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# Analysis of setback options and harvesting implications for forestry in the Marlborough Sounds

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## Report information sheet

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# Executive summary

Land-based activities such as forestry affect the waters of the Marlborough Sounds. An option for preventing fine sediment being carried to and deposited in coastal waters is to replant setback areas in riparian zones and around the coast. However, increasing setbacks will have economic and other effects.

Coastal setbacks of 30 m, 100 m and 200 m will reduce the harvestable area, log volume and increase the cost of harvesting, all contributing to a decrease in revenue from forestry (around 16% for a 200 m setback). Employment opportunities in forestry will also be reduced. On the positive side, increased setbacks will lead to slightly more carbon sequestration and avoided sedimentation (around 1% and 6%, respectively, for a 200 m setback).

## The problem

The Marlborough Sounds is an important part of New Zealand's landscape and seascape. The complex coastline and network of bays houses the nation's largest aquaculture industry, and attracts domestic and international tourists. The Marlborough District Council (MDC) undertook a review of scientific studies of the Sounds on the effects of forestry harvesting and earthworks activities on the production of fine sediment deposited in coastal waters (Urlich 2015). This set out a number of options around different replanting setback areas from the coastal margin, riparian zones, and retirement of erosion-prone gullies, gully heads and steep faces. However, the economic effects of implementing these options on planted forests had not been investigated.

## Client initiatives

The 2015 review of scientific studies prompted the MDC to seek advice from Scion as to the market and non-market economic implications of implementing the options resulting from the review. This would assist MDC in understanding the opportunity costs involved in applying greater regulatory controls. MDC was also interested in understanding the effects of different harvesting approaches and the relative costs of employing these techniques on steepland country of the Sounds.

## This project

We report here on:

- (1) The economic trade-offs of the proposed setback options on production and environmental values.
- (2) The potential effects of a selection of different harvesting approaches on sediments produced in forest areas adjacent to the marine environment, and the relative economic costs involved.

## Key results

The project team has collected data and developed a set of assumptions to conduct a spatial, economic and qualitative analyses of setback options. Based on the spatial and economic analyses, setbacks would reduce the utilisation of productive areas which could lead to lesser employment opportunities and reduce returns from forestry. We found that the 200 m setback could potentially reduce production forestry employment by 17% and overall returns from forestry by 16%. This setback option could also contribute to some small gains in environmental values such as increase in carbon sequestration by 1% and avoided sedimentation by 6%. These environmental gains may not be able to compensate for the economic losses due to the uncertainties in the carbon market and there is currently no market for avoided sedimentation. It is important to note that current regulation allows all planted forests to be harvested, therefore all benefits and costs shown in this report will not be realised until the end of the next rotation or when the setback is put in place.

We have also found that about 85% of the existing 17,029 hectares of planted forests in the Sounds are located on steep slopes. We described some of the most appropriate forest harvesting systems in the area which include various hauling systems for steep slopes and key ground based systems for flat to rolling areas.

Setbacks will increase the cost of harvesting and reduce the volume harvested. Using expert harvesting knowledge, we found that the application of a setback on an existing stand will reduce the planted and harvest area and thus the volume of logs available at a given extraction point. As the area and volume that can be extracted at a given point is reduced, the harvesting equipment will have to be moved from

landing to landing more frequently. Moving haulers from site to site is time consuming and has costs associated with it.

From the qualitative analysis on fine sediments, we found that the proposed riparian replanting setbacks (5 m and 10 m) from perennial streams are likely to provide limited protection from fine sediment inputs into waterways from harvesting activities. The proposed wider coastal setbacks (30 m, 100 m and 200 m) are likely to provide a higher level of protection to marine environments, particularly the 200 m setback covering the more erosion-prone lithologies, although the site conditions in the Marlborough Sounds and the propensity to landslides and debris flows means that total protection from fine sediment generation is not feasible.

Overall results indicate that the 30 m, 100 m and 200 m coastal setbacks will decrease revenue from the forestry blocks and increase the cost of harvesting. There are likely to be substantial financial impacts of setbacks of this size on some forest owners. However, these impacts will vary from site to site as they will be dependent on the location; some cases studies of the financial impact of these setbacks on specific woodlots are described in this report.

### **Implications of results for the client**

The MDC will be able to account for the economic costs and environmental benefits in policy and resource management discussions using quantified values of ecosystem services from setback areas, combined with other qualitatively described values. MDC will be able to account for some quantified economic impacts of setbacks such as reductions in full-time employment and returns from forestry. They will also be able to account for some environmental gains such as increase in carbon sequestration and in avoided sedimentation. With about 85% of planted forests are on steep terrain (15 degrees or greater), harvesting by haulers is recommended for those areas.

### **Further work**

This study focused on the economic and environmental impacts of setbacks in production forests in the Sounds. We did not examine in detail the recreational opportunities of forestry in the Sounds. Given the iconic status of the Sounds in the country and globally, there is a potential to create high-end recreational amenities that can contribute to the further development of eco-tourism. A study on the value of establishing recreational or tourism amenities in the setback areas using spatial and economic valuation techniques, may help better demonstrate the broader natural capital and ecosystem services values of the setback options.

We did not investigate any economic or environmental effects on the marine environment which can include fish stocks, commercial fishing and marine recreation and tourism. A future study can help examine how setbacks can affect the ecosystem services provided by the adjacent marine environment. Furthermore, we also recommend a future study to use estimated ecosystem services values (e.g. recreation, biodiversity, avoided erosion, carbon sequestration) as starting values or prices to establish new markets for bundles of ecosystem services that would incentivise improved land use management.

A further study should also examine the erosional feature and risk mapping of planted forests in the Sounds as well as assess the effectiveness of the proposed setbacks and retirement areas in reducing fine sediment production under current harvesting and engineering technologies and management practices. Such study would contribute to a more informed evaluation of the potential gains on reducing fine sediment reduction against potential impacts on the logistics and economic (market and non-market) viability of harvesting.

# Analysis of setback options and harvesting methods for forestry in the Marlborough Sounds

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# Introduction

The Marlborough Sounds is an important part of New Zealand’s landscape and seascape. It covers 4,000 square kilometres of sounds, islands and peninsulas accounting for one-tenth of the nation’s coastline (Cotton 1969; Singh 2001). The Sounds complex coastline and network of bays houses the nation’s largest aquaculture industry where at least 60% of the country’s mussels and salmon are produced (Clough and Corong 2015). The Sounds’ sheltered coastal waters have high biodiversity and landscape values which attract domestic and international tourists. However, land-based activities, including forestry, affect the waters of the Sounds.

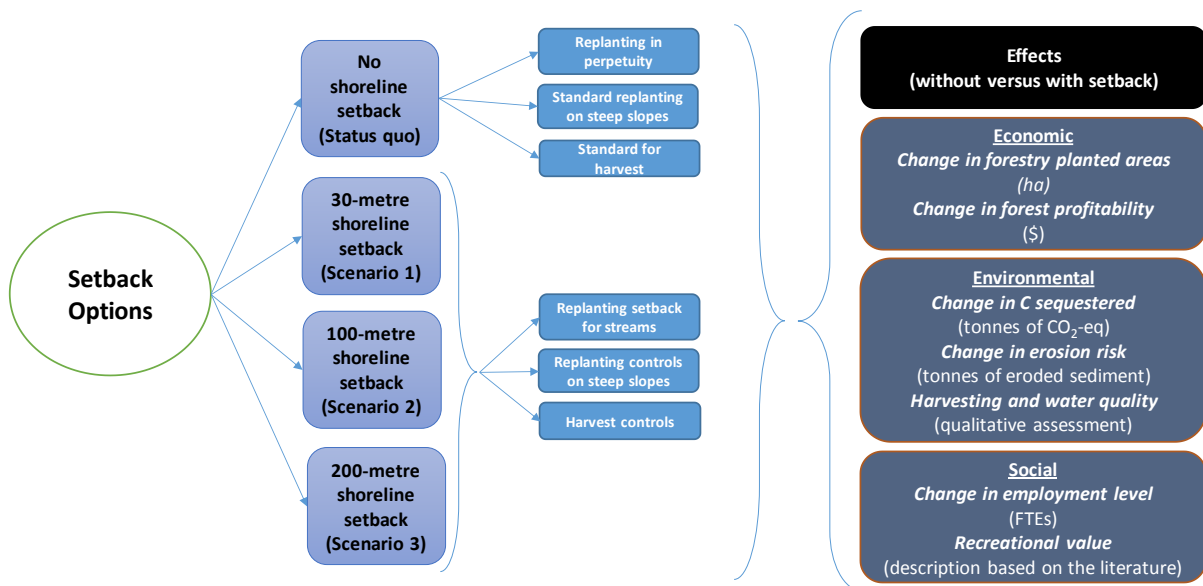
The Marlborough District Council (MDC) undertook a review of scientific studies in the Sounds to assess the effects of forestry harvesting and earthworks activities on the production of fine sediment deposited in coastal waters and the consequences of damage to seabed ecosystems (Ulrich 2015). The report set out a number of potential options to reduce the generation and transport of fine sediment from forestry activities, including different replanting setback areas from the coastal margin, riparian zones, and retirement of erosion-prone gullies, gully heads and steep faces.

The review prompted MDC to seek advice from SCION as to the market and non-market economic implications of implementing the different options. Analysing these implications would assist MDC in understanding the opportunity costs involved in applying new regulatory controls on forestry. MDC was also interested in understanding the effects of different harvesting approaches and the relative costs of employing these techniques on steepland country of the Sounds.

## Project outline and scope

The effects of the proposed setback options were assessed across a range of ecosystem services provided by planted forests, including provisioning, regulating and social and cultural services (MEA, 2005; Yao et al, 2013). The methodology was structured into two steps, namely: (1) spatial economic and economic analyses that account for both market and non-market values; and (2) analysis of impacts of setbacks based on expert knowledge and related literature.

The project was implemented using the best available spatial, economic and environmental information. The implications of setback scenarios and other sediment mitigations approaches were investigated across economic, environmental and social effects (Figure 1).



**Figure 1.** Flow diagram showing the plan for the scenario analysis of the setback options identified in Ulrich (2015).

The project focused on key economic, environmental and social values of the terrestrial areas of the catchments into the Sounds, excluding the larger mainland catchments such as of the Pelorus River.<sup>1</sup> The particular focus was on the areas planted in forestry within the Sounds. Impacts on the marine environment were outside the scope of this study.

The project did not cover the flow of ecosystem services (e.g. sediment movement) to the neighbouring marine environment due to very limited data and resources. The analysis focused on aggregated sediment (as modelled in the New Zealand Empirical Erosion Model (NZEEM) (Dymond et al. 2010)) and did not distinguish between different types of sediments (e.g. coarse, fine). Although evidence is lacking on the effectiveness of some of the sediment mitigation measures in reducing the volume of fine sediments going into the Sounds (Ulrich 2015), for the purposes of this project it was assumed that some form of protection will be achieved.

The values and quantities reported here are approximations based on best knowledge, available cost estimates, and spatial modelling techniques as used in the spatial economic framework used. The economic, environmental and social values reported here should be treated as indicative relative values and not absolute values.

## Input data

The spatial data for the Geographical Information System (GIS) analysis was sourced from the council and from available national databases (Table 1).

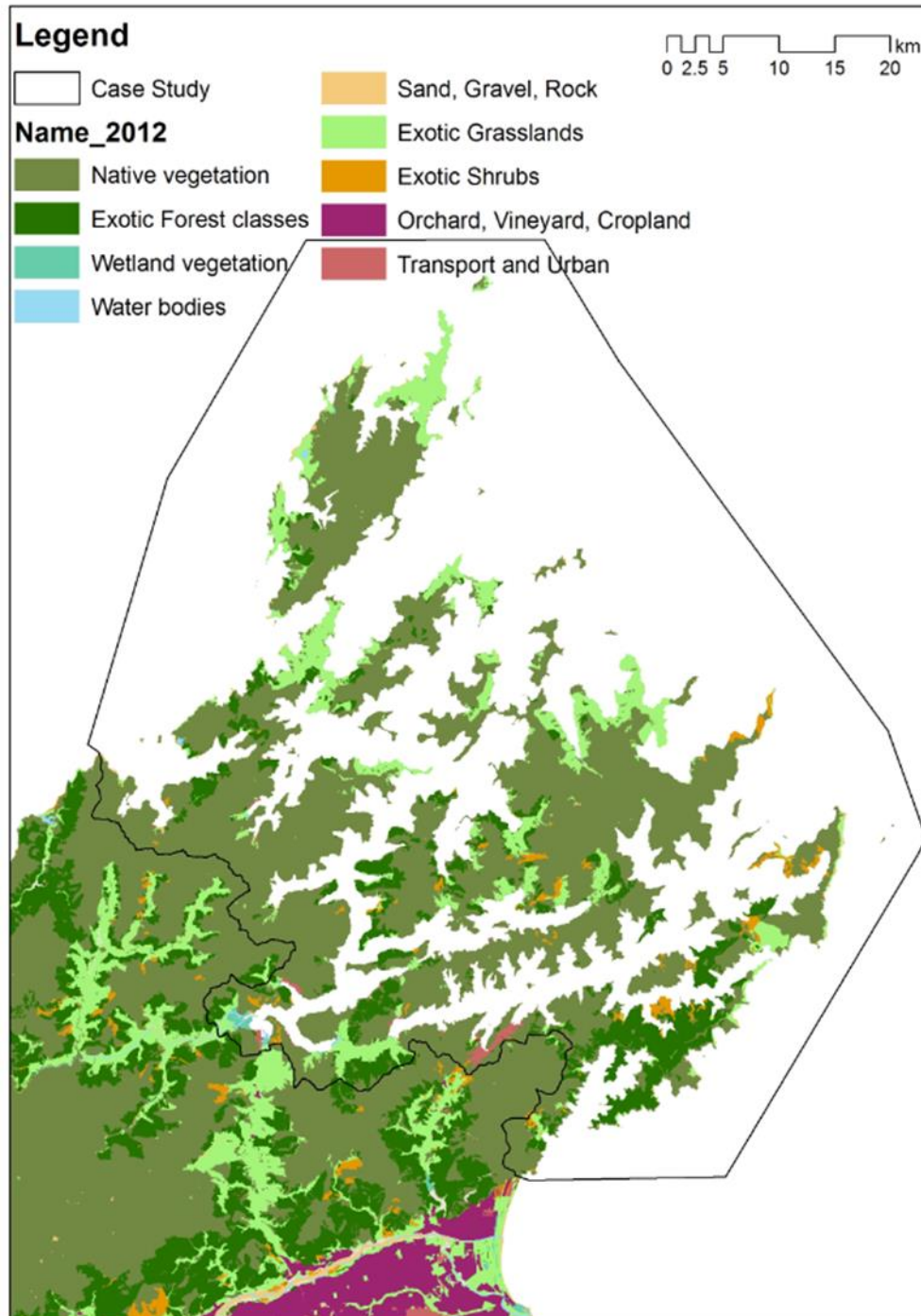
**Table 1:** Spatial data used in this report.

Source	Database	Comments
MDC	River beds – as lines and as polygons	
	Road zones	
	Case study extent	Boundary of study
MfE (Ministry for the Environment)	Landcover Database (LCDB) version 4.1	Likely plantation locations
LINZ (Land Information New Zealand)	Topographical data including coastline and road centre lines	For setbacks and roading
	Aerial photography	Locations of barge points
	DEM for slopes	Slope thresholds
Landcare	Fundamental Soils Layer	For harvesting modelling
NIWA (National Institute for Water and Atmosphere)	NZ River Environments Classification (REC)	Stream orders
Scion	Setbacks	Buffers of Topographical coastline
	Planted forests in the Sounds	Edited LCDB
	Water-based transportation routes, including barge landing sites and ports	Includes digitising off aerial photography

<sup>1</sup> A historic context describing how the Pelorus Sound has changed over time has been reported recently by Handley et al. (2017).

