, J.R. (Ed.), *Ecosystem Services in New Zealand – Conditions and Trends*. Lincoln, NZ: Manaaki Whenua Press.

Urlich, S.C. 2015. *Mitigating Fine Sediment from Forestry in the Marlborough Sounds*. Technical Report 15-009. Blenheim, NZ: MDC.

Urlich, S.C. and Handley, S.J. 2020. History of Pine Forestry in the Pelorus/Te Hoiere Catchment and the Marlborough Sounds. *New Zealand Journal of Forestry (forthcoming)*.

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