Ministry for the Environment
Manatū Mō Te Taiao

PO Box 10362, Wellington 6143
Website: www.mfe.govt.nz
Freephone: 0800 499 700

20-D-00807

9(2)(a) [redacted]
9(2)(a) [redacted]

Dear 9(2)(a) [redacted]

Thank you for your email of 19 April 2021 requesting the following under the Official Information Act 1982 (the Act):

> *In October 2020 the Ministry in conjunction with Statistics NZ published a paper titled "Our Atmosphere and Climate 2020". This paper made a number of claims with regard to the impact of climate change on fire danger and an increase in the risks of wildfire in NZ. The data used to support your claims was based upon an analysis of Fire Danger Class levels at twenty sites over a 17 year period.*
>
> *Under the provisions of the Official Information Act I request from you the following information:*
>
> - *Copies of correspondence (letters, email, etc) received to date by the Ministry supporting the findings of this report with the respect to the increasing risks of wildfire as a consequence of climate change; and*
> - *Copies of correspondence (letters, emails, etc) received to date by the Ministry challenging or disputing the findings of this report with respect to the increasing risk of wildfire as a consequence of climate change and/or the methodology and data used to arrive at this finding, and if any, what action has the Ministry taken to address any concerns raised.*

The Ministry for the Environment has identified seven documents in scope of your request, as listed in the attached table.

Some information within these documents has been withheld under section 9(2)(a) of the Act, to protect the privacy of natural persons.

In terms of section 9(1) of the Act, I am satisfied that, in the circumstances, the withholding of this information is not outweighed by other considerations that render it desirable to make the information available in the public interest.

As you will note in the attachments, the Ministry for the Environment (the Ministry) received questions from a journalist regarding the report. While these were not specifically in support or dispute of claims made in the report, we have provided them as they may be of interest to you. Note the original questions were made via phone call, so we are only providing a copy of the Ministry's response.

You will also note in the attachments that a meeting was held between Fire and Emergency NZ, SCION and Stats NZ. The actions agreed upon in this meeting were that Stats NZ would reassess the data used in the report. No formal actions were agreed by the Ministry, and we do not hold any further information in scope.

You have the right to seek an investigation and review by the Office of the Ombudsman of my decision to withhold information relating to this request, in accordance with section 28(3) of the Act. The relevant details can be found on their website at: www.ombudsman.parliament.nz.

Please note that due to the public interest in our work the Ministry for the Environment publishes responses to requests for official information on our OIA responses page shortly after the response has been sent. If you have any queries about this, please feel free to contact our Ministerial Services team: ministerials@mfe.govt.nz.

Yours sincerely

Sean Poff
Director, Environmental Reporting

Document schedule

Document no.	Document date	Content	Decisions	OIA sections applied
1	2 November 2020	[Email] Our Atmosphere and Climate 2020 - detailed feedback	Released in part	S9(2)(a)
2	6 November 202-	[Email] request to meet - Our Atmosphere and Climate 2020	Released in part	S9(2)(a)
3	22 November 2020	[Email] RE Question from MfE on their OAC2020 Report	Released in part	S9(2)(a)
3.1		Attachment to email - *Assessment of multiple climate change effects on plantation forests in New Zealand*	Released in full	N/A
4	13 January 2021	[Email] Gore fire danger Media	Released in part	S9(2)(a)
5	11 November 2020-	[Email] Recent NIWA-led research on wildfire risk	Released in part	S9(2)(a)
6	19 February 2021	[Letter] Ministry for the Environment Feb 2021	Released in part	S9(2)(a)
7	19 April 2021	[Letter] 21-M-00588 Response	Released in part	S9(2)(a)

From: s 9(2)(a)
To: John Robertson; Drew Bingham
Subject: Our Atmosphere and Climate 2020 - detailed feedback
Date: Thursday, 22 October 2020 9:25:37 pm
Attachments: image001.png
image002.png

Kia ora John and Drew,

Following my cheeky approach to Tash about the small correction and reference to Fire and Emergency, I learnt some of my colleagues in the wildfire area have got some concerns around the data (and assumptions) in the report.
I am not yet 100% across what those concerns are but I will be reaching out in the next few weeks we can all meet and discuss, and kickstart a more collegial working relationship between our two organisations.

Best regards

s 9(2)(a)

From: Natasha Lewis <Natasha.Lewis@mfe.govt.nz>
Sent: Wednesday, 21 October 2020 6:15 PM
To: s 9(2)(a)
Cc: Drew Bingham <Drew.Bingham@mfe.govt.nz>; John Robertson <John.Robertson@mfe.govt.nz>; Katherine Wilson <Katherine.Wilson@mfe.govt.nz>
Subject: RE: Kia ora! and a tiny bit of feedback

Hola s 9(2)(a)

Good to hear from you and thanks for your feedback on the report- will make sure to pass that onto the team as they will love to hear it. s 9(2)(a)

Thanks for the correction reference for the report and will make sure that is logged as an error so the online report is accurate.

I've copied in John Robertson who is the Director responsible for Environmental Reporting at present – he will ensure the correction gets sorted but would I'm sure be interested in any feedback you may have on what data and evidence might be useful into the future – this new indicator was a start but I'm sure there is more to be done and fire risk was certainly an area of considerable media interest.

Drew Bingham was the science lead for the report so deserves a lot of the credit and can share it with the team.

Katherine Wilson is the Director responsible for Adaptation so as you embark on a learning trip with adaptation I'm sure she can help connect you up with relevant members of the team.

Say hi to s 9(2) – I hope you two enjoy working together. The little village of Wellington.

Hasta luego

Tash

Natasha Lewis (she/her*) –Deputy Secretary, Strategy and Stewardship
Ministry for the Environment – Manatu Mo Te Taiao
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23 Kate Sheppard Place, Thorndon, Wellington 6143

*Curious about the use of pronouns on my signature block?   Please read more here to understand why it is important to me.

http://intranet/sites/all/files/Lockup-8pt.png

From: s 9(2)(a)
Sent: Wednesday, 21 October 2020 11:52 AM
To: Natasha Lewis <Natasha.Lewis@mfe.govt.nz>
Subject: Kia ra! and a iny bit of feedback

Hola Natasha,
Hope all is well at your end. Last time we chatted it was post-lockdown and working remotely was going great.

We've been reading Our atmosphere and climate 2020 with our team and I wanted to pass a little feedback to your team that the reference to the National Rural Fire Authority on page 44 is outdated, as the NRFA is now Fire and Emergency New Zealand.
The report is fantastic and very timely to my work and my colleagues in Risk Reduction, as we'll be embarking on a trip to Adaptation land and what it means for us.

I couldn't find who in your team I could approach for this, so I though I'd take the opportunity to say hi to you too.

Saludos,

s 9(2)(a)

s 9(2)(a) [redacted]

s 9(2)(a) [redacted]

Organisational Strategy & Capability Development

P: s 9(2)(a) [redacted]

www.fireandemergency.nz

From: Drew Bingham
To: s 9(2)(a)
Subject: RE: request to meet - Our Environment and Atmosphere 2020
Date: Friday, 6 November 2020 3:48:00 pm
Attachments: image002.png

Hi s 9(2)(a)

That sounds good, happy to keep it at a high level. Hope you have a good weekend as well.

Drew

From: s 9(2)(a)
Sent: Friday, 6 November 2020 3:40 PM
To: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Subject: RE: request to meet - Our Environment and Atmosphere 2020

Hi Drew,

Thank you for your message. Our main concern is to understand the detail of the datasets that lead to the report's fire risk statements for some of the regions, so I think it will be beneficial that we slowly dive into that side of the methodology to start with.
I am not a technical lead in this, but I understand some of the statements in the report do not match our long-term trends (i.e. reduction/increase of fire risk for a given region)
At a later point, we may benefit of discussing options for co-funding research so we can improve the analysis/prediction tools for everyone's benefit.

This is high-level sort of agenda, I am comfortable that it will suffice, as what's more important from our meeting is the opportunity to establish a more robust relationship for future work.

Have a good weekend,

s 9(2)(a)

From: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Sent: Friday, 6 November 2020 3:25 PM
To: s 9(2)(a)
Subject: RE: request to meet - Our Environment and Atmosphere 2020

Kia ora s 9(2)(a)

I think we have everything set up for the meeting, so looking forward to chatting next week.

Just wondering if you have specific points you'd like to discuss or if we need an agenda for the meeting to help us prepare and have a more informed discussion.

Thanks,
Drew

From: s 9(2)(a)
Sent: Friday, 30 October 2020 9:47 AM
To: John Robertson <John.Robertson@mfe.govt.nz>; Drew Bingham <Drew.Bingham@mfe.govt.nz>
Subject: request to meet - Our Environment and Atmosphere 2020

Kia ora John and Drew,
Hope you are both well.

As I mentioned in my email last week, we would like to meet and discuss the detail of the Wildfire Risk section in the "Our Climate and Atmosphere" report released earlier this month.