# The study site and site data

The study is based in the Marlborough Sounds which are part of New Zealand's Marlborough District. Located at the northern end of the South Island (Figure 2), the Marlborough District has approximately 71,885 hectares of planted forests (MPI 2016). Ninety-five percent of the planted forests is in *Pinus radiata* (a.k.a. Monterey pine) while the remaining areas are in Douglas fir, cypresses, eucalypts and some remnant native trees.

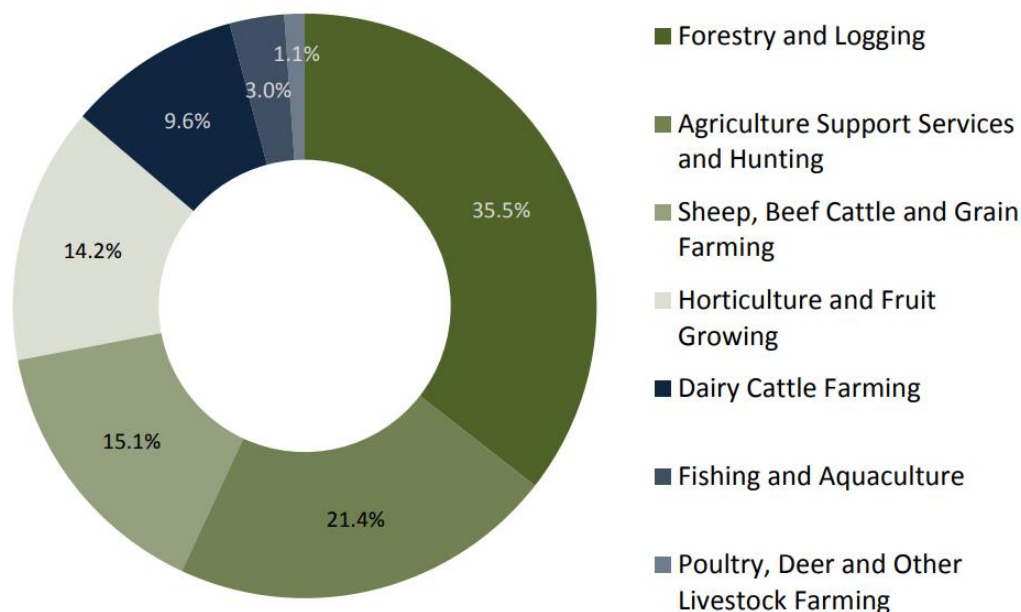


**Figure 2.** Map of the Marlborough Sounds case study area.

Primary industry in the Marlborough District was the second largest industry in 2012, (closely following manufacturing). It accounted for 18% of the District's economic output which had an



estimated value of \$252 million.<sup>2</sup> Amongst the seven sub-primary industries, forestry and logging provided the largest contribution at 36% (Figure 3). In 2012, this sub-primary industry contributed \$93 million to GDP and employed 246 workers (Mandoline Associates 2013). Workers in the forestry industry can be involved in forest production operations such as establishment, silviculture and harvesting, while others can be involved in wood product manufacturing.



**Figure 3.** Distribution of the economic contributions of sub-primary industries in the district. (Source: Mandoline Associates (2013)).

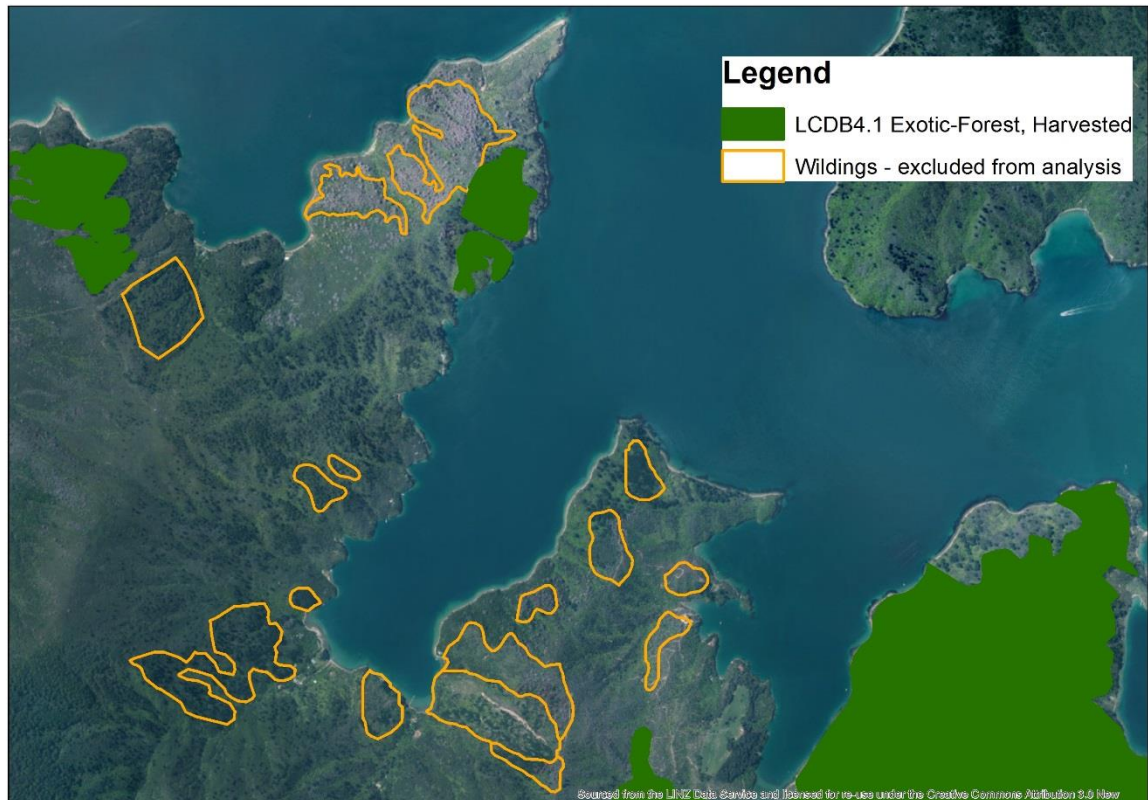
### Planted forests within the case study

The locations of the planted forest areas were identified based on the Landcover Database (LCDB) 4.1. Two landcover classes were combined; the exotic forest and the forest harvested classes. Together they indicate the total area actively managed for forestry, and the combined classes are hereafter referred to as the exotic forest in the Sounds. The assumption is made that the harvested areas identified in LCDB 4.1 will be re-planted in exotic trees, i.e. will remain in forestry.

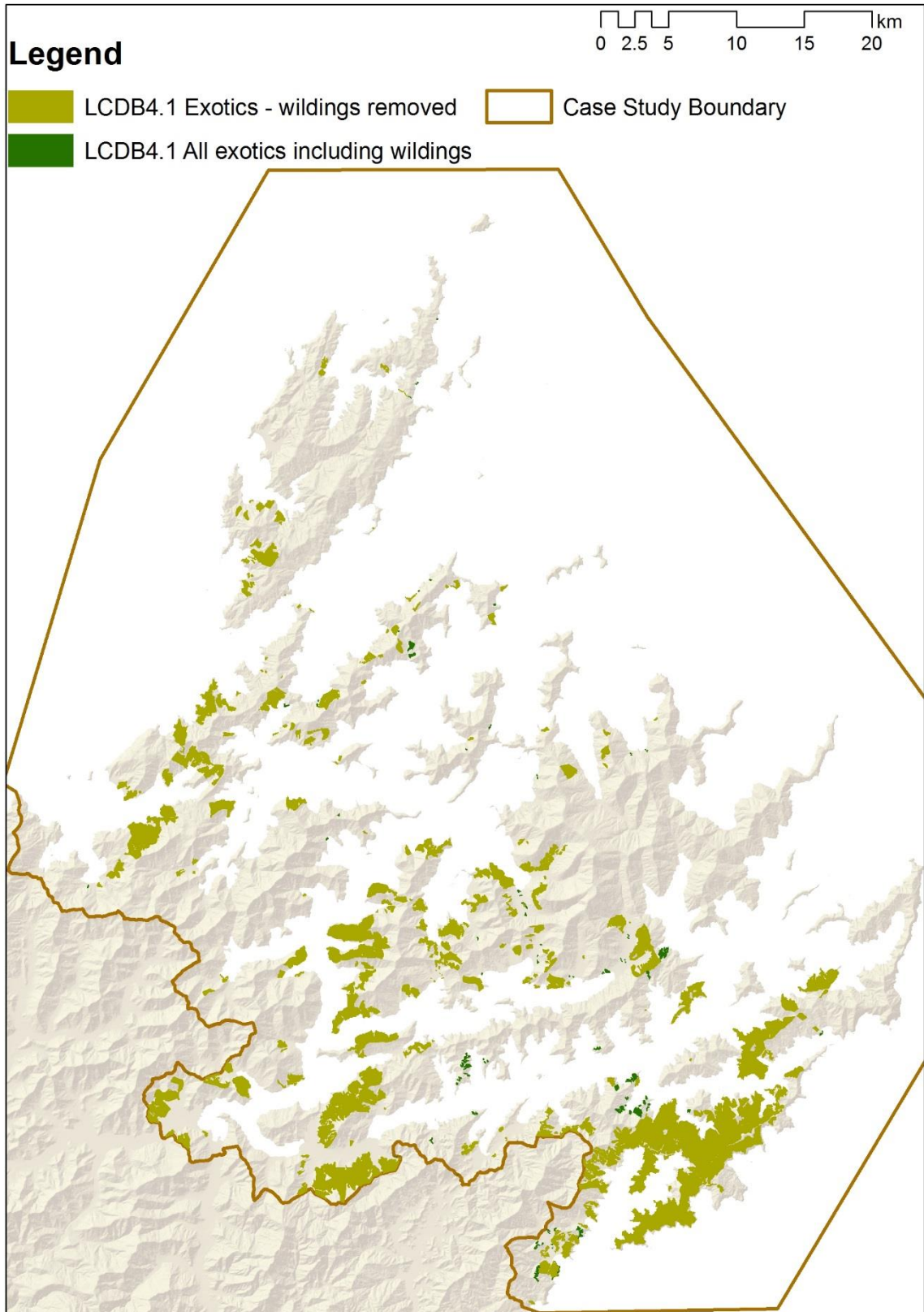
LCDB data is based on the classification of satellite imagery taken in the summer of 2012/13. Satellite images have a lower resolution than aerial photography. A number of the LCDB forest areas could be identified on aerial photography as no longer being production forests. The areas were identified as either post-harvest regenerating vegetation, i.e. while typical harvest roading tracks were visible, no replanting could be detected in the recent aerial photography or wilding pines rather than planted production trees (Figure 4). An example of an area with wilding pines, as identified on the aerial photography and excluded from the planted forest dataset, is shown in Figure 5. The result was 17,029 hectares of planted forests in the Sounds.<sup>3</sup> All references to the LCDB forests in the report refer to this dataset, i.e. including the updates from the aerial photography.

<sup>2</sup> The primary industry in the District is a close second as economic output from manufacturing was 19% in 2012.

<sup>3</sup> At the time of this study, the area of planted forests in the Sounds accounted for about 24% of planted forests in the Marlborough District.



**Figure 4.** Example of areas identified in LCDB4.1 as exotic forests or harvested forests, and identified as either no longer in forestry or as covered by wildings

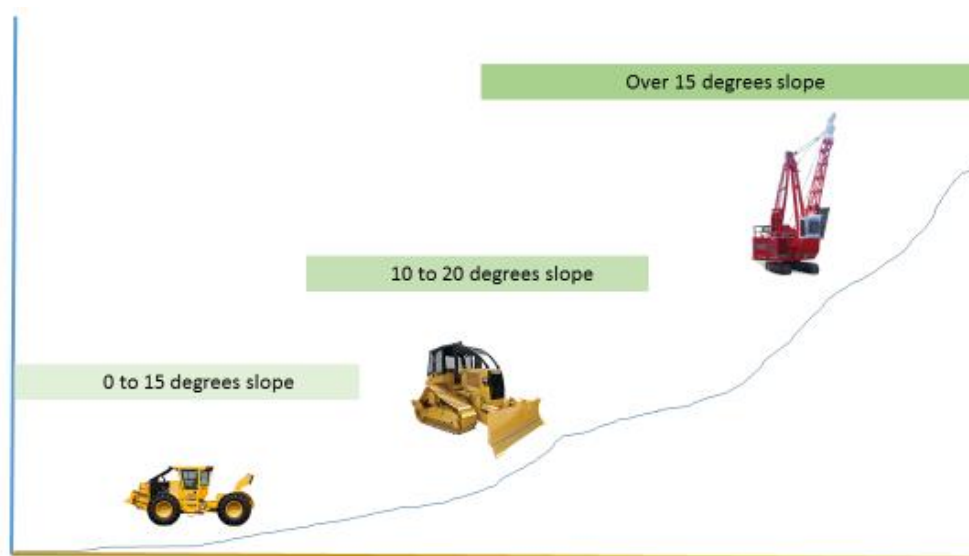


**Figure 5.** Forests and wildings in the Marlborough Sounds

## Slope constraints

Harvesting costs and equipment are directly related to the slope of the forest being harvested (Figure 6). In harvest planning, slopes greater than 15 degrees are recommended to have equipment suited for steep slopes, for example, harvesting by haulers (described in more detail in the Objective 2 section of the report). For slopes less than 15 degrees, ground based equipment is common. Actual equipment used for harvesting depends on various land characteristics, such factors as accessibility and the 'brokenness' of the terrain. However, the classification of an area into greater or less than 15 degrees gives an indication of the need for steep slope versus ground-based harvest planning. Approximately 85% of the planted forests in the case study area are on steep slopes of 15 degrees or greater.

Ulrich (2015) used a 30 degree cut-off point to classify the steep slope areas that would be subjected to re-planting controls. Based on the LCDB forests, approximately one third of the forest areas classified as potential hauler lands are also steeper than 30 degrees.



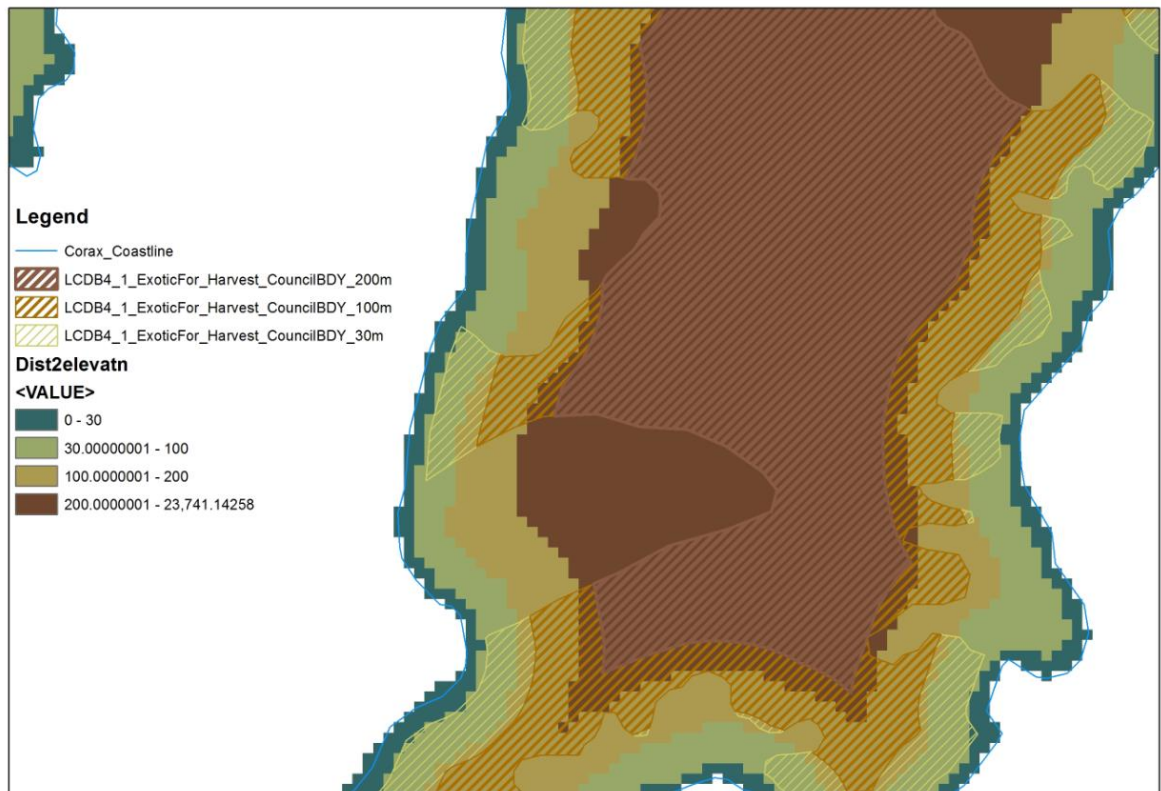
**Figure 6.** Diagrammatic representation of the relationship between harvesting equipment and slope.

## Setbacks

Forests in the Sounds have been planted without a systemic setback from the shoreline and the buffer between forest edge and shoreline varies. Setbacks from the shoreline – buffers between the planted forest and the coastline – were calculated based on the coastline in LINZ Topographic data.

Setbacks can be calculated based on slope distance and planimetric distance. Slope distance is the distance measure from coastline uphill, i.e. following the slope. Planimetric distance is measured equivalent to a horizontal distance on a plan.

Figure 7 shows setback sizes based on planimetric distances that were used for the economic analysis. Three setback widths were: 30 m, 100 m and 200 m. Using a slope buffer was outside the scope of this project.



**Figure 7.** Example area in the Sounds, showing the land remaining when a setback has been applied.

## Streams and rivers

NIWA's River Environment Classification (REC) data was used for assessing the frequency and lengths of the streams by stream order (Figure 8). NIWA REC data differs from MDC river data in particular for stream order 1 rivers, however it is both useful to have the stream order differentiation and it is a national dataset allowing positioning within the national context. MDC data overlaps only with REC order 1 and part of 2, and extends beyond order 1 (Figure 9). The magnitude of difference between REC and MDC data is, acknowledging that MDC data only partly overlaps with REC order 2 data, very approximately double the kilometres of rivers in MDC data. The analysis used both data sets.

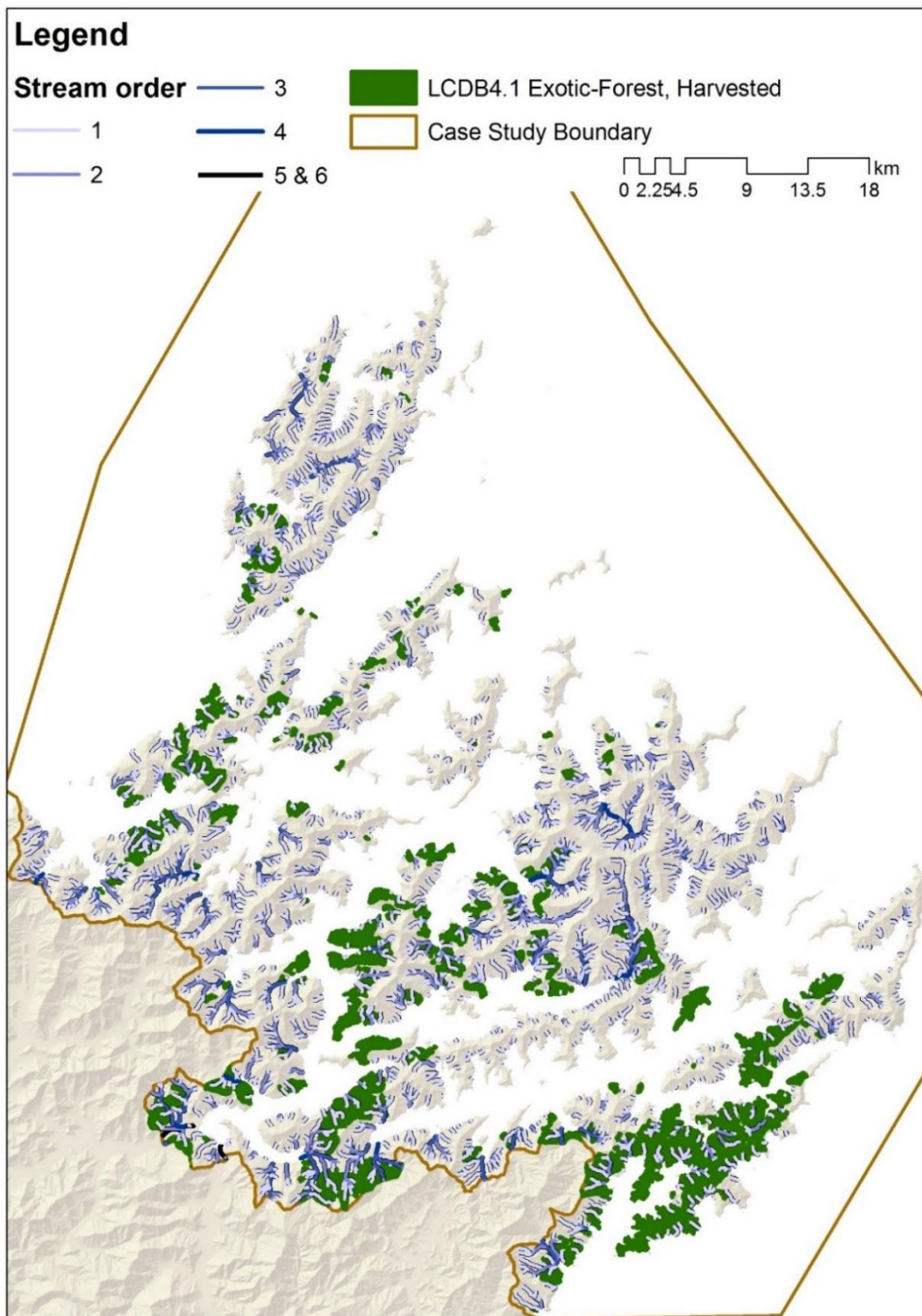
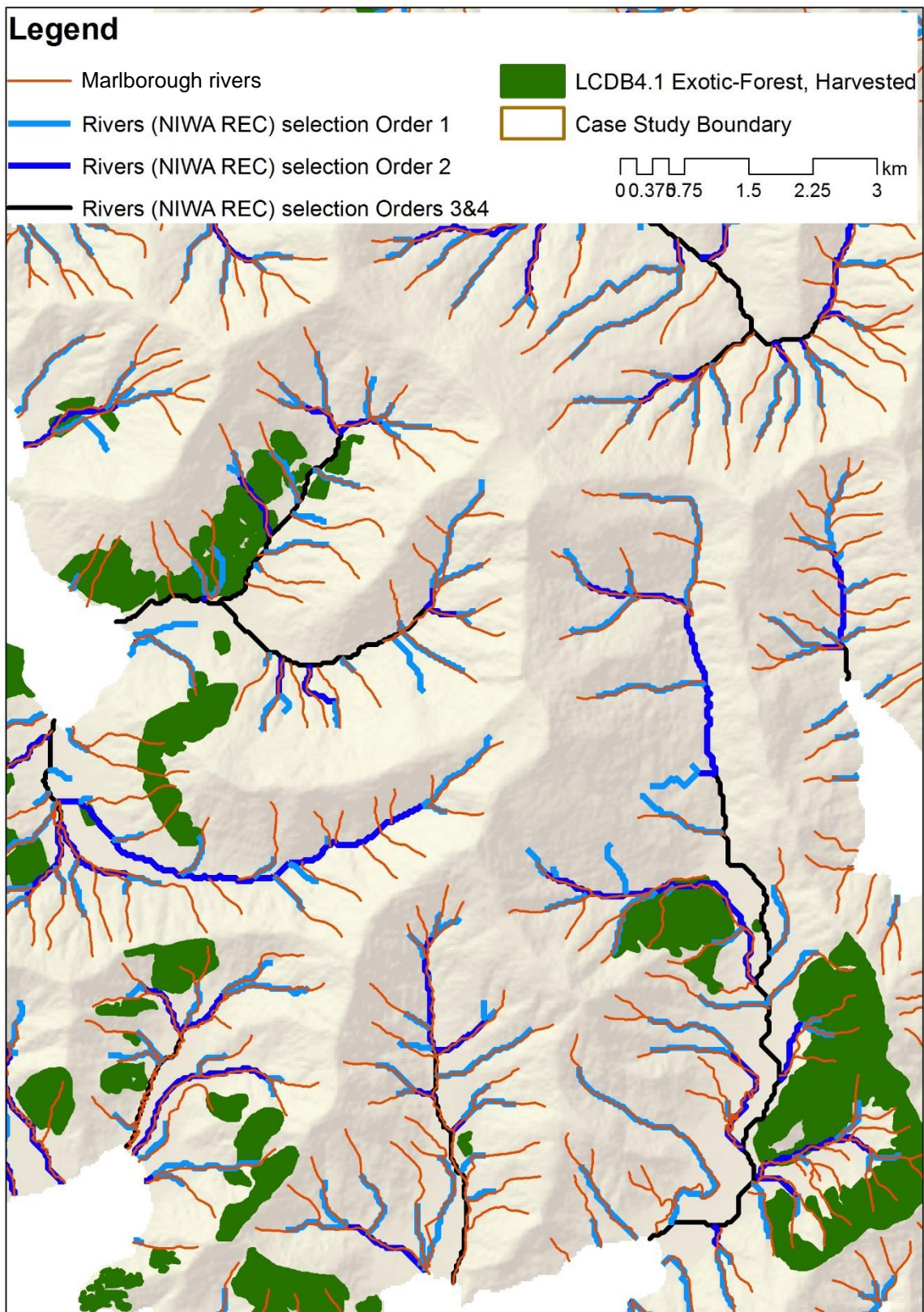


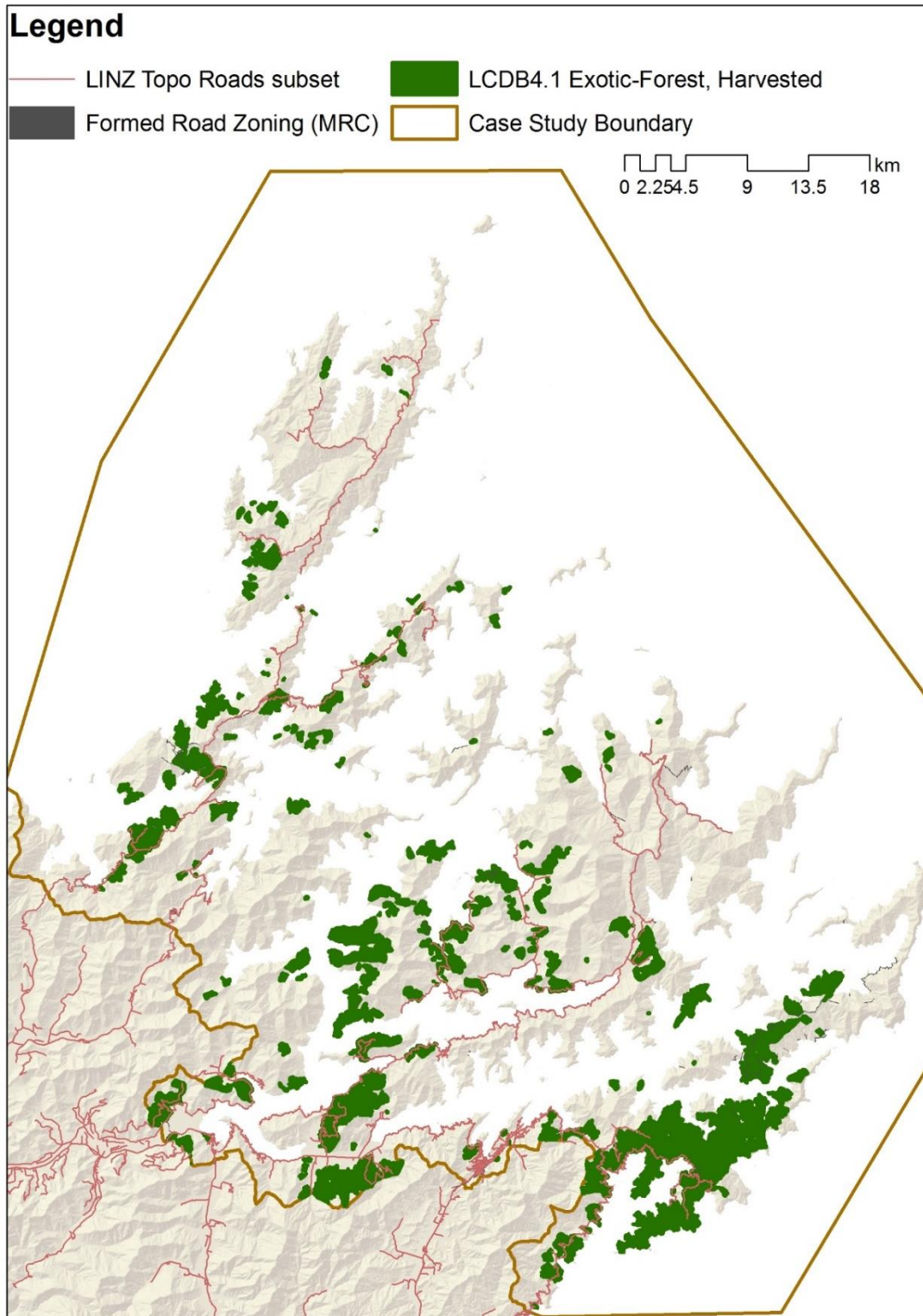
Figure 8. NIWA REC data by stream order



**Figure 9.** Comparison of NIWA REC data and MDC river data (identified river beds).

## Roading

The roading subset used in the analysis (Figure 10) extended beyond the case study area to the potential processing and export sites – the nearest wood processors and ports. A number of the analysis steps were performed using rasters (grid-based GIS layers), so in order to model at sufficiently high resolution to preserve the windy nature of many roads, all grid analyses were performed at 10m resolution.



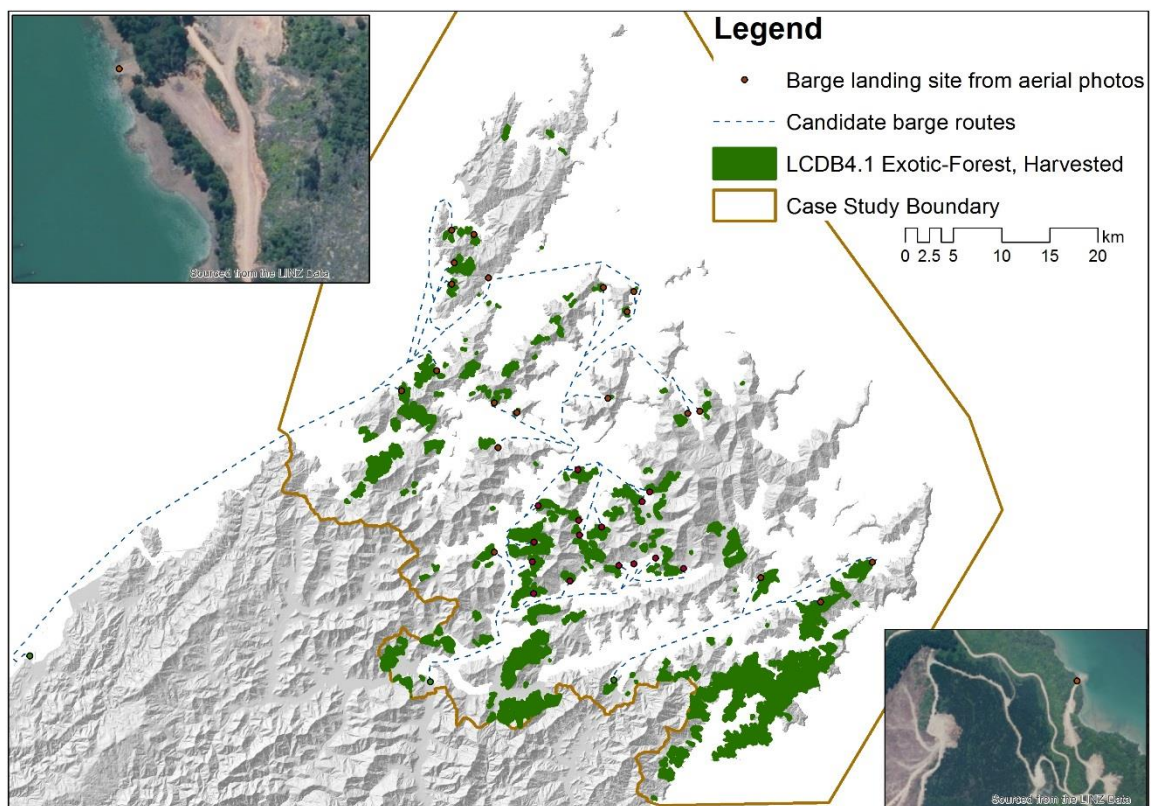
**Figure 10.** Roads relevant to the case study area, showing public roads from topographical maps and zonings for roads



## Barging

Coastal barging is one of the operations used to transport harvested logs from forests in the Sounds. To model barging, barge landing sites and ports were digitised off visible features on the aerial photography and connected by potential water-based transportation routes (Figure 11). In total 35 barge landing sites were identified, and they consisted of 16 barge sites in Pelorus Sound and 19 across the remainder of the Sounds. This was not exhaustive as at least one other was identified after the analysis had been completed. Three ports were identified for barges to berth – Picton (Shakespeare Bay), Havelock and Nelson.