We would like to understand how the process and methodology for completing the report was decided and comment on some of the resulting consequential implications of the statements in the main report and stats supporting the report. The main focus of the discussion is identify what can be done to address some of the issues and develop a way in which we may be able to support and work together on future reports.

At the meeting, we will have
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And s 9(2)(a) from SCION, who is a senior wildfire science person with a long working relationship with us.

Please let me know when is a suitable time on the 11th or 12th of November as we will all be in Wellington at the time and can meet in person.

Best regards,

s 9(2)(a)

s 9(2)(a)
Organisational Strategy & Capability Development

s 9(2)(a)
s 9(2)(a)
www.fireandemergency.nz

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From: [redacted] s 9(2)(a)
Sent: Wednesday, 9 December 2020 4:34 pm
To [redacted] s 9(2)(a)
Cc: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Subject: RE: Question from MfE on their OAC2020 Report

Hi [redacted] s 9(2)(a) & Drew

Regards correct citation, the Pearce et al. (2011) report does include a statement (on pg 29 – see below) hat he average increase in fire dange (days of VH+E) across all models and station locations is around 70% (62% to the 2050s, and 74% to the 2080s). How ver, wi h hindsight, this result w ghlig ted as prominently as it should have been in other parts of the report, such as the Exec. Summary and Conclus n (where there was a clear lack of quantitative results!).

However, perhaps a better and more up-to-date reference is actually the Watt et al. (2019) per i Forestry – see attached. This is the source for the Scion Connections article cited in the OAC report. In the fire risk section, Watt et al. contains the statement: "When averaged ver a l sites, th number of days with VH + E fire risk was projected to increase by 71 per cent by 2040, and by a further 12 per ent by 2 90" e below. It al o says the abstract that: "The average season length with 'very high and extreme' climatic fire risk increases by 71 per cent up to 2040 and by 83 per cent up to 2 90", which n't necessarily the tidiest way as saying the same thing (for no. days of VH+E, not fire season length which is a dif erent easu that wasn't looked at i this paper).

The key difference between the two analyses was that Watt et al. used res ts fo l 2 of the 17 GCMs sed b Pearce et al., to be comparable with the other CC impacts they looked at.

Scion (and FENZ) are happy to stick with the current text on pg 64 of the OA report around he above wi the citation corrected. The issue was more about the how discussion around this projected future increase can be related the discussion of obse ed c rrent trends on pgs 44-45, especially given the section title of "The risk of wildfires is changing". This might be achiev d by including an introductory en nce o two clarifying this distinction in the objectives of the studies, e g. around whether the observed trends over recent years are sh wing any evidence o the inc eases projected. This would also lead nicely into the section that follows around natural climate variations, which provides o possible xplanation of why the more widespread increases projected with climate change aren't being seen yet.

Hopefully this helps clarify what we were sug sting by way of change to he report

Regards, [redacted] s 9(2)(a)

2080s. For some models and at some locations, fire climate severity exhibits a tendency to peak by the 2050s and then remain at about the same level for the 2080s. This is the case at Kaikoura (KIX) for the IPCM4 model, where the SSR and number of days of VH+E fire danger increase significantly to the 2050s (by 161% and 310%, respectively), but then stay the same or even decrease slightly by the 2080s (164% and 304%), indicating little or no change between the two projection periods (-18% and -3%). Kaikoura (KIX) also shows a similar tendency under the HADGEM model, as does Dunedin (DNA) under the MIMR model. Some locations and models also show a greater decrease in fire climate severity from the 2050s to 2080s. Examples of this Dunedin Aero (DNA) under the ECHOG and GIEH models, where SSR increases by 59% & 26% and VH+E by 160% & 264% to the 2050s, and then decreases by -135% & -402% for SSR and -40% & -120% for VH+E from the 2050s to the 2080s, for each model respectively. Wellington (WNA) under HADGEM and MRCGCM, and again Kaikoura (KIX) under a number of models including GFCM21, GIAOM, MIHR, MPEH5 and MRCGCM, also show similar trends.

These variances in trends are further evidenced by differences in the rate of change in fire climate severity projected for the two periods. When averaged across all 17 models and station locations, the number of days of VH+E fire danger during the fire season is projected to increase by 62% from current values for the 2050s and 74% for the 2080s, but only 12% (based on current values) from the 2050s to the 2080s. There is obviously much variability between models in these rates of change, although model ranges for the 1990s to 2050s period (-12% to +490%) are less variable than those for the 2050s to 2080s (-16% to +460%). In real terms, these average changes correspond to an average increase of 3.6 day/season of VH+E fire danger from the 1990s to 2050s (range -2 to +35 days/season), and just 0.81 days/season for the 2050s to 2080s (range -10 to +16 days/season). The rates of change in SSR for the two projection periods vary less, at 26% for the 1990s to 2050s (and 30% for 1990s to 2080s), and 29% from the 2050s to 2080s, although the ranges in these rates between models are much less variable for the 1990s to 2050s (-5% to +160%) than 2050s to 2080s (-400% to +770%)

Variation Between Models

The individual Global Circulation Models (GCMs) are different representations of the climate system with different model sensitivities, rates of warming and interannual variability derived from differences in modelling resolution and the way the represent interactions between the atmosphere, oceans and land surface (and the effects of factors such as the reflective and absorptive properties of atmospheric water vapour, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries) (MfE 2008). The advantage of utilising an increased number of GCMs that each model climate slightly differently is that together they encompass a wider range of possible future climate outcomes, and also potentially better capture future climate variability. While the GCMs show some consistency in the relative amplitude and spatial pattern of their respective changes, there is also considerable variability (e.g. in the multi-decadal rates of warming) that results in widely varying estimates of the climate changes that influence fire danger.

2090 showed that the AEP increased on average by 0.066, and for four of the six scenarios, the AEP was >0.2 (Table 2).

The risk of wind damage for the unpruned regime was very similar to the risk for pruned stands in both 1990 and 2040. However, for projections to 2090, the risk of wind damage for the unpruned regime was substantially higher than for the pruned regime due to the higher ratio of height to diameter for this regime. These increases were particularly marked for emission scenarios that assumed a full response to increasing CO_2 (Table 2). The risk of wind damage was markedly higher for the carbon regime than for the other two regimes due to the higher height to diameter ratio of trees. The carbon regime had very high sensitivity to increasing CO_2. For projections made to 2090, scenarios that assumed a full response to increasing CO_2 had an AEP that was on average 0.33 higher than those that assumed no response, and the AEP of these three scenarios ranged from 0.639 for the B1 to 0.922 for the A2 emission scenario (Table 2). Stands grown on a carbon regime tended to be overstocked, particularly in the latter part of the rotation and the increased risk of wind damage in such situations is consistent with experiences in other regions of the world (Mitchell, 2000; Cameron, 2002).

The relative contributions of different factors on AEP at 2040 and 2090 were determined using previously described methods (Hawkins and Sutton, 2009, 2011; Melia et al., 2015). Figure 4 shows that currently, most of the variation in AEP is attributable to location, with stand age and silvicultural regime also being important. Under future climates, mean values of AEP for a 30-year-old stand ranged from 0.18 to 0.79 across locations (data not shown). Stand age accounted for 27 per cent of the variance in AEP under future climates (Figure 4). The change in mean AEP for increasing stand age from 20 to 30 years ranged from 0.09 to 0.33 in 2040 and from 0.12 to 0.49 in 2090.

Silvicultural regime was relatively important (Figure 4) under future climates, accounting for 19 per cent of the variance in AEP (Figure 4). Mean AEP ranged from 0.21 under the pruned regime to 0.24 under the unpruned regime and 0.50 under the carbon regime (Table 2). The growth response to increasing CO_2 had relatively little impact on AEP in 2040 but a greater impact in 2090 at which time it was equal in importance to the silvicultural regime. Relative to other factors, both emissions uncertainty and increasing wind speed had very little effect on AEP, and together, they accounted for less than 4 per cent of the total variance during both 2040 and 2090 (Figure 4).

Table 2 AEP of wind damage in 30-year-old stands as a function of simulation year, emission scenario and CO_2 concentration for three silvicultural regimes. Values shown represent the means across seven bio-geo-climatic zones defined by their current wind climate. Values of AEP are differentiated by colour into the categories of AEP < 0.20 (green), 0.2–0.5 (orange) and >0.5 (red).

Year	Emission scenario	Inc. CO_2	Silvicultural regime		
			Pruned	Unpruned	Carbon
1990			0.110	0.094	0.166
2040	B1	N	0.152	0.141	0.262
2040	A1B	N	0.164	0.155	0.291
2040	A2	N	0.286	0.154	0.288
2040	B1	Y	0.150	0.172	0.415
2040	A1B	Y	0.164	0.201	0.507
2040	A2	Y	0.164	0.197	0.495
2090	B1	N	0.186	0.182	0.344
2090	A1B	N	0.228	0.242	0.443
2090	A2	N	0.272	0.278	0.483
2090	B1	Y	0.191	0.256	0.639
2090	A1B	Y	0.267	0.421	0.850
2090	A2	Y	0.321	0.522	0.922

Fire risk

Under the baseline climate, dryland areas on the east coast had the highest average number of VH + E fire danger days per year, while many areas on the west coast had a very few, or no VH + E days. There was widespread spatial variation in the degree of change in frequency of VH + E days between baseline and future climate (Figure 5). The regions with the most notable VH + E increases were located on the eastern coast in the southern half of both islands.

Examination of the fire risk by location demonstrates the high variation between sites with the frequency of VH + E fire risk under the baseline climate ranging from 0 to 40 days (Figure 6). When averaged over all sites, the number of days with VH + E fire risk was projected to increase by 71 per cent by 2040, and by a further 12 per cent by 2090. All sites on the east coast showed increases under climate change. The locations with highest current fire risk, Christchurch and Gisborne, had significant further increases in VH + E fire risk by 2090 to 44 and 48 days, respectively. However, the most marked relative changes occurred in Wellington (lower North Island) and Dunedin (south-eastern South Island) where VH + E fire risk increased to 2090 by, respectively, 89 per cent to 32 days and 207 per cent to 18 days (Figure. 6).

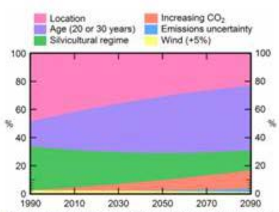

Figure 4 Relative contribution of location, stand age, silvicultural regime, increasing CO_2, emissions scenario and wind speed to AEP. Values of relative importance used in the figure were extracted from Table 2 and relative importance was interpolated between years using second-degree polynomials.

s 9(2)(a)
Scion
s 9(2)(a)
Web http://www.ruralfireresearch.co.nz

From: s 9(2)(a)
Sent: Wednesday, December 9, 2020 2:26 PM
To s 9(2)(a)
Cc: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Subject: Question from MfE on their OAC2020 Report

Hi s 9(2)(a)

I trust this finds you well.

I have been in touch with Drew Bingham at MfE regarding our recommendations. One of the recommendations I sent was a "corre n is required in the OA 2020 (Our Atmosphere and Climate 2020) report; such that the MAF report from 2011 and the results it presents (attached) re u ed as the c ation on pg 64 of OAC2020. According to s 9(2)(a) , these are the most recent and relevant research results available on this topic.

In response, Drew asks:

"I just wanted to clarify with you on the third point – is the recommendation that only the citation on p 4 nee s to be changed and ev rything el e is fine, or that the entire paragraph needs to be changed to reflect the new citation? I can't really tell if he's saying t t the port is the basis of t e stateme ts on the web page that we originally cited, or that the statements on the Scion webpage that we cited are inco rect and hat we should be cit g t repo t instead, and updating the paragraph as well with different findings.

I had a look through the report and did not see any sections that appear to readily sup ort e ma erial on the Scion web age (a d s sequently in our report), but there is a lot of technical information, so if the author tells me to use that report to support th statements on the webpage a d report, I'm happy to do so.

s 9(2)(a) - Can you please let us know your response to the query above? I've Cc'd D ew Bi h m here so he can receive yo r thoughts directly – rather than me risk miscommunicating them by being the messenger.

Many thanks, s 9(2)(a)

s 9(2)(a)

s 9(2)(a)
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Forestry An International Journal of Forest Research

Institute of Chartered Foresters

Forestry 2019; **92**, 1 15, doi:10.1093/forestry/cpy024
Advance Access publication 3 August 2018

Assessment of multiple climate change effects on plantation forests in New Zealand

Michael S. Watt[1]*, Miko U. F. Kirschbaum[2], John R. Moore[3], H. Grant Pearce[1], Lindsay S. Bulman[3], Eckehard G. Brockerhoff[1] and Nathanael Melia[3]

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[2]*Landcare Research, Private Bag 11052, Palmerston North 4442, New Zealand*
[3]*Scion, Private Bag 3020, Rotorua 3046, New Zealand*

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Received 21 March 2018

Determining the magnitude of climate change effects is crucial for informing national economic strategies, forest management and offsetting increasing carbon emissions. This study synthesizes predicted climate change impacts and future biosecurity threats to New Zealand's plantation forests. Projected productivity increases for radiata pine (*Pinus radiata* D. Don), the main commercial forest species in New Zealand, are slight due to changing climatic conditions. However including photosynthetic effects from increasing CO_2, productivity gains across New Zealand averaged 19 per cent by 2040 and 37 per cent by 2090. This increased productivity results in marked increases in wind risk due to trees becoming taller and more slender. The average season length with 'very high and extreme' climatic fire risk increases by 71 per cent up to 2040 and by 83 per cent up to 2090. Currently, the most significant biotic disturbances in New Zealand plantations come from two needle cast diseases, for which climate projections show slight increases or decreases depending on the disease and region. Although insect pests currently cause little damage to New Zealand plantations, damage may increase in the future with projected increases in population and host susceptibility. It has not been possible to fully account for the effects of any new introductions of pests and pathogens and evidence from other countries with a significant resource of planted forests suggest this should not be underestimated. Potentially invasive weedy and damaging tree species are likely to expand their range under climate change and compete more strongly with plantations.

Introduction

Climate change is emerging as one of the key influences to shape the future of natural and anthropogenic systems across the world (Cramer *et al.*, 2014). As forests cover about one quarter of the Earth's land surface area, they play a major role in current and projected future carbon budgets. Determining the influence of climate change on planted forests is of importance as these forests provide about half of the global wood supply and are a vital natural mechanism to offset future carbon emissions (Payn *et al.*, 2015). Increased disturbances to forests may reduce carbon stocks, result in substantial economic impacts and have consequences for ecosystem functioning.

Considerable research has investigated how climate change influences forest productivity. A recent review that synthesized findings from 31 studies found that 87 per cent of them identified positive changes in forest productivity when the effects of climate change and increasing CO_2 were combined (Reyer, 2015). Although gains in forest productivity are likely to occur as a result of climate change and CO_2 increases, there is some uncertainty around the magnitude of this response. Photosynthesis of C_3 plants, including trees, increases strongly up to an ambient CO_2 concentration of about 300–400 ppm. Current observations show CO_2 rising above 400 ppm (Betts *et al.*, 2016), and with increasing CO_2 concentrations, relative photosynthetic gains by ongoing increases in CO_2 concentrations become progressively smaller (Kirschbaum, 2011; Hickler *et al.*, 2015).

However, while there may be gains in productivity realized through increased CO_2 and temperature up to the optimal value, they may be counteracted to varying degrees by changes in abiotic and biotic stressors (Reyer *et al.*, 2017). Climate change will influence the distribution and abundance of many forest pests (Unless otherwise stated (i.e. insect pest), pest refers to all agents injurious to trees or tree products (i.e. insects, pathogens and weeds)) and alter the frequency and intensity of damaging abiotic factors, such as wind and fire (e.g. Walther *et al.*, 2009; Allen *et al.*, 2010; Anderegg *et al.*, 2015). Predicted changes in these factors under climate change have often been found to lead to reduced productivity (Kurz *et al.*, 2008; Seidl *et al.*, 2014). Although a comprehensive assessment of changes in productivity has to account for the impacts of changes in all these factors, combined assess ments such as in this paper have rarely been done in the past (e.g. Chen *et al*., 2000; Wolken *et al*., 2011; Shanley *et al*., 2015).

New Zealand provides a useful case study for examining the overall effects of climate change on plantation productivity as a single species, *Pinus radiata* D. Don, covers 90 per cent of the 1.7 million hectare plantation resource (NZFOA, 2016). There is much information describing the physiology and morphology of *P. radia ta*, and how this species responds to changes in environmental factors. Using this information, previous research has modelled the growth of *P. radiata* under current (Kirschbaum and Watt, 2011) and future (Kirschbaum *et al*., 2012) climatic conditions within New Zealand. The major needle diseases of *P. radiata* are well known, and the spatial variation in the severity of two prob lematic diseases (caused by *Dothistroma septosporum* (Dorogin) M. Morelet and *Cyclaneusma minus* (Butin) DiCosmo, Peredo and Minter) has been described under both current and future cli matic conditions (Watt *et al*., 2011a, b, 2012a, b). Spatial vari ation in wind risk under current and future climate has also been quantified (Moore and Watt, 2015).

The primary aim of this study was to synthesize knowledge describing the likely impacts of climate change on *P. radiata* plan tations. Specifically, we summarize previously published studies describing the impact of climate change on radiata pine product ivity and damage from wind and two of the major needle dis eases of *P. radiata*. We complement this synthesis with additional, previously unpublished, research describing the potential impacts of fire on plantations. A general more qualitative synthesis of the literature was undertaken to describe the potential impacts of biotic factors that includes a key report describing changes in trade patterns and their effects on the origin of biosecurity risks (Kean *et al*., 2015). We describe the potential future impacts of key diseases, weeds and insects that are either currently in the country or could pose major incursion risks. We conclude with sections describing key sensitivities highlighted by the study and areas for further research.