The barge site dataset included a proposed site in northern Kenepuru Sound that the council has plans for investing in<sup>4</sup>. The proposed barge site would require logs from surrounding forests to be routed through the new site; the modelling did not apply this restriction. All digitised barge sites were available for transportation, with the modelling typically selecting the landing sites that provided the shortest route. This countered the new barge site proposal and is only an approximation to the actual costs and practise of barging. However the magnitude of this project precluded more sophisticated modelling of barging.



**Figure 11.** Barging options in the Sounds, showing example barge landing sites

<sup>4</sup> <http://www.stuff.co.nz/marlborough-express/news/89979224/marlborough-forestry-barge-site-plans-progress-as-council-prepares-to-invest>

## Barging costs

Barging costs vary by distance. We present in Table 2 the barging costs, unless otherwise indicated, which are based on productivity as per McConchie (1992). The list of cost items in Table 2 have been made up to date (in 2017 NZ\$) specifically for this study. The productivity of the barge is from the 1992 study while the costs applied to the system are from 2017. The barging system speed of operation is assumed to have not significantly changed because it is still based on loaders, tugs and barges which are fundamentally the same.

**Table 2.** Indicative costs of barging.

	Speed	Barging Distance			
		25	40	55	140 (*)
Start		10	10	10	10
Travel empty	10	150	240	330	840
Dock		10	10	10	10
Load		110	110	110	110
Depart		9	9	9	9
Travel Loaded	9	167	267	367	933
Berth		18	18	18	18
Unload		80	80	80	80
Total mins		579	784	989	2150
Total hours		9.64	13.06	16.48	35.84
\$/hour for Barge		\$300	\$300	\$300	\$400
\$/load		\$2,893	\$3,918	\$4,943	\$14,336
Payload / tonnes		240	240	240	600
\$/t		\$12.06	\$16.33	\$20.60	\$23.89
\$/t/KM		\$0.48	\$0.41	\$0.37	\$0.17

(\*) Estimated, based on Moynihan (2003) report on Te Kaha barging, and operating cost estimate based on purchase price of a 400-tonne barge).

# Objective 1: Economic and environmental effects based on a spatial economic framework

Objective 1 of this study employs an ecosystem services approach that enables the representation of the multiple benefits (both market and non-market values) provided by a productive ecosystem such as planted forests. Key values from a forestry ecosystem were quantified using a spatial economic tool called Forest Investment Framework (FIF).<sup>5</sup> FIF enables the quantification of the market values of provisioning services, e.g. timber (\$ per cubic metre of logs) as well as quantitative indicators of regulating services, e.g. carbon sequestration and avoided erosion.

## Forest Investment Framework

The FIF is a spatial economic tool that has been used by government agencies, indigenous groups and the forest industry to analyse ecosystem services in New Zealand (Barry et al., 2014a; Yao et al., 2016). It combines biophysical, spatial, economic and environmental data to provide indicative ES values from existing and planned forests anywhere in New Zealand.<sup>6</sup> The FIF enables the quantification and estimation of forest benefits, whether through market (cash) income from timber, non-wood products and carbon sequestration, or through non-market returns such as the values directly or indirectly placed on avoided sedimentation.

- *Timber viability component:* this FIF component assesses which among prospective afforestation sites would be profitable or not. The FIF calculates revenue using a timber-yield surface for radiata pine that enables the estimation of volume of logs that can be harvested at each prospective site and allows the use of corresponding log prices. Production cost surfaces are calculated based on reported and imputed costs (e.g. establishment, silviculture, roading and harvesting) as well as impedances derived from biophysical characteristics (e.g. rainfall, slope and erosion class). Profitability, in the form of land expectation value (LEV)<sup>7</sup>, is then calculated using the revenue and cost estimates, and an appropriate discount rate. For this exercise, we used a discount rate of 8% based on Manley (2012).
- *Environmental benefits component:* carbon sequestration and avoided erosion, two key environmental benefits of planted forests, can be quantified and valued. The amount of carbon sequestered is estimated from the same productivity surface used to determine timber productivity combined with the C-change carbon model (Beets et al., 1999). To calculate the indicative revenue from sale of carbon credits, the estimated spatially explicit quantity of carbon sequestered is multiplied by the reported carbon price in New Zealand. The value from the sale of logs and carbon credits represent the two main revenue surfaces in FIF (Barry et al. 2014).

As much as we would like to calculate the carbon monetary benefits from setbacks, we found that approximating the difference between the setback carbon value and forest areas is complex. In New Zealand, the revenue from carbon is earned through participation in the Emission Trading Scheme (ETS). In the ETS carbon credits are earned as a stand grows and sequesters carbon. If the stand is harvested and returned to pasture, all units must be surrendered; some at harvesting and the rest as the harvest residues decay (MPI 2017). If the stand is replanted, the carbon stock will not decline to zero after harvesting as residues decay as it will be balanced and exceeded by regrowth. If a stand is not harvested it will

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<sup>5</sup> FIF addresses one of the proposed constraints on forestry in the Sounds which is the constraint on replanting requirements for steep slopes (Urlich, 2015). Using FIF, we can make the assumption that forestry continues into perpetuity.

<sup>6</sup> For a full description of FIF data and steps, we refer the reader to Hock et al (2016).

<sup>7</sup> Land Expectation Value or LEV is defined as “the present value, per unit area, of the projected costs and revenues from an infinite series of identical even-aged forest rotations, starting initially from bare land” in McDill, M.E. 1999. Forest Resource Management. Pennsylvania State University.

continue to accumulate carbon. Under the ETS, setbacks would be considered as part of the original forest and not a separate area in its own right. An age-weighted equation is used to calculate the “age” of the whole forest and carbon credits are allocated accordingly. Furthermore, there has been some considerable uncertainties in the carbon market due to fluctuation in carbon prices over the past decade. The price of tradeable carbon unit rose to \$29.24 in November 2008, then went down to \$0.19 in November 2012, then its price as of 30 June 2017 was \$17.00<sup>8</sup> per tonne of CO<sub>2</sub> equivalent (Yao et al. 2013).

- *Avoided erosion benefits* are quantified using the New Zealand Empirical Erosion Model (NZEEM) (Dymond et al., 2010) to estimate the reduction in sediments due to land stabilisation. The volume of sediment reduced is spread over the 28-year rotation period where it is assumed that full canopy cover provides maximum soil protection when land is changed from bare land (e.g. pasture) to forestry. It is also assumed that sedimentation from forestry may be the same or worse during the first three years of establishment, as well as during harvesting. The FIF avoided erosion component assumes that off-site avoided erosion takes the value of approximately \$6.50/tonne of sediment prevented from going into the waterways (Barry et al. 2014). This \$6.50/tonne value consists of \$0.90/tonne for avoided flood damage and \$5.60/tonne for avoided water treatment costs to consumptive water. These values would be more suitable for avoided erosion values of forestry that are located further inland and not on forests next to the marine environment. For this reason, we have elected focus on the quantities of avoided erosion in tonnes and expressed the change in index or percentage form.

## FIF methodology

National statistics indicate around 95% is in *Pinus radiata* (MPI 2016) with the remaining 5% in other productive species, however for the purpose of this modelling we assumed all trees to be Radiata. About half of the radiata pine forests are in pruned regime while the other half is unpruned. The locations of the different regimes was not available and the main purpose of the modelling was to estimate the effects of the scenarios, hence a standard regime was used for the planted forests to allow comparisons.

The model was run for the current forest areas, the status quo, using a standard 28-year *Pinus radiata* sawlog or unpruned regime. The three scenarios – the 30 m, 100 m, and 200 m setback options – were developed based on the modelled data. All economic data used in FIF which include the three-year average log prices and harvesting costs were derived from MPI (2017) and AgriHQ (2017).

## FIF Results

### Forestry area

The area of production forests in the Sounds was calculated to be approximately 17,029 hectares. The reduced planted forest areas for the setback scenarios were 16,819 ha (98%) for the 30 m setback scenario, 15,929 ha (92%) for the 100 m setback scenario, and 14,179 ha (82%) for the 200 m setback scenario. The area loss by steepness was:

- for the 30m scenario: 27% with slope <15°, 73% with slope >15°
- for the 100m scenario: 15% with slope <15°, 85% with slope >15°
- for the 200m scenario: 13% with slope <15°, 87% with slope >15°

The narrowest setback width had the highest percentage of low slope lands as the lower slopes, if any, tended to be near the shoreline.

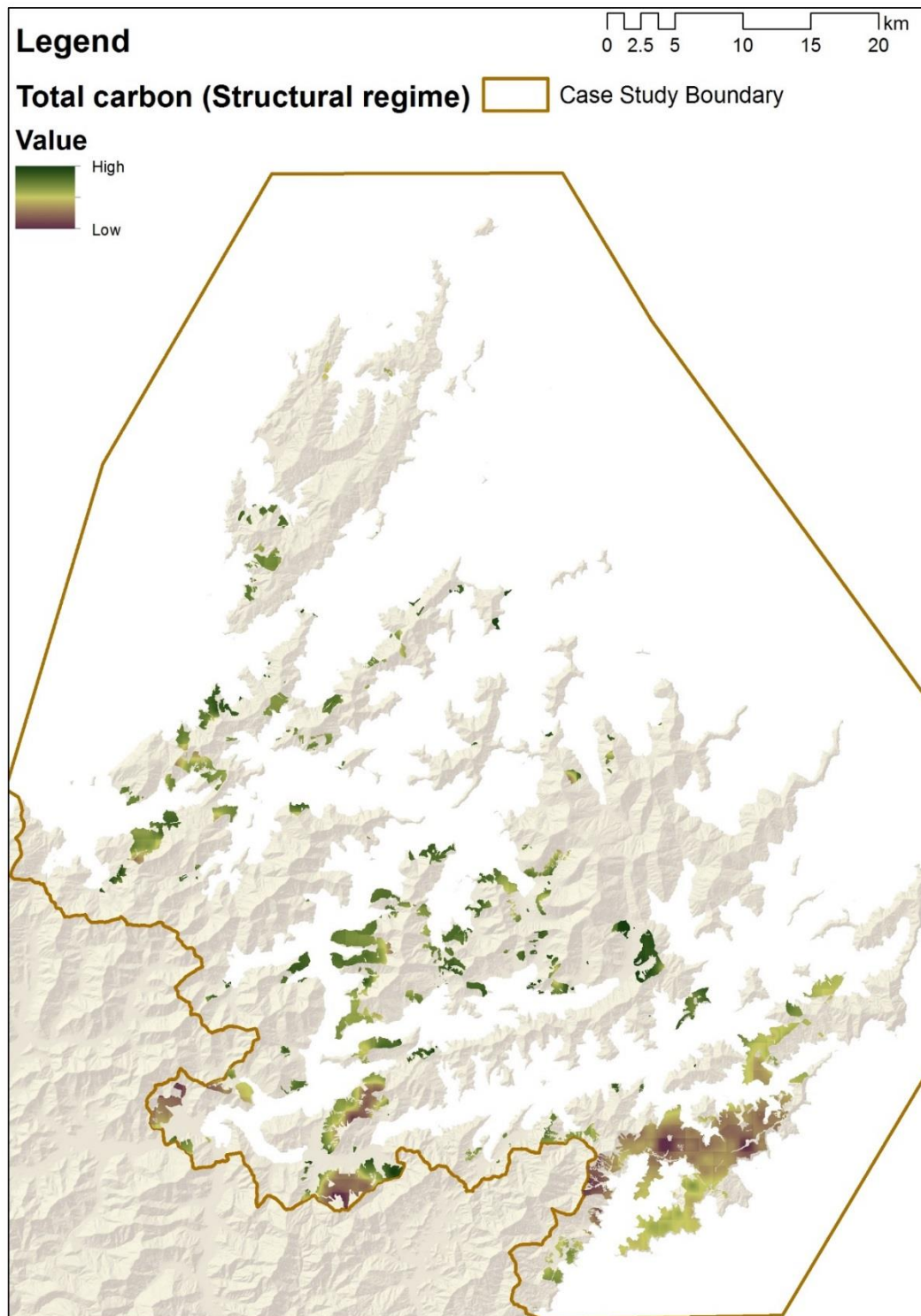
### Forest economics

Forest productivity across the Sounds would be considered to be above average on a national scale, but there is some variation within the region - Figure 12 shows carbon sequestration rates which are equivalent to productivity rates, with the south eastern area of the Sounds showing the lowest productivity. The inner Sounds area has the highest productivity, with the north settling somewhere in between. Though again none of the productivity levels within the region would be considered low on a national scale.