New Zealand's climate and the location of plantations

New Zealand's mean annual temperature at low elevation sites ranges from 8°C in the south to 16°C in the north, with colder conditions at higher elevations, especially in the South Island (Figure 1a). Variation between summer and winter tem peratures is generally relatively small, especially in coastal regions. Consequently, there are currently few periods with extremely hot or cold conditions in the low to moderate eleva tion areas of New Zealand where plantation forests are grown.

Precipitation within most of New Zealand ranges from 500–2000 mm yr $^{-1}$ (Figure 1b). Mountain ranges extending throughout New Zealand provide a barrier to the prevailing westerly winds, dividing the country into markedly different climatic regions. The west coast of the South Island is the wettest area of New Zealand, with a num ber of locations receiving over 5000 mm yr^{-1}, whereas the area to the east of the mountains, just over 100 km away, is the driest, with annual precipitation reaching minima of 500 mm yr^{-1}.

New Zealand's exotic plantation estate is distributed through out most of the country, with the largest areas in the central North Island. Substantial areas of plantation are also found in the far north and east coast of the North Island, the upper South Island and various locations along the east coast of the South Island, especially in the far south (Figure 1c).

Materials and methods

Climate change projections

Values of meteorological variables were estimated for the whole of New Zealand on a 0.05° latitude/longitude (≈5 × 5 km) grid, using a thin-plate smoothing spline to spatially interpolate daily observational data (Tait *et al*., 2006; Ministry for the Environment, 2008; Tait, 2008; Tait and Liley, 2009). Climate change projections used in this study were derived from the factorial combination of 12 Global Climate Models (GCMs) and the SRES emission scenarios, B1 (low), A1B (mid-range) and A2 (high), described by Meehl *et al*. (2007). The B1, A1B and A2 scenarios approximately correspond to the newer representative concentration pathways 4.5, 6.0 and 8.5 (Rogelj *et al*., 2012). The 12 GCMs used in this study had been selected because of their utility in modelling 1971 2000 climatic conditions (mean sea level pressure, temperature and precipitation) over New Zealand from the widely used NCEP reanalysis (Kalnay *et al*., 1996; Ministry for the Environment, 2008). They were as follows: CNRM, CCCma, CSIRO Mk3, GFDL CM 2.0, GFDL CM 2.1, MIROC32, ECHOG, ECHAM5, MRI, NCAR, UKMO-HadCM3 and UKMO-HadGEM1. Monthly temperature and rainfall scenarios from each GCM were statistically downscaled to a resolution of 0.05° for 1990 (henceforth 'baseline'), 2040 and 2090, using the methods of Mullan *et al*. (2002).

Modelling forest productivity

The process-based model CenW version 4.0 (Kirschbaum, 1999) was used to project productivity of *P. radiata* across New Zealand under current and future climates (Kirschbaum and Watt, 2011; Kirschbaum *et al*., 2012). CenW has been developed primarily for climate change investigations and incorporates the key processes and feedbacks between plants and their environment that can operate on timescales ranging from daily (for water relations) to decadal and longer (for soil organic matter feedbacks and wood growth). Kirschbaum and Watt (2011) demonstrated that CenW can successfully model stand productivity of *P. radiata* under current climatic conditions within New Zealand, providing confidence that the model incorporates the key processes underpinning productivity.

CenW was parameterized for current climatic conditions using growth data from permanent sample plots covering almost the complete environmental range across which *P. radiata* is grown in New Zealand. These data consisted of 101 sites with 1297 individual observations of height and/or basal area from which diameters and volumes were calculated. Using the parameter values determined by Kirschbaum and Watt (2011), there was excellent correspondence between model predictions and measurements of a range of tree dimensions.

Simulations were run under both current and future climatic conditions using projections from the 12 GCMs and the three emission scenarios described previously. Future climate scenario outputs were used in CenW with both constant and increasing CO_2 to isolate tree responses to changing climatic conditions and elevated CO_2. The results presented hereafter are the mean of the 12 GCMs unless otherwise stated.

Wind damage

The risk of wind damage was quantified using the approach described by Moore and Watt (2015). They investigated both the direct effects of increasing wind speeds and the indirect effects of changes in stand structure, which affects the underlying susceptibility to wind damage. These impacts were investigated using representative growth rates and climatic conditions for seven bio-geo-climatic zones for *P. radiata* in New Zealand (Goulding, 1994). Site productivity metrics for these zones were

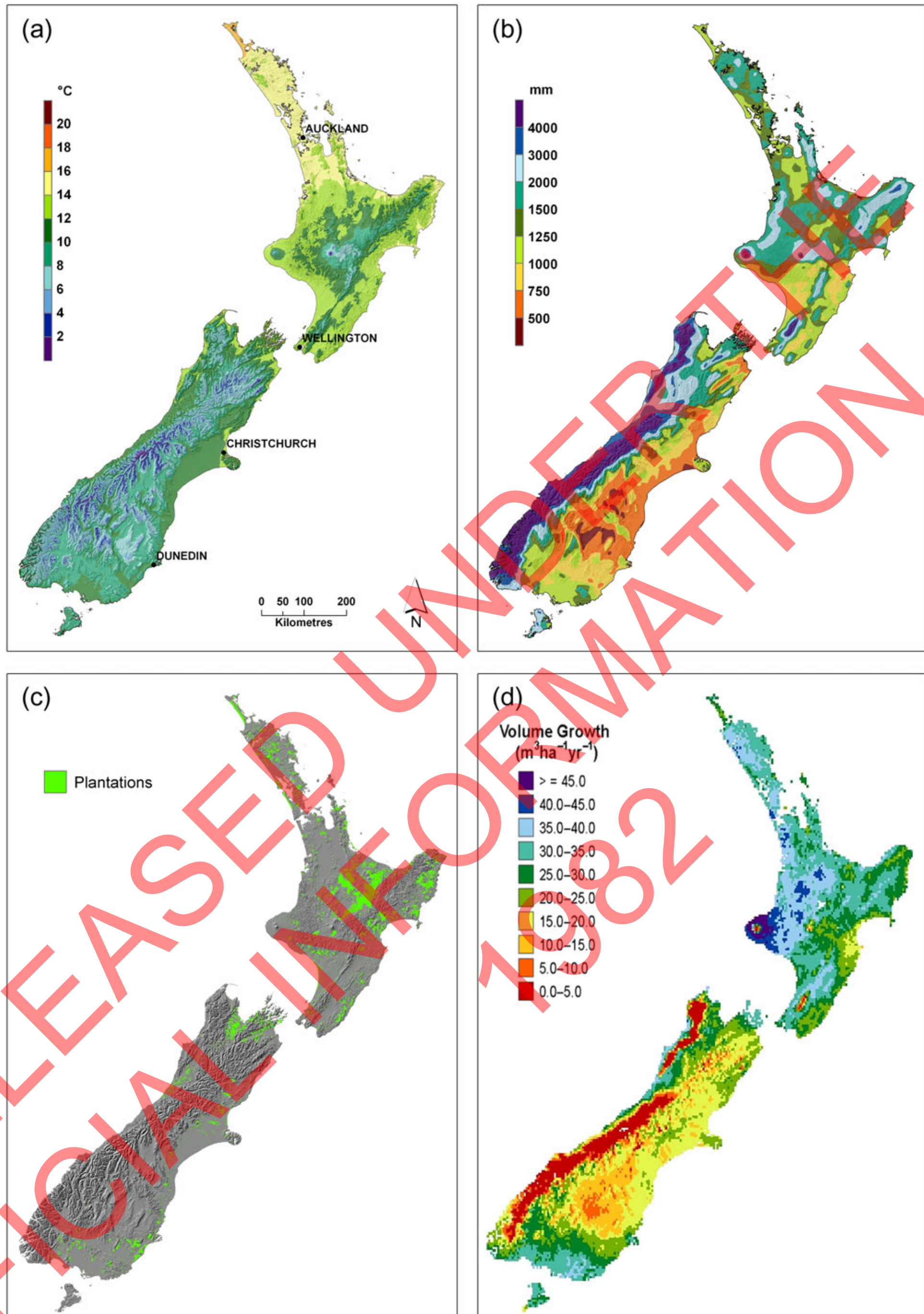

Figure 1 New Zealand maps of current (1980-1999) (a) mean annual temperature and (b) mean annual rainfall (after Wratt *et al.* (2006)), (c) the current location of plantation forests and (d) modelled wood productivity (as volume growth) of *P. radiata* under current climatic conditions (redrawn from Kirschbaum & Watt, 2011).

used to predict the stand structure (diameter, height, volume and spacing) for three contrasting silvicultural regimes (pruned, unpruned and carbon) under current and future climatic conditions. Stands grown under a carbon regime are planted at a very high stand density and left in perpetuity with the sole purpose of maximizing carbon sequestration. This information was then input into a mechanistic wind damage model, ForestGALES (Gardiner *et al.*, 2000), in order to predict the critical wind speed required to damage mean trees within a stand. The average annual probability that these critical wind speeds were exceeded was estimated from frequency distributions of extreme wind speeds calculated from time series of observations from long-term meteorological stations in each zone.

Although there is still considerable uncertainty around New Zealand's future extreme wind climate, an analysis carried out by Mullan *et al.* (2011)

has indicated that extreme wind speeds are only likely to increase by between 1 and 5 per cent under the A1B scenario, with no predictions of any changes available under other future scenarios. We accounted for these potential increases through increasing the mode of the extreme wind speed distribution by 5 per cent for all simulated time periods (Quine and Gardiner, 2002). All results are expressed at the age of 30 years as an annual exceedance probability (AEP) which is defined as the likelihood of a damaging wind event occurring in a given year, with values ranging from 0 to 1.

Fire risk

Fire danger ratings (using 1970 1999 as a baseline) were computed using temperature, humidity, wind speed and rainfall data from the A1B emissions scenario, previously described. These changes were applied to 20 weather station sites across New Zealand with at least 20 years of observations to calculate future daily Fire Weather Index (FWI) and fire danger class values (Anderson, 2005). Fire risk is classified as being Low, Moderate, High, Very High, or Extreme. The fire climate severity is quantified here as the frequency of days in each fire season that had Very High or Extreme (VH + E) fire danger. Further details of the methods used in this study are described by Pearce *et al.* (2011) and Simpson *et al.* (2014).

Projected changes in fire danger for the whole of New Zealand were produced by spatially interpolating the changes predicted at each of the 20 station locations using the co-kriging technique (Goovaerts, 1999). The co-kriging technique allowed inclusion of additional surface prediction variables for station location (latitude/longitude), elevation and information from additional stations in data sparse locations (Pearce *et al.*, 2011).

Disease damage

Damage from foliar pathogens is currently the most costly natural disturbance to New Zealand plantation forests (Watt *et al.*, 2008). *Dothistroma septosporum*, which causes dothistroma needle blight is currently the most damaging forest pathogen of *P. radiata* plantations. *Phytophthora pluvialis* (Reeser *et al.*, 2013), which is associated with red needle cast, was detected in 2008 and has the potential to cause significant damage within plantations (Scott and Williams, 2014). *Cyclaneusma minus* which results in cyclaneusma needle cast is also important but of lesser concern. Other pine pathogens currently within New Zealand may cause sporadic or localized damage but their national impact is not significant (Watt *et al.*, 2008).

The approach used to determine damage from *D. septosporum* and *C. minus* has been described in detail previously (Watt *et al.*, 2011a, b, 2012a, b) and is briefly summarized in the following. Disease incidence and severity data were collected from plantations throughout New Zealand over a 45-year period for dothistroma needle blight and over a 34-year period for cyclaneusma needle cast. Disease severity, S_{sev}, was determined at the stand level by multiplying the percentage of trees in the stand affected by mean severity (percentage of needles affected) on affected trees (scale 0 100). Growth reduction generally occurs when disease severity exceeds 20 per cent, whereas disease severity values of 2 10 per cent (Table 3) are not likely to significantly impair growth. However, stands and individual trees growing in disease-prone regions may have values at which significant growth loss occurs. Multiple regression models of S_{sev} were developed for both diseases from meteorological data, described above, using the methods described fully by Watt *et al.* (2011b, 2012b). Using these multiple regression models, spatial predictions of S_{sev} were made under current climate and to 2040 and 2090 using the climate change scenarios previously described.

Impacts

Climate change projections

Averaged across the 12 GCMs, mean air temperature in New Zealand was projected to increase between the three emission scenarios by 0.7–0.9°C by 2040 and by 1.3–2.6°C by 2090, although the inter model uncertainty outweighs the scenario uncertainty (Table 1). Projected multi model mean increases in rainfall for New Zealand under the three emission scenarios were between 0.9 per cent – 2.1 per cent by 2040 and 2.6 per cent –3.2 per cent by 2090, with significant inter model variation with even the sign of the change differing between GCMs implying con siderable uncertainty in regional and national precipitation projec tions (Table 1). However, a consistent pattern in these simulations was the absence of any extreme changes, with all model projec tions falling within the range between −5.6 and +12.9 per cent. Changes under the A1B scenario showed the largest increases in rainfall by 2090, with changes under the A2 scenario falling between those under the B1 and A1B scenarios.

The mean 2090 projections for the A2 scenario (Figure 2) illus trate the regional patterns of the expected changes in tempera ture and precipitation. Expected temperature changes broadly correlated with latitude, with expected warming ranging from 2.7°C in the north to 2.2°C in the far south. Variation in precipita tion also showed a latitudinal correlation, with rainfall increasing in the already wet south western and elevated areas, while rela tively drier areas along the east coast and in the north are pro jected to become drier (Figure 2b).

Table 1 Summary of the mean simulated changes in temperature, precipitation and CO_2. GCM minimum (min) and maximum (max) refer to the GCM with the lowest and highest spatially averaged changes. Variation of simulated changes between the GCMs is also expressed as a standard deviation (SD) which expresses the variation between the average NZ values between the 12 GCMs.

Year	Emission scenario	CO_2 (ppm)	Temperature change (°C)				Rainfall change (%)			
			Mean	GCM			Mean	GCM		
				Min	Max	SD		Min	Max	SD
2040	B1	457	0.7	0.4	1.2	0.3	1.6	2.1	5.6	2.3
	A1B	483	0.9	0.4	1.3	0.3	2.1	0.0	5.0	1.6
	A2	481	0.9	0.3	1.3	0.3	0.9	5.6	4.3	2.6
2090	B1	538	1.3	0.7	2.3	0.4	2.6	4.7	7.9	3.8
	A1B	674	2.1	1.2	3.4	0.6	3.2	1.5	12.9	3.9
	A2	754	2.6	1.6	3.6	0.5	3.0	3.8	11.5	5.6

Modelling forest productivity

Under baseline climatic conditions, there was wide regional vari ation in predicted stem volume growth (Figure 1d). Values were highest in the warm and moderately wet northern and western areas of the North Island, reaching maximum growth rates of >40 m^3 ha^{-1} yr^{-1} in the fertile Taranaki region. Productivity was considerably lower within the South Island, partly attributable to cooler temperatures that were generally sub optimal. Reduced productivity was also attributable to excessively high rainfall (>3000 mm yr^{-1}) on the west of the main axial mountain ranges and relatively low rainfall (<750 mm yr^{-1}) on the eastern side. In contrast, in the most southerly regions, where there is moderate

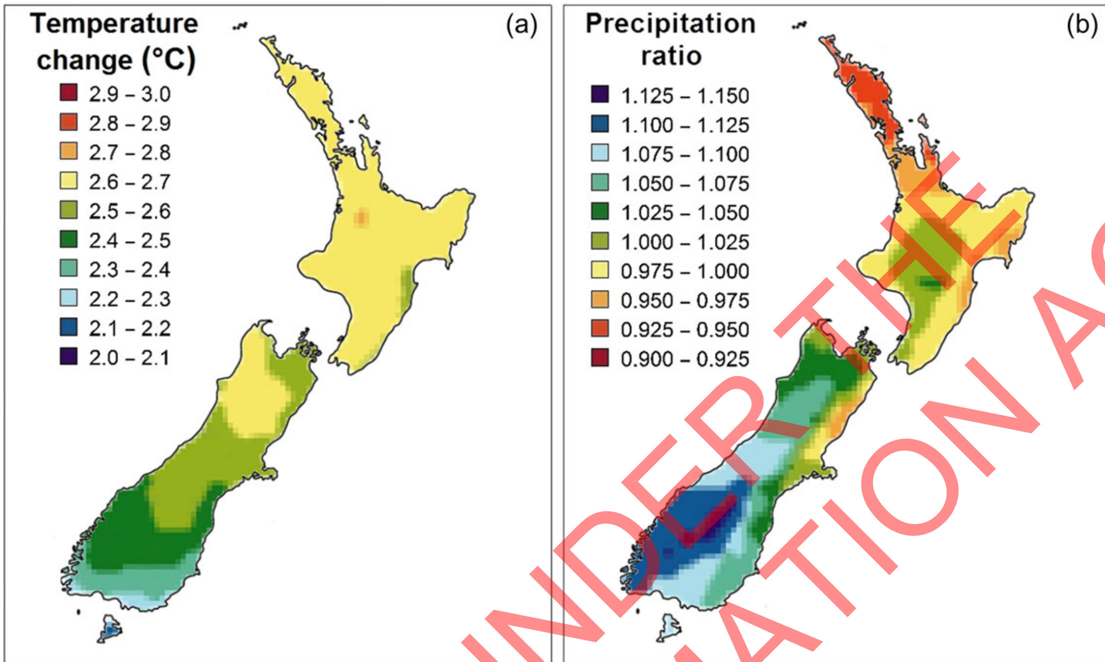

Figure 2 Projected changes in temperature (a) and precipitation (b) for 2090 from baseline under the A2 emission scenario.

rainfall (Figure 1b) and little seasonal water deficit, productivity was predicted to be higher than in regions with greater rainfall extremes (Figure 1d) but still considerably lower than in the North Island, owing to the much lower temperatures.