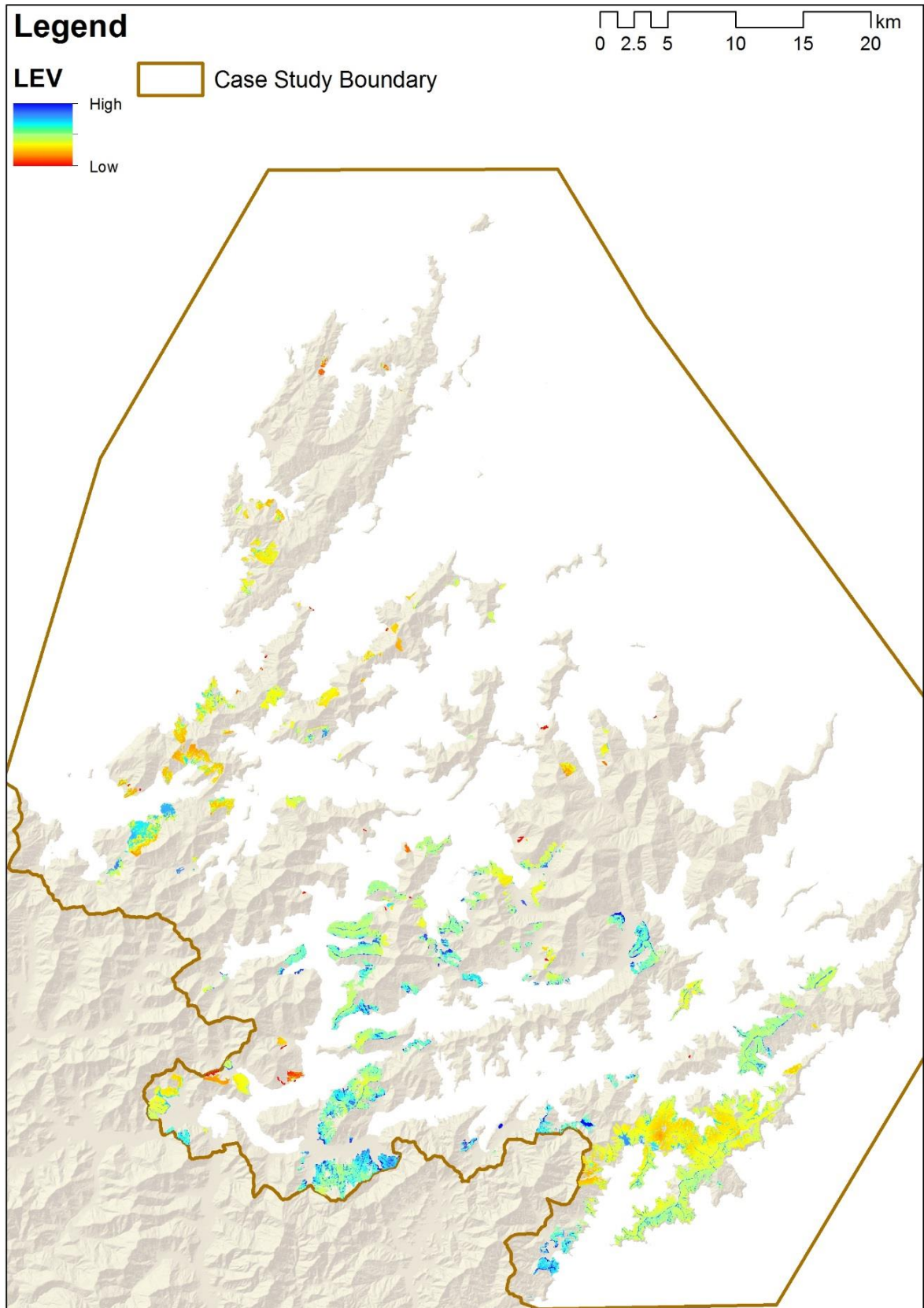
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<sup>8</sup> <https://www.comtrade.co.nz/>

FIF combines the productivity with economic analysis. The land expectation value or LEV (profit from forestry in perpetuity) estimated for the Sounds is shown in Figure 13. A FIF scenario was also run with local FIF costs, modified based on conversations with local forestry contractors and operators (Harris 2017; Karalus 2017). These conversations indicated that some of the transportation costs could be considerably higher in the Sounds than other areas of New Zealand. In some cases, forest can only be accessed by barge as roads either do not exist or are unsuitable for log trucks. The robustness test suggests that increasing the cost of transport by 1.5 times led to a very significant reduction in profitability level, as indicated by the proportion of profitable forest spatial model units being reduced from 97% to 48%.



**Figure 12.** Spatially explicit carbon sequestration values based on a structural or unpruned regime



**Figure 13.** Spatially explicit land expectation values of structural regime

## **Effects of Setbacks**

It is important to note that current regulation allows all planted forests to be harvested, therefore all benefits and costs shown in this report will not be realised until the end of the next rotation or when replanting setback occurs.

We used FIF to provide some indicative quantities of three key ecosystem services (timber, carbon sequestration and avoided sedimentation) provided by the current forestry in the Sounds. We have estimated the profit from a 28-year rotation of forestry and the corresponding volume of carbon dioxide that can be sequestered. We have also quantified the protective function of forestry on reducing the flow of sediments. For this exercise, we have calculated the profit from timber in monetary terms while carbon sequestration in tonnes of CO<sub>2</sub> equivalent and avoided erosion in cubic metres. To provide anonymity to the sensitive financial data and to allow easier comparisons across the three ecosystem services, we have expressed the effects of setbacks on these ecosystem services in index or percentage form.

### **Change in returns from forestry**

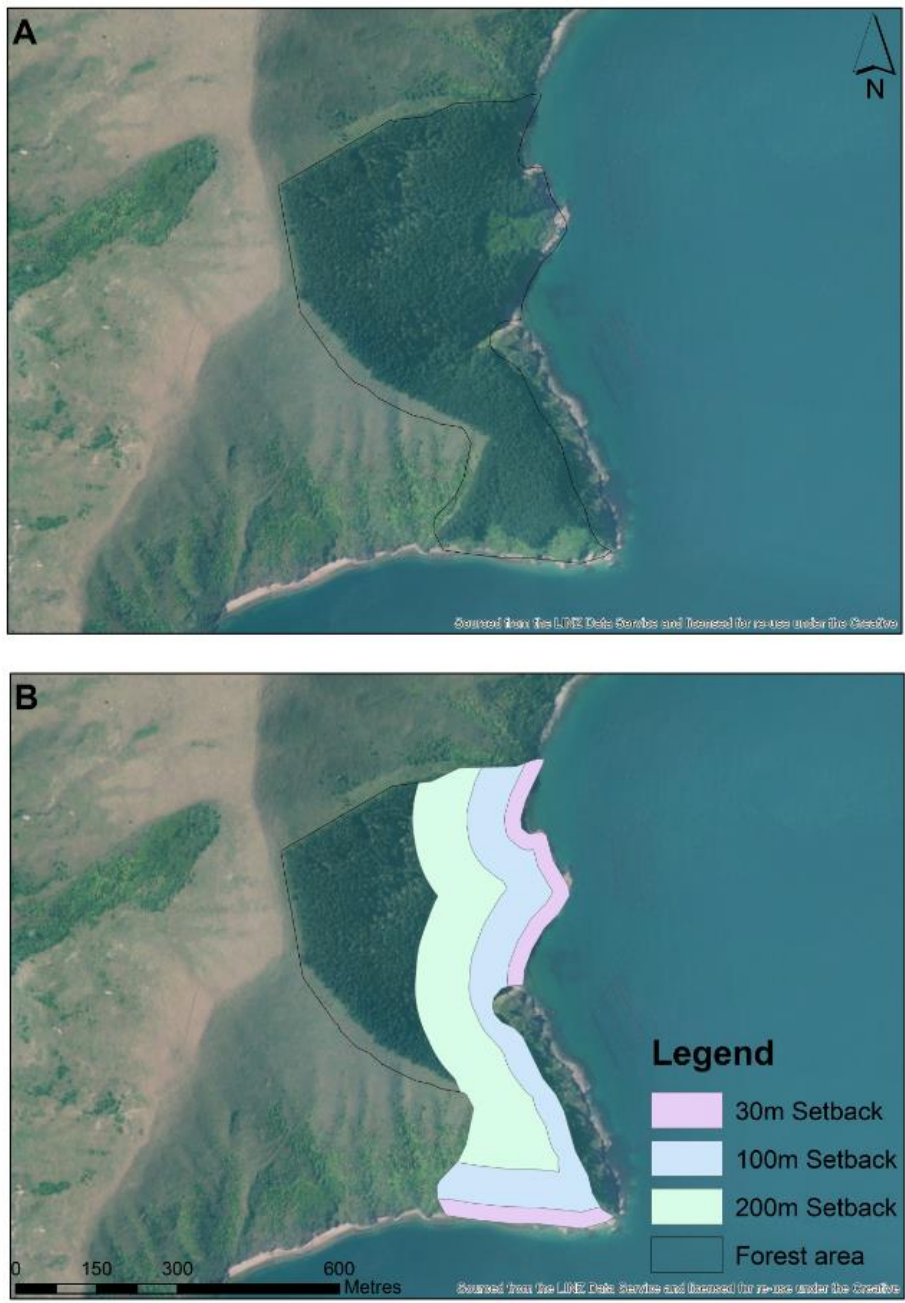
The no-setback scenario represents the status quo. Based on our FIF analysis, the setback scenarios will reduce the returns of timber production or LEV of forestry<sup>9</sup> in the Sounds (Table 3). We also found that some of the smaller remote forests become uneconomic, or even infeasible as forests, as they lose a significant part of their area (Figure 14).

**Table 3.** Estimate of reduced returns resulting from the setback areas.

<b>Setback scenario</b>	<b>Proportion reduction in modelled forest returns</b>
30m	1.3%
100m	5.8%
200m	15.9%

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<sup>9</sup> A rotation of forestry has been assumed to take 28 years.



**Figure 14.** An example of a small forest that becomes uneconomic with a 200 m setback

### Change in the volume of carbon sequestered

Quantifying carbon with and without setbacks is complex. We have employed a simpler and intuitive approach. To quantify the volume of carbon sequestered by *Pinus radiata* for the 100-year period, we used FIF’s carbon sequestration spatial functions to quantify the volume of carbon sequestered (Barry et al. 2014). To quantify the volume of carbon sequestered from the naturally regenerating native trees in the setbacks (after a 28-year rotation of *Pinus radiata*), we used the indicative carbon sequestered volumes reported by MPI (2015). Using FIF and MPI’s carbon sequestration data sets, our analysis assumed the following four scenarios: (1) under no setback, all the 17,029 ha forest area were to be planted with *Pinus radiata* under structural or unpruned regime, and all will be harvested at age 28 and then replanted; (2) under the 30 m setback, 203 ha of the planted radiata pine area will be harvested at age 28 and will be left to naturally regenerate to native vegetation; (3) with 100 m setback, 1,085 ha will be harvested at age 28 and will be left to regenerate to native; and (4) with 200 m setback, 2,771 ha will be harvested at age 28 and will be left to regenerate to native. We present the volume of carbon sequestered for each scenario in Table 4.



**Table 4.** Volume of carbon sequestered for each scenario over a 100-year time horizon.

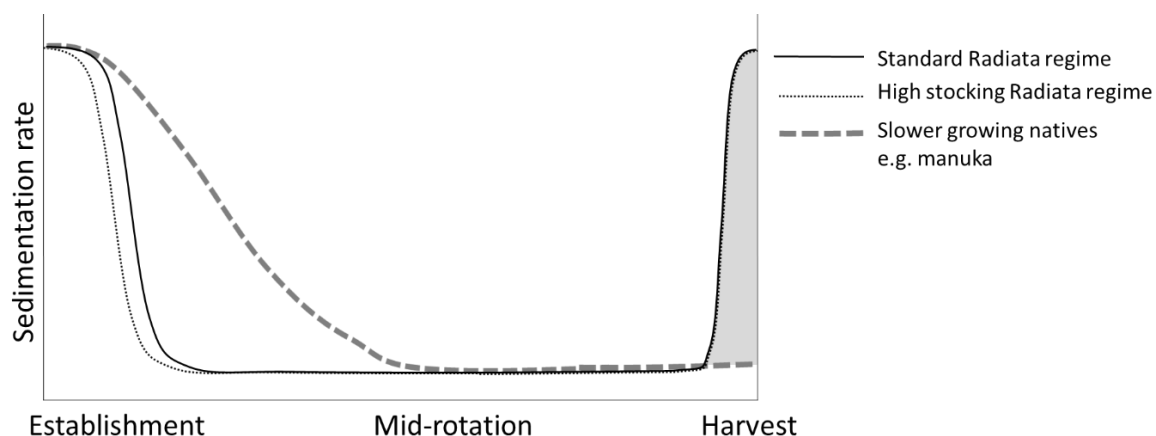
Setback scenario	Volume of carbon sequestered in tonnes of CO <sub>2</sub> -equivalent (CO <sub>2</sub> -eq)	Carbon sequestration index (with no setback as reference or base scenario)
No setback	10,171,799	100.0%
30 m	10,181,671	100.1%
100 m	10,224,616	100.5%
200 m	10,306,641	101.3%

Results in Table 4 suggest that as the area of setback increases, the volume of carbon sequestered also increases. However, the proportion of increase in carbon sequestered is significantly smaller to the proportion of the reduction in forestry returns reported in Table 3.

The setbacks themselves have the potential to become permanent forests, meaning that initially they would continue to receive credits. However, there are limitations to the duration of the credits i.e. when no additional carbon is sequestered once trees have matured, then no further credits are paid (MPI 2017). Options for second rotations, or any higher number of rotations, would vary even more and therefore implications are more complex. Because of the above reasons, we have elected not to report the carbon values in monetary terms.

#### Change in avoided erosion quantities

Avoided erosion was incorporated through a model of sedimentation rates that includes vegetative cover of the land; the methodology is described in Barry et al (2014). For this report, sedimentation over a 100-year period was computed based on the spatially explicit estimates of change in erosion rates from the NZEEM model. The sedimentation for current planted forests with harvesting, is compared to the sedimentation for combined forest and setback areas where the latter is not harvested. The assumption is that the setback areas are under trees in order to be comparable to the remaining forest, as other vegetation types have sedimentation rates different to trees. Sedimentation rates also vary by density of the vegetation cover and the rate of growth of the vegetation cover (Figure 15).



**Figure 15.** Rate of reduction in sedimentation as vegetation grows after clearfelling. The grey-shaded area represents the corresponding reduction in sedimentation by converting an area (setback) into a permanent forest. (Graph should be considered as indicative and is envisioned to somewhat roughly illustrate differences between the three forest regimes.)

Based on the NZEEM based approach, we find that the 200 m setback would lead to a reduction in sedimentation rate by approximately 6% over a 100-year period (Table 5). The effect as proportion of NZEEM-derived sedimentation for the whole planted forest area is shown in Table 5.

**Table 5.** Reduced sedimentation per setback area.

<b>Setback scenario</b>	<b>Avoided soil erosion (in tonnes of sediment)</b>	<b>Avoided sedimentation index (with no setback as reference or base scenario)</b>
no setback	14,703,545	100.0%
30m	14,745,330	100.3%
100m	15,006,915	102.1%
200m	15,540,883	105.7%

## **Objective 2: Effects of setbacks on harvesting, fine sediments and employment**

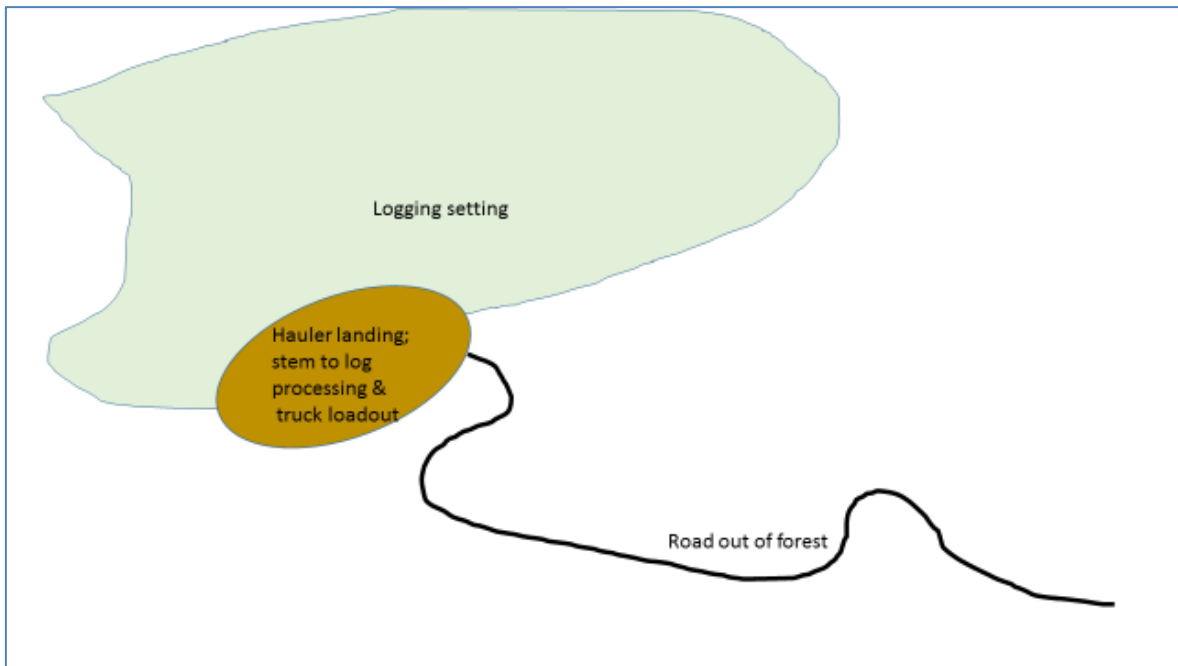
This section provides a qualitative assessment of the setback scenarios for harvesting in the Sounds. This also includes effects of harvesting on fine sediments and a description of employment level and recreation and how they can be potentially affected by setbacks.