Neglecting future increases in CO_2 isolates the effect of expected climatic changes on future volume productivity. Projections to 2090 showed reduced productivity in northern and low elevation regions and increased productivity in southern and upland regions (Figure 3a–c), likely due to shifts in temperature towards the optimum range for *P. radiata*, which Kirschbaum and Watt (2011) found to be at a mean annual air temperature of 12–15°C. These changes in climatic conditions resulted in growth gains for about half of all plantations (Kirschbaum *et al.*, 2012), with mean changes in volume productivity within plantation forests averaging +3 per cent by 2090.

Simulations with increasing CO_2 led to productivity increases during 2090 for all regions and under all emission scenarios (Figure 3d–f). Increasing CO_2 completely reversed the losses in low lying and northerly regions that had been modelled due to climatic shifts. Productivity gains were predicted throughout New Zealand and reached increases exceeding 100 per cent within parts of the South Island (Figure 3d–f). Within the current plantation estate, simulations showed mean productivity increases to 2040 and 2090 of 19 per cent and 37 per cent, respectively (Kirschbaum *et al.*, 2012).

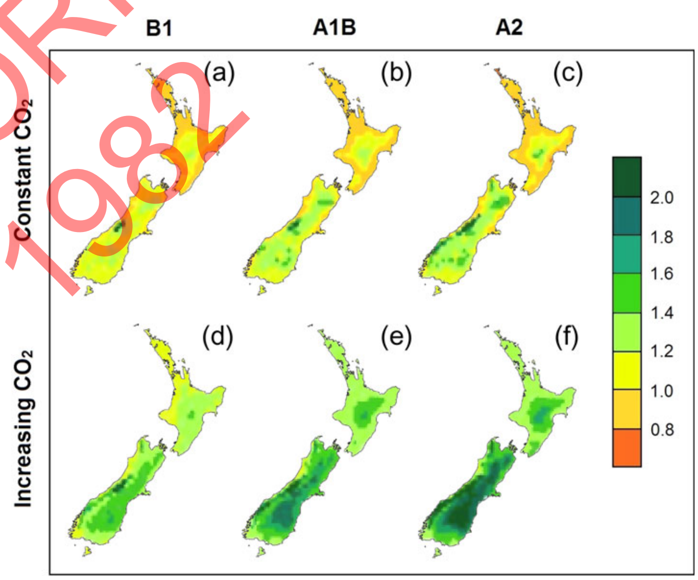

Figure 3 Mean volume productivity ratio in 2090 compared to current productivity with constant (top row) and increasing CO_2 (bottom row) under the B1 (a, d), A1B (b, e) and A2 (c, f) emission scenarios.

Abiotic impacts

Wind damage

The AEP, which is defined as the likelihood of a damaging wind event occurring in a given year, at the age of 30 years is given for each silvicultural regime and emission scenario in Table 2. For a 30 year old stand, i.e. at typical harvest age, the risk of wind damage was relatively low under the baseline climate. Under this baseline, AEP ranged from 0.094 for the unpruned regime to 0.166 for the carbon regime (Table 2). Projections to 2040 for the pruned regime show that AEP was less than 0.2 for all scenarios apart from the A2 emission scenario with CO_2 held constant at 1990 levels where the AEP was 0.286. Projections to

2090 showed that the AEP increased on average by 0.066, and for four of the six scenarios, the AEP was >0.2 (Table 2).

The risk of wind damage for the unpruned regime was very similar to the risk for pruned stands in both 1990 and 2040. However, for projections to 2090, the risk of wind damage for the unpruned regime was substantially higher than for the pruned regime due to the higher ratio of height to diameter for this regime. These increases were particularly marked for emission scenarios that assumed a full response to increasing CO_2 (Table 2). The risk of wind damage was markedly higher for the carbon regime than for the other two regimes due to the higher height to diameter ratio of trees. The carbon regime had very high sensitivity to increasing CO_2. For projections made to 2090, scenarios that assumed a full response to increasing CO_2 had an AEP that was on average 0.33 higher than those that assumed no response, and the AEP of these three scenarios ranged from 0.639 for the B1 to 0.922 for the A2 emission scenario (Table 2). Stands grown on a carbon regime tended to be overstocked, particularly in the latter part of the rotation and the increased risk of wind damage in such situations is consistent with experiences in other regions of the world (Mitchell, 2000; Cameron, 2002).

The relative contributions of different factors on AEP at 2040 and 2090 were determined using previously described methods (Hawkins and Sutton, 2009, 2011; Melia *et al*., 2015). Figure 4 shows that currently, most of the variation in AEP is attributable to location, with stand age and silvicultural regime also being important. Under future climates, mean values of AEP for a 30 year old stand ranged from 0.18 to 0.79 across locations (data not shown). Stand age accounted for 27 per cent of the variance in AEP under future climates (Figure 4). The change in mean AEP for increasing stand age from 20 to 30 years ranged from 0.09 to 0.33 in 2040 and from 0.12 to 0.49 in 2090.

Silvicultural regime was relatively important (Figure 4) under future climates, accounting for 19 per cent of the variance in AEP (Figure 4). Mean AEP ranged from 0.21 under the pruned regime to 0.24 under the unpruned regime and 0.50 under the carbon regime (Table 2). The growth response to increasing CO_2 had relatively little impact on AEP in 2040 but a greater impact in 2090 at which time it was equal in importance to the silvicultural regime. Relative to other factors, both emissions uncertainty and increasing wind speed had very little effect on AEP, and together, they accounted for less than 4 per cent of the total variance during both 2040 and 2090 (Figure 4).

Table 2 AEP of wind damage in 30-year-old stands as a function of simulation year, emission scenario and CO_2 concentration for three silvicultural regimes. Values shown represent the means across seven bio-geo-climatic zones defined by their current wind climate. Values of AEP are differentiated by colour into the categories of AEP < 0.20 (green), 0.2–0.5 (orange) and >0.5 (red).

Year	Emission scenario	Inc. CO_2	Silvicultural regime		
			Pruned	Unpruned	Carbon
1990			0.110	0.094	0.166
2040	B1	N	0.152	0.141	0.262
2040	A1B	N	0.164	0.155	0.291
2040	A2	N	0.286	0.154	0.286
2040	B1	Y	0.150	0.172	0.419
2040	A1B	Y	0.164	0.201	0.507
2040	A2	Y	0.164	0.197	0.495
2090	B1	N	0.186	0.182	0.344
2090	A1B	N	0.238	0.242	0.443
2090	A2	N	0.272	0.278	0.483
2090	B1	Y	0.191	0.256	0.639
2090	A1B	Y	0.267	0.423	0.850
2090	A2	Y	0.321	0.522	0.922

Fire risk

Under the baseline climate, dryland areas on the east coast had the highest average number of VH + E fire danger days per year, while many areas on the west coast had a very few, or no VH + E days. There was widespread spatial variation in the degree of change in frequency of VH + E days between baseline and future climate (Figure 5). The regions with the most notable VH + E increases were located on the eastern coast in the southern half of both islands.

Examination of the fire risk by location demonstrates the high variation between sites with the frequency of VH + E fire risk under the baseline climate ranging from 0 to 40 days (Figure 6). When averaged over all sites, the number of days with VH + E fire risk was projected to increase by 71 per cent by 2040, and by a further 12 per cent by 2090. All sites on the east coast showed increases under climate change. The locations with highest current fire risk, Christchurch and Gisborne, had significant further increases in VH + E fire risk by 2090 to 44 and 48 days, respectively. However, the most marked relative changes occurred in Wellington (lower North Island) and Dunedin (south eastern South Island) where VH + E fire risk increased to 2090 by, respectively, 89 per cent to 32 days and 207 per cent to 18 days (Figure. 6).

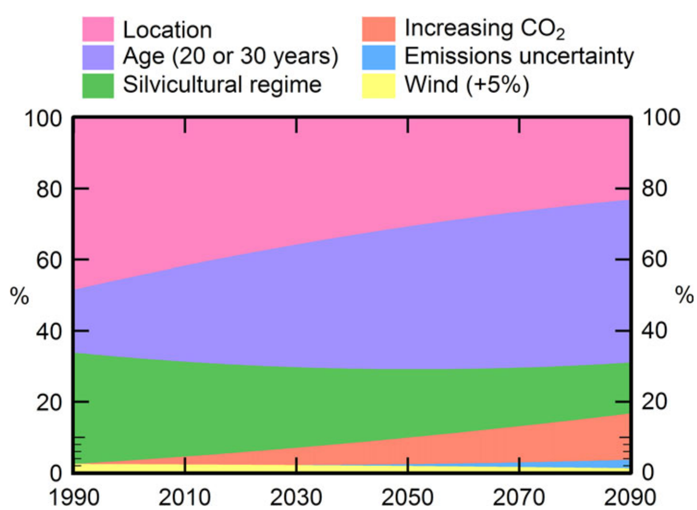

Figure 4 Relative contribution of location, stand age, silvicultural regime, increasing CO_2, emissions scenario and wind speed to AEP. Values of relative importance used in the figure were extracted from Table 2 and relative importance was interpolated between years using second-degree polynomials.