### **Harvesting**

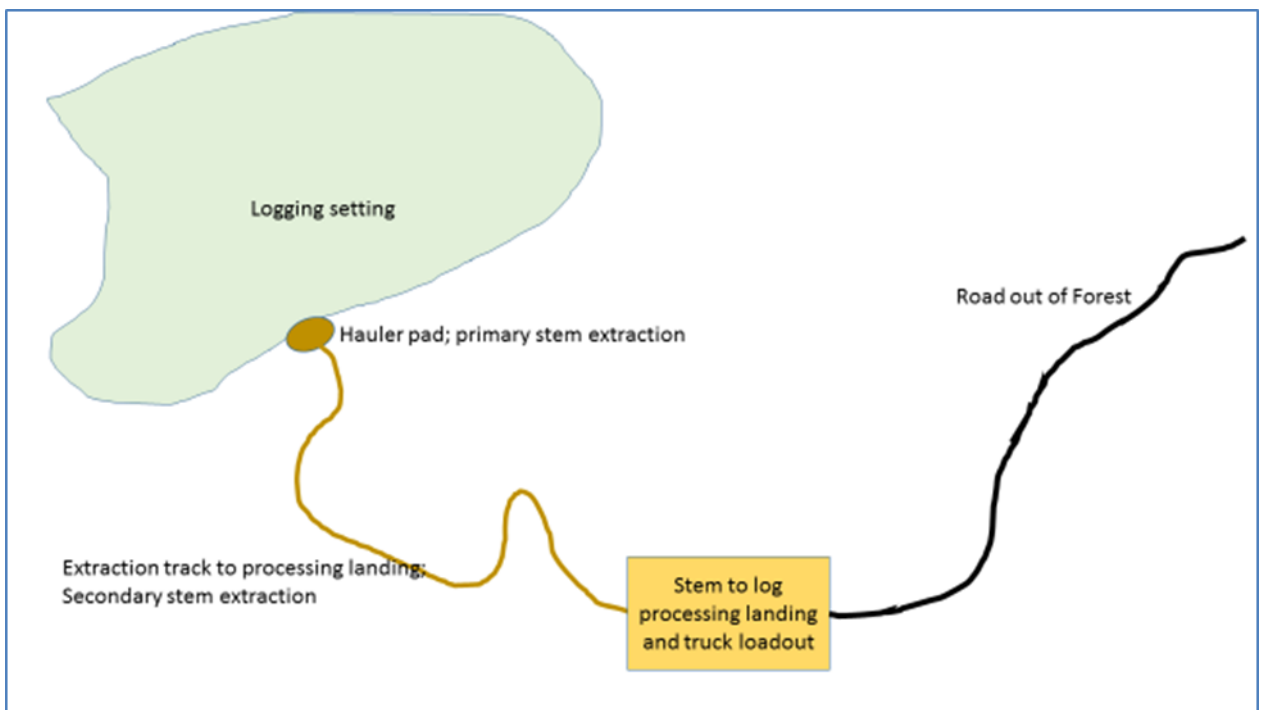
While the FIF costs are representative of real harvesting cost, actual costs are site specific. For a specific site the actual cost may be higher or lower than FIF average prices as harvesting costs are affected by a range of factors. Harvesting costs account for the highest proportion of total cost of all forest operations (Maclaren 1993).

The trees themselves can begin to show the cost associated with harvesting them. In general, the larger the tree and the higher the stocking the cheaper it will be to harvest. However, in some cases, smaller trees and higher stockings would enable the use of smaller-scale harvest equipment hence reducing the cost of harvesting.

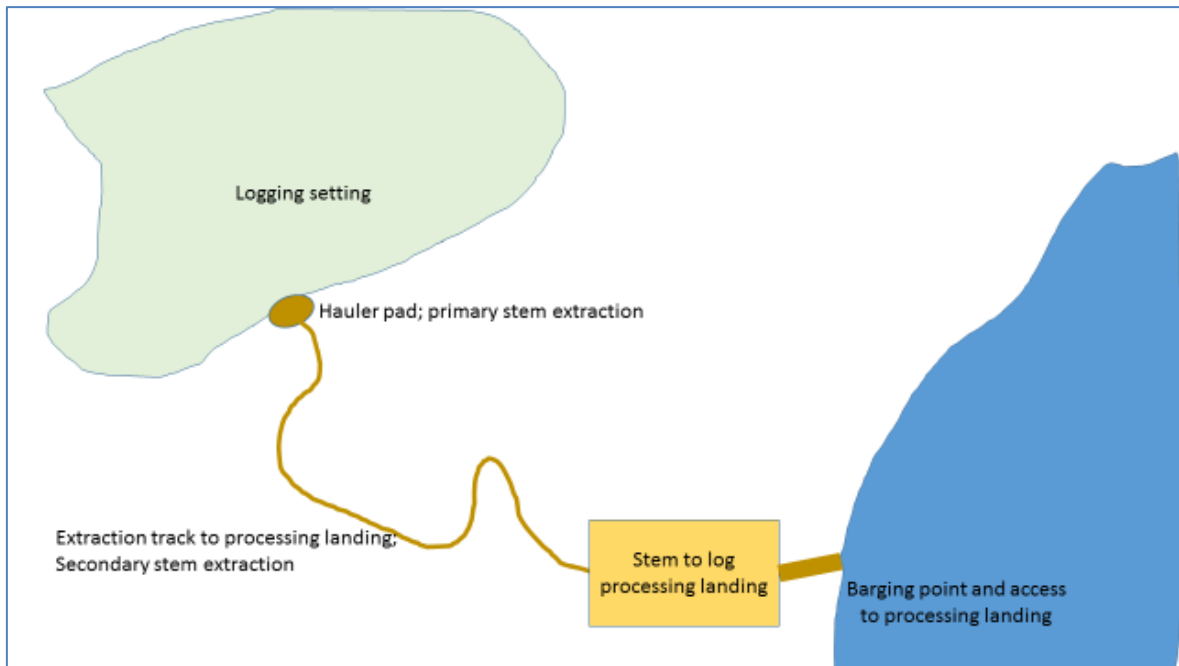
Existing forest infrastructure can have a big impact, as the requirement to build new internal roads, landings and barge terminals for the first rotation can increase the cost to the forest owner. Conversely the existence of infrastructure can greatly reduce the cost burden and a forest that lost money in its first rotation may become profitable in the second. Cost will also be affected by the configuration of the extraction and log processing (by road or barge or both). This will also include any requirement for two-staging. This relates to the log movement prior to it going on-truck/barge; for example a hauler to primary landing and a skidder to a secondary (processing / truck loading) landing (Figures 16 - 18).



**Figure 16.** Single stage logging – stem to log processing happens adjacent to the primary extraction.



**Figure 17.** Two stage logging – primary extraction is separated from the log processing by a second extraction phase. Most likely to occur where the cost of constructing a landing of sufficient size for processing is prohibitive.



**Figure 18.** Two staging in association with barging of the logs from remote forests.

A consideration in many logging operations within the Sounds is the difficulty of forest access and the limited public road infrastructure. Two staging has been used in logging operations in the Marlborough Sounds, in association with barging of the logs from remote forests. Harvesting on remote sites with difficult access and a requirement for two-stage logging can incur costs 1.5 times that of steepland harvesting elsewhere in NZ.

Topographic factors such as slope, slope distance and shape (concave or convex) will determine which harvest system can be used. This is due to the following reasons: (1) slope as ground based systems can generally only operate on slopes of less than 20 degrees; (2) slope / haul distance and shape - convex slopes are likely to be more expensive to harvest as the deflection available to the system, and so the payload, is reduced; and (3) soils with poor soil bearing capacity (or the soil's ability to support the weight of a harvest machine), particularly on steep slopes, are unsuited to ground based harvesting. A combination of the above slope and soil characteristics can help guide the identification of the appropriate harvesting system. Most planted forests in the Sounds would be classified as suitable for cable hauler systems because of steep slopes, roading location, road construction difficulty/costs and poor soil bearing capacity.

### ***Harvesting systems***

A harvesting system is a group of different elements that are interrelated and contribute to the common objective of harvesting a stand of trees. The steps in the process are tree felling, delimiting, removal to skid site, bucking (log making), loading onto transporter (truck or barge). The applicability of selected harvesting systems are described in the next three paragraphs. We also present examples of harvesting systems for steep and flat terrains in Appendix A.

There are a variety of different cable hauler systems available, often differentiated by tree/haul size and extraction distance required. In general, larger haul settings are more economic to log. Large tower haulers are suited for larger tree sizes (e.g. tree size 2 m<sup>3</sup> and above) and for longer haul distances. They typically give good deflection meaning larger loads can be carried by the ropes. If extracted tree size is less than 1.5 m<sup>3</sup> then a smaller hauler system may be suitable.

Chainsaw safety requirements on steep slopes mean hauling primarily extracts with full tree-lengths where trees are manually felled. Manual felling on some steep sites can be replaced by winch-assisted feller bunchers. New winch-assisted felling systems have opened the opportunity for mechanised felling and tree-length bunching or log-length extraction. Manual breaking out with chokers can also be replaced by grapple carriage extraction. The manually felled trees are delimiting at the landing.

Where possible, ground based harvesting systems are preferred as they represent a cheaper option. However, ground based systems (machine travel) can lead to a greater level of soil disturbance as a large majority of the forests are on steep slopes. This raises the potential for sediment transport, although smaller machines, whether wheeled or tracked, may cause less soil disturbance than larger ones. If managed well, the soil disturbance and soil compaction impacts of ground based systems can be minimised.

### **Setback impacts**

The primary effects of the implementation of restrictions or setback scenarios are given in Table 6.

**Table 6.** Potential primary effects of restrictions or changes based on best available knowledge.

<b>Impact of 30 m setback</b>	<b>30 m setback impact leads to:</b>	<b>Impact of 100/200 m setback</b>	<b>100/200 m setback impact leads to:</b>	<b>Impact of &gt;30 degree slope excision</b>	<b>Leading to:</b>
Reduced haul setting area	More frequent harvesting system moves (take down/assembly), leading to higher harvesting costs	Significantly reduced haul setting area	Owner's losses – inability to replant. Remaining forest volume may be un-economic to log in some circumstances.  More frequent harvesting system moves (take down/assembly), leading to higher harvesting costs	Reduced area	Forest area removed from harvesting.  Exacerbated impacts from setbacks.
Reduced haul distance	Faster cycle times	May substantially affect harvesting options and plans.	Existing infrastructure may no longer be optimal.	"Islands" restricting extraction lines and settings	More landings and smaller settings. Some forested areas unreachable.
Changed deflection – slope shape	Smaller average extracted loads/larger loads	Changed deflection – slope shape	Smaller average extracted loads/larger loads	Changed deflection – slope shape	Smaller average extracted loads/larger loads
Changed setting shape	Re-location of existing landings	Changed setting shape	Re-location of existing landings	Changed setting shape	Re-location of existing landings
Different harvesting system/s required	Taller hauler towers/or shorter towers/smaller yarders	Different harvesting system/s required	Taller hauler towers/or shorter towers/smaller yarders	Different harvesting system/s required	Taller hauler towers/or shorter towers/smaller yarders
Less area harvested per unit of roading and landing construction	Higher roading cost component	Less area harvested per unit of roading and landing construction	Higher roading cost component	Less area harvested per unit of roading and landing construction	Higher roading cost component

The application of a setback on an existing stand, potentially one with existing road and landing infrastructure will be to reduce the area of harvest, and hence the volume of logs available to a given extraction point. This reduces the revenue associated with the established area and with the cost of roading and landing infrastructure. Further, as the area and volume that can be extracted to a given point is reduced, the harvesting equipment will have to move from landing to landing more frequently. Moving haulers from site to site is time consuming and has costs associated with it. Overall, the impact of the setbacks will be to increase the cost of harvesting and reduce the volume harvested. The impacts will vary with the specifics of the site, but could be substantial. These setbacks would not have been considered when the forests were planted and some road and landing infrastructure may be rendered sub-optimal.

## Evaluation of the effects of the proposed harvest options on fine sediment generation

### **Background**

The key environmental factors that increase the risk of fine sediment production during harvesting operations in the Marlborough Sounds include the underlying geology and soils, terrain and susceptibility to extreme weather events. The drowned valley landscape of the Marlborough Sounds is dominated by steep terrain rising up to around 1,000 m a.s.l., with many slopes over 30°. Soils in the region have been derived from the predominantly underlying greywacke geology along with schist and smaller areas of volcanic parent material. Regoliths (layers of unconsolidated solid material overlying the bedrock) below 200 m have formed from strongly weathered rocks resulting in thick, clay-dominated highly weathered and erodible soils. Above 200 m, regoliths have developed from less weathered parent material and contain higher proportions of stony material. While all of this terrain is potentially erosion prone, the regoliths below 200 m are more susceptible to erosional events.

The Marlborough Sounds are subject to high intensity rainfall events. During these events, most failures occur below 200 m on slopes over 30°, originating as upper- or mid-slope failures, particularly in headwater gullies, where they can transform to debris flows as the material is transported downstream (Laffan and Daly 1985; Laffan et al. 1985; Phillips et al. 1996; Ulrich 2015). Most streams in the Marlborough Sounds are directly linked to the marine environment so any sediment transported via this pathway will almost entirely discharge into the sea; few water ways have low energy depositional storage zones above the point where the stream enters the sea. As much of the planted forest is located in areas above bays with slow flowing sea water, any sediment entering the marine area is likely to settle out close to the shore line (Laffan et al. 1985; Phillips et al. 1996; Ulrich 2015).

Most of the streams in areas of planted forest in the Marlborough Sounds are of low (1<sup>st</sup> and 2<sup>nd</sup>) order and the majority are less than 3 km in length (based on NIWA REC data). The total length of streams in the Marlborough Sounds varies considerably, depending on the underlying database used to make the calculation (Figure 9) making it difficult to determine the length of perennial streams subject to the riparian planting setbacks. For the purposes of this broad qualitative assessment, the main stem of the stream network in a catchment was assumed to be perennial with the length of stream in the middle to upper part of the catchment considered to be <3m in width. Land Air Water Aotearoa (LAWA) turbidity data for several small catchments in the Marlborough Sounds (Cullen Creek, Linkwater Stream, Waitohi Stream, Graham River - indicative of the catchment sizes currently containing areas of planted forests) ranked turbidity levels as being in the best 25-50% of like sites. Forests (indigenous and planted) along with scrub dominated the land cover in these catchments, although most contained varying proportions of dairying or pastoral land use in the lower catchment area. However, when the LAWA website<sup>10</sup> was accessed on 12 May 2017, no median turbidity data was available.

Harvesting activities in the Marlborough Sounds in the past have caused concern with regard to the amount of fine sediment generated during these operation, particularly in conjunction with high rainfall events and the impacts on the nearby marine environment (i.e. Fahey and Coker 1992; Fransen et al. 1998; Phillips et al. 1996). For example, O'Loughlin (1979) measured sediment in streams in a logged and unlogged plantation forest in Queen Charlotte Sound after heavy rain. The logged stream carried loads of 13,000 ppm into nearby coastal waters, whereas the unlogged had concentrations in the region of 30 ppm. Another study that measured marine fine benthic sediments below logged and unlogged catchments in Onepua Bay, found no increases in fine sediment attributable to logging. Instead, significant differences in fine sediment between the two catchments were attributed to natural variation, in particular differences in near-shore sediment flushing capability, and storm induced sedimentation (McMahon et al. 1996). These factors may have obscured any harvesting effects on fine sediment generation. However, Fahey and McGlone (1990) found that the increase in sedimentation rates in Onapua Bay calculated from pollen dating within two sediment cores had increased significantly since the introduction of pine in the 1960s, although the authors noted that only gross calculations were possible from these two cores and further samples were needed to better calculate background sediment rates.

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<sup>10</sup> <https://www.lawa.org.nz/explore-data/marlborough-region/river-quality/>

## ***Environmental Assessment***

The previous section on harvesting identified hauler logging as the most suitable option for most of the planted forests in the Sounds. We outline a qualitative assessment of the potential effects of fine sediment generation using hauler systems where:

- There are riparian planting setbacks for permanently flowing streams of 5 m for streams <3 m in width, and 10 m for streams >3 m in width
- Replanting is a discretionary activity on steep slopes (> 30°) and where retirement from planted forests or increase set back distances are likely options harvest and engineering controls
- There are harvest controls on woody debris material left on slopes and earthwork requirements for certification by a Chartered Professional Engineer and requirements for the re-establishment of vegetation cover on loose fill within 12 months.
- 

Assessments were made against three set-back distances from the shoreline of 30 m, 100 m and 200 m.

### ***Effectiveness of 5 m and 10 m perennial stream replanting setbacks***

We were unable to identify any New Zealand based research on the effectiveness of a 5 m setback from waterways on mitigating sediment input into streams during hauler harvesting operations. Streams harvested up to the edge in Coromandel, North Island (n = 8) where either no or minimal intact vegetation was retained (maximum width 5.5 m), or where riparian cover was patchy, tended to contain higher quantities of stored sediment than sites with continuous riparian buffers. However, there were no obvious difference in median sediment size (Quinn et al. 2004). One study in Otago/Southland did assess the effectiveness of a 10 m buffer in protecting waterways at one site, which was hauler logged with full suspension of logs off the ground (Thompson et al. 2009). While this site showed fewer changes in physico-chemistry compared to streams where a vegetation buffer was not retained, there was still a significant decrease in substrate size due to bed aggradation from fine sediment inputs. Similarly in an Australian study, the amount of fine sediment in riffles was significantly higher in harvested sites in the buffer width classes of 0-10 m and 10-30 m compared with buffer widths 30 m or greater (Davies and Nelson 1994). Lakel et al. 2010 found that Streamside Management Zones ranging from 7.6 m to 30.5 m in width (16 sites) were generally effective in trapping sediment and found no significant differences in sediment trapping ability across the range of widths.

We acknowledge that one New Zealand site provides insufficient robust scientific data to assess the effectiveness of a 10 m setback in mitigating sediment inputs into waterways in the Marlborough Sounds. Nevertheless, although Fransen's (1990) review found that a significant proportion of sediment is retained within the first 2 m margin of a riparian buffer, based on both New Zealand and overseas studies, it is likely that a 10 m setback will provide a limited degree of protection from diffuse sediment inputs during harvesting which would be further reduced with a 5-m setback. This viewpoint is based on the assumption of hauling back from the stream edge, which may not be logistically or economically feasible in all hauler settings (see earlier section on 'Setback impacts'). Based on Quinn et al. (2004), a continuous set-back along the stream margins is likely to be more effective in mitigating diffuse source inputs compared with discontinuous cover.

Both 5 m and 10 m setbacks will have limited capacity to prevent sediment input into waterways from point sources such as slips, landslides (Phillips et al 1996) and concentrated run-off sources from roads and landings (Fahey and Coker 1992) particularly those areas with high connectivity to the stream system (Croke and Hairsine 2006). However, the combination of logging slash and dense riparian vegetation was effective in retaining sediment and reducing the erosive power of flood waters during a high rainfall event in the Marlborough Sounds (Phillips et al. 1996). Bank erosion can be a significant source of sediment into waterways and downstream marine environments. Intact riparian setbacks assist in maintaining bank stability and reducing the amount of bank-stored sediment mobilising during flood events. In harvested Coromandel streams, bank erosion in streams where riparian buffers of varying widths were retained intact, were about 1/3 that of streams that had been harvested up to the stream edge (Boothroyd et al. 2004). Therefore setbacks as narrow as 5 m are likely to afford some degree of bank protection, however data to quantify this assumption was lacking.

Road construction and maintenance associated with harvesting can contribute to the production of sediments in waterways (Fahey and Coker 1992; Basher et al. 2016). However, improved engineering methods and water and sediment controls when establishing roads and landings are likely to have a greater impact on mitigating both diffuse and point source sediment inputs into waterways. As noted by Phillips et al (1996), good harvest and post-harvest practices minimised the contribution of roading sources of sediment during a high rainfall event in the Marlborough Sounds (Phillips et al. 1996) and assessments of other more recent storm events have found limited damage due to poorly designed roading and landing infrastructure (Basher et al. 2016).

Although the scope of this review is on sediment, we acknowledge that the retention of stream setbacks can provide varying degrees of protection for other physical and chemical aspects of stream environments (Boothroyd et al 2004; Quinn et al 2004; Thompson et al 2009).

### ***Effectiveness of shoreline setbacks (30 m, 100 m, 200 m)***

Overseas studies indicate that a 30 m set-back (or greater) is usually effective in trapping most of the sediment sources, particularly diffuse sediment sources generated by harvesting operations (Croke and Hairsine 2006; Davies and Nelson 1994). The above proposed shoreline setbacks to protect the marine environment, will also have the potential to prevent some point sources of sediment such as those generated by landslides, from reaching the marine environment. This will be dependant on the size and momentum of the landslide and the steepness of the slope, generating sufficient velocity and power to move through the riparian setback and obviously, as the setback distance widens, fewer landslides or debris flows are likely to reach the marine environment. Rivenbark and Jackson (2004) found that of 187 breakthroughs (flow and/or sediment moved through a streamside management zone into the stream channel) only 14% travelled more than 30 m through an SMZ, indicating that this width has the potential to markedly reduce point sediment sources reaching the marine environment. They found that the product of the size of the contributing area, percentage of bare ground and average slope were factors contributing to the success of breakthroughs reaching the stream channel. In the case of Graynoth (1979), a riparian setback ranging from 30m to 150m in width was ineffective in preventing point source sediment and finer suspended sediment from a skid site entering the stream channel. The proposed 200m setback will encompass most of the more highly erodible soil sequence below 200 m. In one storm event in the Marlborough Sounds, all the landslides originating in steep post-harvest cut-over occurred within this 200 m boundary (Phillips et al 1996), highlighting the potential of the 200 m setback in removing the post-harvest window of risk of landslide generation during high rainfall events.

Urlich (2015) proposed that the above coastal and riparian replanting setbacks be implemented along with retirement of erosion prone steep slopes and incised gullies in an integrated suite of measures to target different sources of sediment established by the mechanism of a mandatory replanting management plan. The potential benefits of retiring high risk erosional features such as gully heads from production forestry have been discussed by Landcare in Appendix 3 (Urlich 2015). McIntosh and Laffan (2005) also identified a suite of erosional features (including gully erosion) correlating to high erosion risk in the riparian areas of forest headwater streams in Tasmania, Australia. Similar to the Landcare review (Appendix 3, Urlich 2015), these authors considered that in the inclusion of erosion features and erosion hazard evaluations when determining the location and width of streamside management zones was likely to be more effective in managing erosion risk than using slope factors alone.

Given that the effectiveness of these measures in minimising delivery of fine sediment to stream and marine environments from both diffuse and point sources is site specific (Basher et al. 2016), research specific to the site conditions in the Marlborough Sounds would be beneficial in assessing the effectiveness of these proposed replanting setbacks and retirement options.

## **Social effects – employment levels**

### ***Forestry Work Hours and Employment Opportunities***

A typical growing period or rotation of radiata pine forest takes approximately 28 years (MPI 2016). This requires various forest operations such as establishment, silviculture and harvesting which generates local employment opportunities. Pizzirani (2016) developed a list of operations required for a rotation of *Pinus radiata* in New Zealand. For each operation, the number of work hours



needed has been approximated. Communications with an experienced forestry consultant and a forest manager in the Sounds were organised to collect ideas on the forestry situation and to rescale Pizzirani's work hours per operation based on local knowledge. The authors discussed the numbers collected and using knowledge on forest operations put together a set of indicative number of hours per operation per hectare for a 28-year rotation (Table 7). Please note that the work hours in this table are indicative only due to varying conditions in the forestry areas and different grower intentions. In addition, these work hours are only about production forestry and does not include timber processing.

**Table 7.** Indicative number of work hours per forestry operation for a hectare of a 28-year rotation of *Pinus radiata* in the Sounds.

Forest operation	<i>Unpruned</i>		<i>Pruned</i>		<i>Weighted ave hours per ha</i>
	<i>hours per ha</i>		<i>hours per ha</i>		
	Flat	Steep	Flat	Steep	
Nursery	3	3	3	3	3
Site preparation	6	2	6	2	3
Planting & spot spraying	12	16	12	16	15
Thinning	12	16	12	16	15
Pruning			32	40	16
Landing & road maintenance	15	15	15	15	15
Harvesting	110	130	110	130	127
Transport	46	46	46	46	46
Administration	26	26	28	28	27
<b>Total hours per ha</b>	<b>230</b>	<b>254</b>	<b>264</b>	<b>296</b>	<b>267</b>
<b>FTE per ha</b>	<b>0.13</b>	<b>0.14</b>	<b>0.14</b>	<b>0.16</b>	<b>0.14</b>
<b>Total FTEs (Area * FTE)</b>	<b>192</b>	<b>1,199</b>	<b>147</b>	<b>931</b>	<b>2,468</b>
<b>FTEs per year</b>	<b>6.8</b>	<b>42.8</b>	<b>5.2</b>	<b>33.3</b>	<b>88.2</b>
<b>Weighting</b>	<b>9%</b>	<b>51%</b>	<b>6%</b>	<b>34%</b>	<b>100%</b>

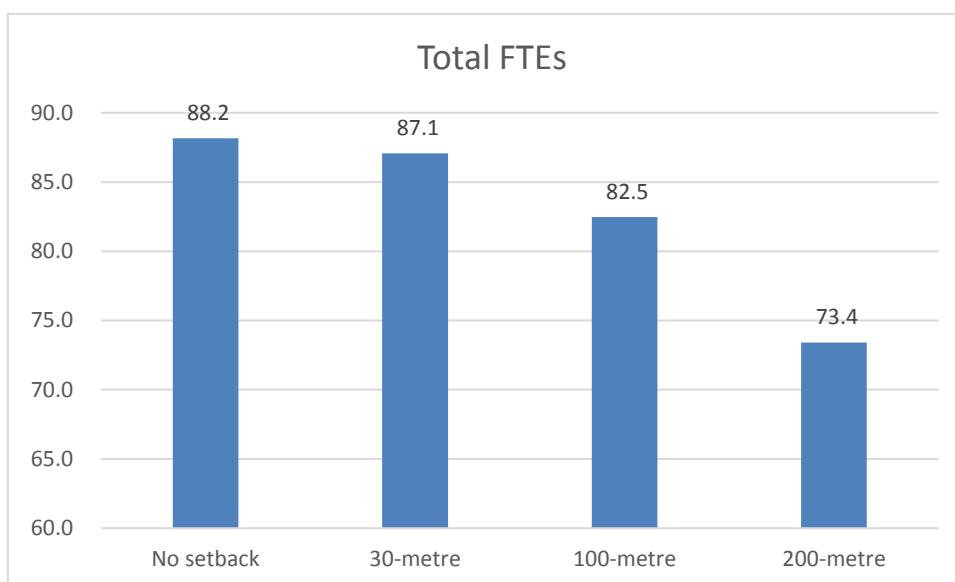
We present in Table 7 that the total number of work hours per hectare varies based on the forestry regime (unpruned/pruned) and steepness (flat/steep). Harvesting and transport operations require the most number of hours on a per hectare basis. The pruning operation, which includes at least two pruning sessions, is the third most labour intensive operation. This makes the pruning regime significantly higher in labour requirement than unpruned regime. These are followed by "planting and spot spray release" and "landing and road maintenance". For the planting operation, an initial stand density of 1,000 stems per hectare was assumed based on Harris (2017 personal communication).

### ***Effects of setbacks on employment levels***

The forest areas lost through the setbacks was converted into reductions in employment hours for each setback scenario (Table 8). We converted the number of hours into full-time equivalents (FTEs) where we have assumed that an FTE consists of 1,840 of actual work hours per year. The pruned regime on steep slopes has the highest FTE of 0.16, while the unpruned regime on flat land has the lowest FTE at 0.13. The FTEs per annum for the without and with setback scenarios are given in Figure 19. We found that three setback options 30 m, 100 m and 200 m would respectively contribute to a reduction of 1.2%, 6.5% and 16.8% in annual FTEs from production forestry.

**Table 8.** Approximate number of work hours for forest production in the Sounds.

Setback	Unpruned		Pruned		Total FTEs/yr	Change in FTEs/yr
	FTEs/year		FTEs/year			
	Flat/Roll	Steep	Flat/Roll	Steep		
No setback	6.8	42.8	5.2	33.3	88.2	
30-metre	6.8	42.3	5.2	32.9	87.1	1.1
100-metre	6.4	40.1	4.9	31.1	82.5	5.7
200-metre	5.7	35.7	4.4	27.7	73.4	14.8



**Figure 19.** Impact of setbacks on employment levels.

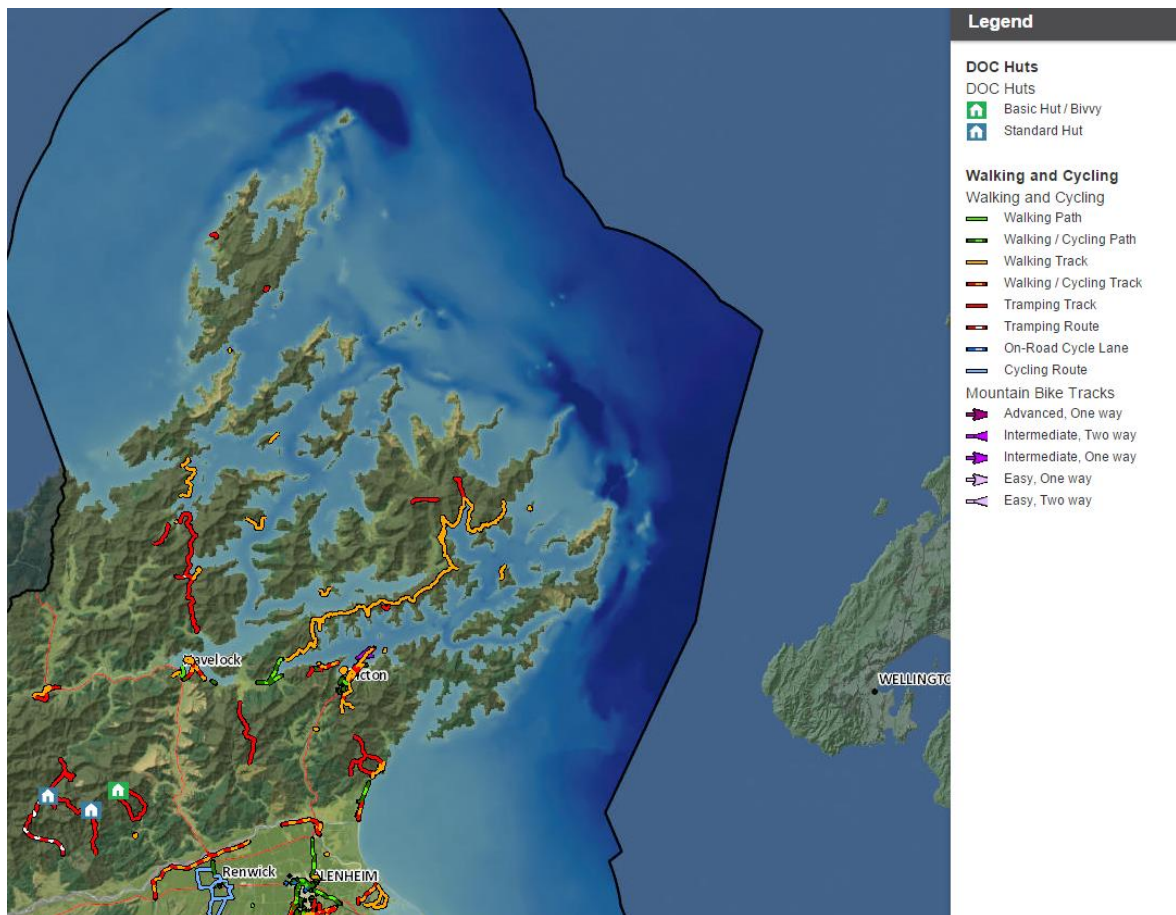
Employment level calculations are only indicative. Some forest areas may experience a disproportionate effect on their profitability by the new requirements, for example, small forests may become uneconomic to harvest because of the setbacks especially the 200 m setback. Hence this calculation may underestimate employment lost due to setbacks.