Biotic impacts

Distribution of pests

One of the most important changes likely to result from climate change is a shift in suitable habitats for certain pests, which is mainly linked to changing temperatures. Temperature influences thresholds for pest growth and survival through events such as frost frequency and the requirement for reproduction as determined through accumulation of thermal units. A benchmark for the effects of temperature on changes in distribution is provided by the relationship of temperature with elevation and latitude (Linacre, 1992). Average warming over the past century has been about 0.85°C (IPCC, 2013), with 2015 having been the first year with temperatures more than 1°C above pre industrial temperatures (Hawkins *et al.*, 2017). Global meta analyses have documented significant range boundary changes for 279 species, which, on average, have shifted poleward by 40 km over an average timespan of 66 years (Parmesan and Yohe, 2003).

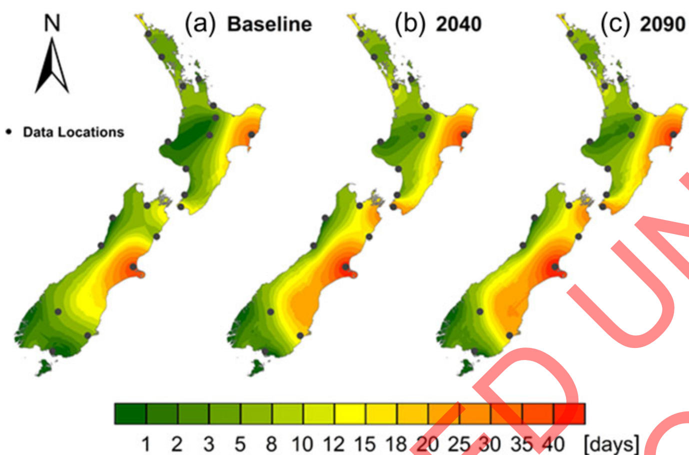

Figure 5 Multi-model-mean projections of annual frequency of Very High and Extreme (VH + E) forest fire danger over fire season months (Oct Apr). Note the non-linear colour scale. The locations used to construct this figure are shown as black dots, and actual fire risks for these locations is given in Figure 6.

Geographic source of future pests

The main pathways for the arrival of pests and pathogens are associated with international trade. This section reviews recent changes in trade patterns and considers future trends based on trade agreements and expert opinion. New Zealand specific import data were obtained from Statistics New Zealand (2017) and for data going back to 1988, from Statistics NZ Infoshare (2017).

Since the 1980s, imports have increased from the established trading countries of Australia, Europe, US and Japan. However, the most significant change has been the dramatic rise of China as the dominant importer to New Zealand (Figure 7). In 1988, only 1 per cent of New Zealand's imports originated from China, but in 2016 these imports represented more than 16 per cent.

Changes in the origins of imported goods and passengers are expected to result in changes in the profile of pest threats. In fact, this has already been observed in several regions. For example, in North America and Europe there has been an increase in insect pest and pathogen incursions originating from north east Asia (Brockerhoff and Liebhold, 2017). Historically, the majority of forest insects invading North America originated from Europe but in the last two decades, north east Asian species, including some high impact invaders, such as the Asian Longhorned beetle (detected in 1998) and Emerald Ash Borer (detected in 2002), have become more prominent (Aukema *et al.*, 2010).

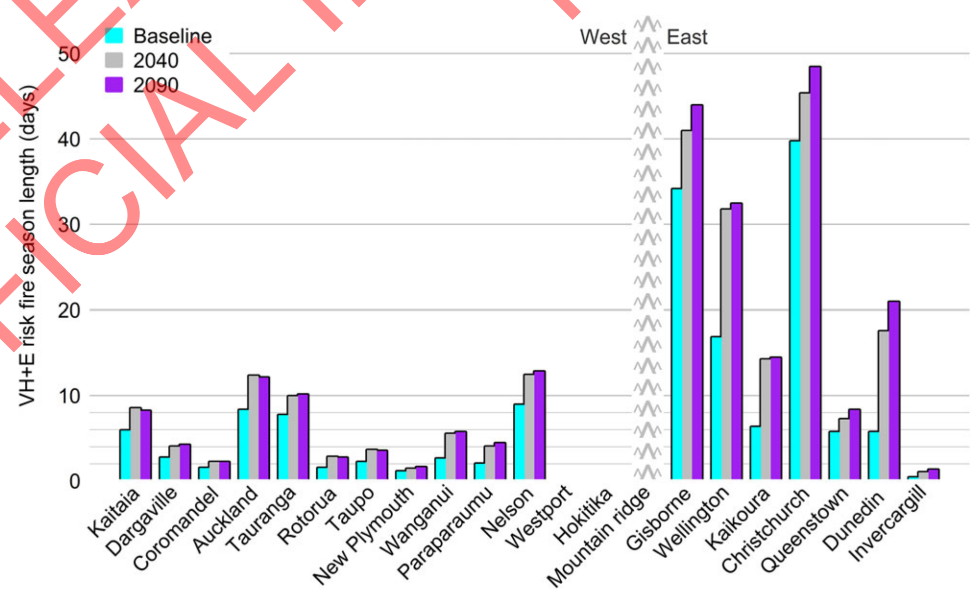

Figure 6 Projected average number of days of the fire season with Very High and Extreme (VH + E) forest fire danger under current conditions and in 2040 and 2090, at individual station locations and averaged for New Zealand across the 12 GCMs. Locations were grouped with respect to New Zealand's main mountain ranges, then ordered by latitude (northern-most left).

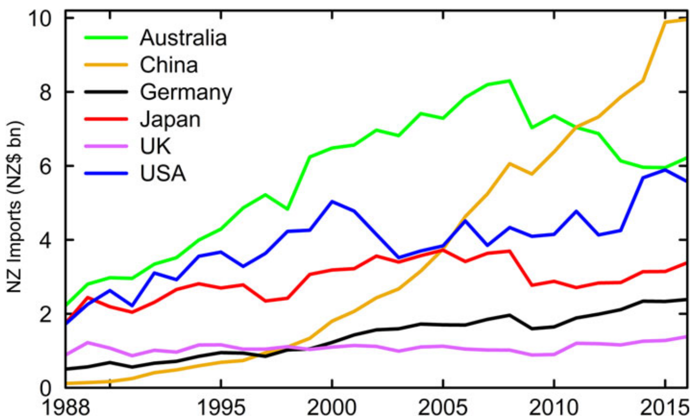

Figure 7 Imports from New Zealand's main trading partners, 1988-2016 (Statistics New Zealand, 2017).

Based on import trends and bilateral/multilateral trade agreements, one can assume that New Zealand's imports from east Asia will continue to increase. New Zealand's traditional trading partners in Europe and North America are likely to remain important sources of imports, even though their relative share may decrease, and Australia is likely to remain a key source of imports owing to its physical proximity. While trade may arguably present the greatest risk of introducing unwanted pests and diseases, the increasing number of international passenger arrivals to New Zealand presents another important pathway for possible pest incursion.

The volume of imports and the number of international visitors may be primary drivers of pest propagule pressure, but several other factors will also affect future biosecurity risks. For example, rapidly growing trade with new trading partners may have a disproportionate effect on biosecurity risks because they may host pests that have not previously had access to New Zealand. Many of the potentially most invasive species from New Zealand's long standing trading partners have either established themselves in New Zealand already or have been excluded by effective border biosecurity measures targeted at specific species or to mitigate specific entry pathways. Such measures include, for example, requirements for pest monitoring, control and treatment by overseas growers and exporters, border inspection and additional treatment requirements for imports, and post border pest surveillance and incursion response capability (Gordh and McKirdy, 2013). Pest specific measures are not necessarily in place for pests from newer non traditional trading partners, although many pests may be excluded by generic measures to prevent pest entry. The greatest threat may be from new 'hitchhiker' species (i.e. species that are transported inadvertently on inanimate objects such as sea containers or vehicles) that are difficult to manage because they are not necessarily associated with particular pathways in a predictable way (Toy and Newfield, 2010).

Climatic similarities between New Zealand and the potential incursion species' native habitat will also be important for the ability of pests and plant weeds to establish and develop pest potential in New Zealand. In this respect the southeast Asian countries will probably pose smaller risks due to their fundamentally different climatic zones. However, pests from temperate and some subtropical regions are of greater concern.