## Forest recreation and related values

Forest recreation has been found to provide valuable health and economic benefits globally (Park et al. 2009; Willis and Crabtree 2011; Dhakal et al. 2012). The value of recreation provided by forests has been evaluated by a number of studies. Several studies in the United States and Europe focused on the impacts of policy and forest management regimes on forest recreational value (e.g. Shelby et al. (2005) Horne et al. (2005); Christie et al. (2007)). There has been a very limited study on forest recreation in New Zealand (Dhakal et al., 2012; Barry et al. 2014; Yao et al. 2017). To the best of our knowledge, there has been no forest recreation study undertaken for planted forestry in the Marlborough Sounds. The project team elected to use completed international and New Zealand studies to provide some indicative values of key forest recreational activities, to illustrate the potential value of the recreation to the Sounds.

Several planted forests in New Zealand provide recreational opportunities to the local people as well as domestic and international tourists (Yao et al. 2013). Recreational activities include walking, mountain biking, horse riding, hunting, running and exercising dogs (Yao et al. 2017). The Marlborough Forest Industry Association website reports the planted forests in the region provide corridors or connectivity to native forests in conservation land in providing amenities for tramping, hunting, horse riding and mountain biking. Locations of walking, tramping and cycling trails are presented in Figure 20. Some indicative numbers forest recreational area and number of visits are not yet available in the region to date. In a very limited number of planted forests in New Zealand, the number of visits, area of hunting and value of a recreational walking visit have been estimated (Yao et al. 2013). Some related studies on forest recreation and health benefits of forests are described in Appendix B.

Harvesting buffers may have an effect on the amount of sediments that may flow downstream (e.g. marine environment). This can have an effect on recreational and marine fisheries. However, marine recreation is beyond the scope of the study and perhaps this can serve as a future research.



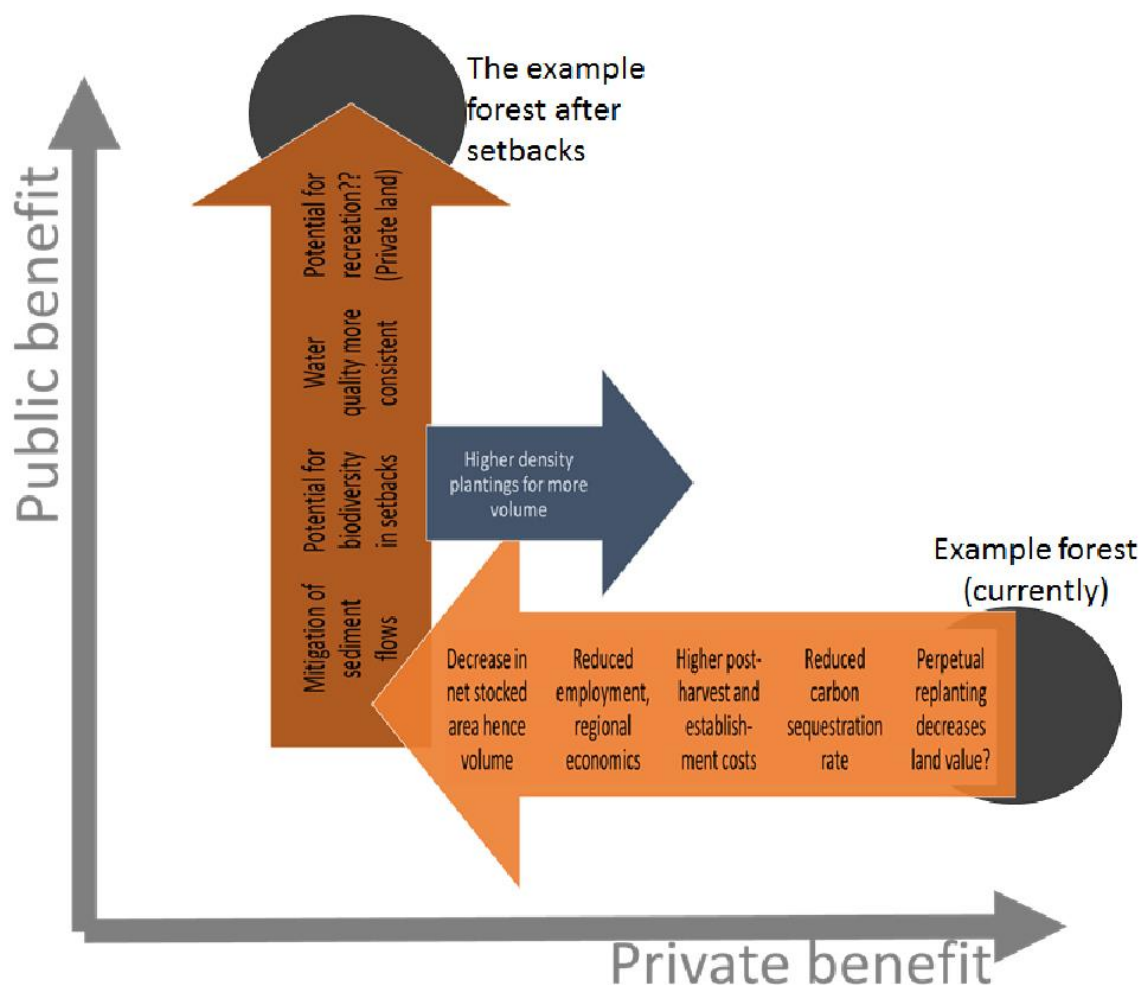
**Figure 20.** Walking, cycling and mountain biking trails in the Marlborough Sounds.  
 Accessed on 4 May 2017 at <https://maps.marlborough.govt.nz/smmaps/?map=9b7a97bded3f4bcc4c9216634a73304>

## Discussion and future directions

Proposed setbacks in the Sounds were modelled using the spatial economic tool called Forest Investment Framework and this represents Objective 1 of the study. Qualitative analysis results of are described in the Objective 2 section.

We have quantified environmental and economic impacts of setbacks, and quantitatively described technological adaptations. Using FIF, we have estimated some quantitative impacts of the setbacks on the economic, environmental and employment values in the Sounds. Setbacks reduce the utilisation of productive areas which leads to lesser employment opportunities and lower overall returns from forestry. Setbacks also lead to gains in environmental values such as carbon sequestration and avoided sedimentation. However, there has been some considerable uncertainties in the carbon market due to volatile carbon prices over the past decade. Although avoided erosion is very important to the environment, it currently does not have a market. We also find that proportional effects of the setbacks are low numerically. However, in actual terms, these may not be insignificant effects, both in terms of gains and losses. This study contributes to better information on what is known and can be modelled based on current information.

Figure 21 adapts the public and private goods framework applied by Barry et al (2014) to account for the private (e.g. forest owner) and public (e.g. recreationist) benefits derived from planted forests. This shows that forests in the Sounds where an increasing public benefit does not necessarily lead to decreasing private benefit. There can be a few measures to offset the losses in private benefits from setbacks. The blue arrow shows an example of a measure that can potentially offset the reduction in forestry return. Specifically, one measure is to have higher density tree planting or increase in stocking rate per hectare to maximise the use of the remaining forest land. This could be investigated using the optimum stocking model described in Watt et al (2017). Watt et al. also suggested that there are opportunities to increase the stocking rate in the majority of existing planted forests in New Zealand.



**Figure 21.** Graphical presentation of private benefit losses and public benefit gains

The quantified values of ecosystem services from setback areas, combined with other qualitatively described values, can promote the recognition of their wider values in policy and resource management discussions. This allows both economic and some representations of environmental values to be accounted for in policy discussions. Due to uncertainties and lack of market mechanisms to recognise important ecosystem services values, environmental gains may not necessarily offset the economic losses from setbacks. The establishment of new markets that better recognise the importance of environmental benefits in the Sounds could help incentivise environmentally beneficial land use management.

This study focused on the economic and environmental impacts of setbacks in production forests in the Sounds. We did not examine in detail the recreational opportunities of forestry in the Sounds. Given the iconic status of the Sounds in the country and globally, there is a potential to create high-end recreational amenities that can contribute to the further development of eco-tourism. A study on the value of establishing recreational or tourism amenities in the setback areas using spatial and

economic valuation techniques, may help better demonstrate the broader natural capital and ecosystem services values of the setback options. In addition, we did not investigate any economic or environmental effects on the marine environment which can include fish stocks, commercial fishing and marine recreation and tourism. A future study can help examine how setbacks can affect the ecosystem services provided by the adjacent marine environment. Furthermore, we also recommend a future study to use estimated ecosystem services values (e.g. recreation, biodiversity, avoided erosion, carbon sequestration) as starting values or prices to establish new markets for bundles of ecosystem services that would incentivise improved land use management.

Another useful future study should examine the erosional feature and risk mapping of planted forests in the Sounds as well as quantify the effectiveness of the proposed setbacks and retirement areas in reducing fine sediment production under current harvesting and engineering technologies and management practices. Such study would contribute to a more informed evaluation of the potential gains on reducing fine sediment reduction against potential impacts on the logistics and economic (market and non-market) viability of harvesting.

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# Appendix A – Examples of Harvesting Systems

## ***A1 - Steep terrain harvesting***

Steep terrains require specialised steep terrain systems / haulers etc.

Large tower hauler - suitable for large settings and long haul distances on steep terrain



Large swing yarder - suitable for medium sized settings with intermediate haul distances, steep terrain.



Grapple carriage - for use on swing yarders - avoids the need for manual breaking out.



Harvestline - excavator based light-weight hauler - suitable for small settings and smaller trees, steep slopes and dissected terrain



Winch assisted feller-buncher - mechanised tree felling on steep slopes



**A2 - Ground-based harvesting systems - suited to flatter / rolling terrain.**

Feller bunchers (similar to above, without the winch system)



Skidders (rubber tyred, often fitted with tyre chains) - flat to rolling terrain - best on down hill hauling



Tracked extraction machine - Custom skidders - can be fitted with a grapple or a winch, winch machines can cope with steeper slopes and dissected terrain better.



Tracked extraction machine - Bulldozers + winch+ trailer arch - suitable for rolling and dissected terrain



Mechanised processors (cut stems to log length at the stump) - flat to rolling terrain



Forwarders (extract logs created by processors from stump to landing) - flat to rolling terrain





Shovel logging with excavator / loaders; a heavy duty excavator traverses the cutover and extracts the stems to the landing by moving them towards the landing 1 boom swing at a time. Suitable for short extraction distance, small settings and flat to roiling terrain. Best suited to downhill extraction.



## Appendix B – Value of forest recreation and aesthetics and health benefits of forests

Mountain biking and walking have a significant role in New Zealand recreation. A significant proportion of the 5,667 ha Whakarewarewa Forest in Rotorua is popular for its publicly accessible mountain biking (Figure B1), walking and horse riding trails (Turner et al., 2011). An APR (2010) survey estimated that there were about 88,500 visits by walkers and another 101,800 visits by mountain bikers to the forest in 2009 and the visits have been significantly increasing for mountain biking. Dhakal et al. (2012) studied the value that mountain bikers and walkers place on each visit to the forest. They used an economic valuation method called Travel Cost to estimate the recreational use value based on the observed behaviour of a sample of 706 forest visitors (366 walkers and 340 mountain bikers). Results suggest that the annual aggregated value of the recreational benefit provided by the forest was more than twice the annual timber revenue. This recreational value represents the public benefit provided by the production forest that is over and above its timber production activities. Most recreational walking and biking tracks are accessible the whole year round. Access is restricted in a few patches or a small fraction of the forest estate where forestry operations (e.g. harvesting, planting) occur while access continues in a large majority of the production forest which remains untouched. Damaged or destroyed walking and mountain biking trails can be restored or upgraded post-harvesting.



**Figure B1.** A mountain biker in the Whakarewarewa Forest, Rotorua who drove from Hamilton (Photo Richard Yao).

More than half of the 30,000-hectare Wenita Forest Products (Wenita) forest estate in Dunedin is accessible for recreational hunting (Yao et al. 2017). Wenita offers hunting access to registered hunters (mostly pig hunters) for a small fee that covers access to the hunting sites and administration costs. Wenita issues more than 200 hunting licences per year and this resulted to more than 3,000 recreational hunting visits taking place in the years 2014 and 2015. Based on Wenita's hunting database, pig hunters collected about 1,792 and 1,361 pigs from the forest estate in 2014 and 2015, respectively. Assuming each collected pig yielded an average of 20 kg of usable game meat for home consumption (and each kg has a value of about \$7 based on the current price

of pork chop at about \$10-15/kg and the imputed hunter's meat processing cost of about \$3-8/kg), the total meat value provided by the forest estate to hunters was \$250,880 and \$190,540 in 2014 and 2015, respectively. Assuming that about half, or 15,000 ha, of the estate is classified as a pig hunting area, the value of pig hunting (based on meat value) is about \$15/ha/year. This value corresponds well to the average game meat or bush meat value (converted to 2016 NZD) in the study by Naidoo and Ricketts (2016). This value represents a conservative estimate of Wenita forest estate's game meat provisioning value.

In terms planted forests' contribution to landscape quality or aesthetic value, the survey-based study by Thorn et al. (1997) provide evidence that foreign tourists (especially from North America and Asia) placed substantially higher aesthetic values on radiata pine forests than New Zealand residents. A possible reason for this is that *Pinus radiata* grow slowly and is usually twisted and knotty in its original area in California (e.g. Monterey Peninsula, Santa Cruz County) while the species grow significantly faster and are healthier in New Zealand. Many tourists are also not aware that radiata pine is not native to New Zealand, while New Zealanders are more aware of the production-related activities of pine forests i.e. clear-felling.

Research in Japan has found that forest visits improve human health by increasing the body's resistance to cancer. The study by Li et al. (2009) indicates that walking in a forest activates *natural killer cells*, a type of cell known to attack cancer cells, and increases three types of anti-cancer proteins.

The above paragraphs can be treated as some indicative public values and recreational values provided by forests in the Marlborough Sounds. They demonstrate that a recreational visit to a forest has a value despite no entrance fee being paid by the recreationist. The value of a recreational hunting visit may vary across different sites as that can be affected by the type of game animal available. A view of radiata pine forests can provide aesthetic values to foreign tourists in the Sounds.

Some of the possible impacts of harvesting buffers on the recreational value of forestry in the Marlborough Sounds are unknown. For the impact on views as seen from the Sounds, the impact is only when close to the shore; views of harvested areas remain visible regardless of setback size as the land is steep. For the within-setback areas themselves, impacts would depend on many factors such as property rights, access and the cost of recreational travel. Perhaps a more detailed study should be undertaken to assess the impacts harvesting buffers on forest recreational values in the Sounds.

As indicated above, planted forests provide corridors or connectivity between native forests for amenities such as tramping. The Walking Commission<sup>11</sup> provides not only walking routes, but also legal access ('paper roads') and campsites (Figure B2).

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<sup>11</sup> [https://www.wams.org.nz/wams\\_desktop/index.html](https://www.wams.org.nz/wams_desktop/index.html)



**Figure B2.** Walking access from the Walking Commission  
 Accessed on 4 May 2017 at <https://www.walkingaccess.govt.nz/>