Table 3 Variation in mean predicted stand severity, S_{sev}, of cyclaneusma needle cast and dothistroma needle blight for New Zealand under current climate and the B1, A1B and A2 emission scenarios, projected for 2040 and 2090 within the North (NI) and South (SI) Islands.

Year	Emission scenario	Cyclaneusma		Dothistroma	
		NI	SI	NI	SI
Baseline		6.40	2.17	10.9	4.26
2040	B1	6.18	3.56	10.0	5.04
	A1B	6.16	3.96	9.52	5.44
	A2	6.17	3.85	9.54	5.47
2090	B1	6.03	4.76	8.69	6.13
	A1B	5.62	5.76	7.51	6.83
	A2	5.25	6.17	5.82	7.89

Climate matching of current and future climates suggests that parts of north east Asia, southern South America, western Europe, and southern Africa, as well as cooler (e.g. montane) regions in subtropical countries may represent sources of species of growing biosecurity concern (Ridley *et al.*, 2000; Peacock and Worner, 2006; Bertheau *et al.*, 2010; Kriticos, 2012).

Damage from tree pathogens

Within the major plantation areas in the North Island, simulations showed that the severity of dothistroma needle blight and cyclaneusma needle cast are likely to decline throughout the 21st century under all emission scenarios; however, increases in disease severity were predicted for large areas of the South Island (Table 3). With the exception of the west coast of the South Island, the actual predicted severity remains relatively low compared to the damaging levels currently found within the North Island. Although high disease severity is predicted within the west coast of the South Island under both projection periods (2040 and 2090), it causes little concern in the national context because this area currently constitutes only 1.8 per cent of the total New Zealand plantation area (Watt *et al.*, 2011a, 2012a).

There are also a number of other pathogens that could cause considerable damage to plantation forests should they establish within New Zealand. Pitch canker is a devastating disease of *Pinus* spp., and *P. radiata* is known to be highly susceptible to the disease (Ganley *et al.*, 2011). Projections using process based distribution models show that the potential New Zealand distribution of this disease could expand from coastal areas of the North Island under baseline climate to almost all of the North Island and eastern parts of the South Island by 2080 (Figure 8) (Ganley *et al.*, 2011).

Red needle cast caused by *Phytophthora pluvialis* causes periodic episodes of defoliation in New Zealand's *P. radiata* plantations, particularly in locations exposed to frequent wet days and fog over the cooler months. *Phytophthora pinifolia* causes similar problems in Chile (Durán *et al.*, 2008) and could be problematic in New Zealand if it were introduced. Perhaps a greater threat is posed by pathogens that are new to science (e.g. *P. pluvialis* was

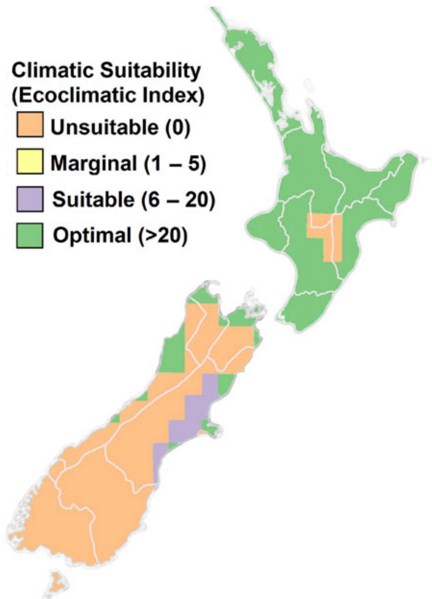

Figure 8 Pitch canker Ecoclimatic Index for 2080 derived from NCAR-CCSM for the A1B emissions scenario. Based on Ganley *et al.*, 2011. The squares evident in the figure reflect the resolution of the underlying climate change scenario.

unknown when the pathogen was first isolated from diseased *P. radiata* foliage in 2008), or by those that behave in unexpected ways in a new environment. For instance, *Neonectria fuckeliana* (C. Booth) Castl. & Rossman was well known in the Northern Hemisphere as a wound invading fungus that was found only on spruce (*Picea* spp.) and fir (*Abies* spp.) and caused little or no damage. When it first established in the Southern Hemisphere on *P. radiata*, it caused severe damage to some plantations in the lower half of the South Island (Crane *et al.*, 2009) until a successful control strategy was developed.

Damage from tree feeding insects

Although climate change effects on tree feeding insects are relatively well known in several countries, and have been the subject of a considerable research effort, little research on this topic has been carried out in New Zealand. However, several general reviews specific to New Zealand exist, and one specific study on effects by a potentially invasive defoliator was undertaken.

Climate change can affect problems related to insect pests through several mechanisms including (i) changing the severity of damage by native or non native insects due to changes in climatic suitability for the pest or the host tree (Battisti *et al.*, 2005; Marini *et al.*, 2012), (ii) changing the likelihood of establishment of invasive species that are not yet present in New Zealand (Sutherst *et al.*, 2007; Kriticos *et al.*, 2013), and (iii) as an indirect consequence through interactions with other disturbance factors, such as increases in fire hazards due to tree mortality or pest susceptibility of stands through increasing wind damage (Stinson *et al.*, 2011; Hickey *et al.*, 2012; Jenkins *et al.*, 2012).

Currently, only a few insect pests affect *P. radiata* plantations in New Zealand. As there are no native *Pinaceae* in New Zealand, most insects feeding on these trees are non native species that were introduced accidentally, but see Berndt *et al.* (2004) for a description of a native defoliator that has adapted to feeding on pines. Fortunately, most of these species cause little or no damage at present. An exception is the woodwasp *Sirex noctilio* that was a concern in the past, but is now largely controlled through the introduction of biological control agents and changes in forest management that reduce stand susceptibility to *S. noctilio* (Bain *et al.*, 2012). However, the pest status of some of these species could change as a result of climate change, and in other countries, there are many pests of conifers that could represent serious threats to plantation forests in New Zealand if they should ever become established in the country (Brockerhoff and Bulman, 2014). These threats could potentially become even more severe in the future.

There are hundreds of damaging pests associated with conifers that are not yet present in New Zealand (Brockerhoff and Bulman, 2014). For example, the Eurasian nun moth, *Lymantria monacha*, and the European pine processionary moth, *Thaumetopoea pityocampa*, would probably cause considerable defoliation if they became established in New Zealand (Withers and Keena, 2001; Kriticos *et al.*, 2013). A climate matching study has indicated that there are also a number of North American bark beetles that attack pines and could present threats to New Zealand's plantation forests. They include *Dendroctonus valens* and *Ips calligraphus* (Lantschner *et al.*, 2017).

Most of the regions in New Zealand where conifer plantation forests occur are expected to be climatically suitable for the pine processionary moth, and estimates of its impacts on pine productivity suggest that significant growth losses would occur if it were introduced (Kriticos *et al.*, 2013). In Europe, the main limiting factor for most insect pests is cold stress (Robinet *et al.*, 2007; Kriticos *et al.*, 2013). Hence, for many species, climate change is expected to increase the area with suitable climate (Robinet *et al.*, 2007). The situation in New Zealand is likely to be similar. This effect of climate change on climatic suitability is likely to have more far reaching implications for species from warmer (e.g. subtropical) regions which currently are unlikely to become established in New Zealand given its mainly temperate climate. Several studies have suggested that climate change will increase the risk of establishment of species from warm temperate or subtropical regions (Peacock and Worner, 2006; Kriticos, 2012).

Climate change may also affect the severity of damage from existing insect pests because warmer temperatures can be expected to accelerate insect development and therefore lead to an increase in population levels, especially in species that can complete more than one generation per year. An example of such a species is the Monterey pine aphid, *Essigella californica* (Watson *et al.*, 2008). Although this aphid is presently not considered damaging in New Zealand, in parts of Australia with a warmer climate (i.e. warmer than New Zealand's current climate), *E. californica* can cause considerable defoliation of pines (May and Carlyle, 2003).

In other parts of the world, warming has been shown to increase population levels and damage by the mountain pine beetle and other bark beetles (Hicke *et al.*, 2006; Marini *et al.*, 2012; Bentz and Jönsson, 2015; Bentz *et al.*, 2016). Warming can thus lead to an expansion of areas affected by tree feeding insects (Battisti *et al.*, 2005; Marini *et al.*, 2012). The unprecedented spread of the mountain pine beetle into the boreal forest east of the Rocky Mountains, as a result of climate change, is of particular concern because it could cause substantial mortality of jack pine, *Pinus banksiana* Lamb., and other eastern pines (Cullingham *et al.*, 2011). Furthermore, warmer temperatures, especially if associated with greater frequency of drought conditions, can increase the susceptibility of trees to attack and damage from bark beetles or wood borers such as *S. noctilio* (Carnegie and Bashford, 2012). Both warming and increasing drought incidence can lead to an expansion of areas affected by tree feeding insects (Battisti *et al.*, 2005; Marini *et al.*, 2012). Although no identified insect pest in plantation forests in New Zealand has yet been observed to have increased in its severity through climate change, this is likely to occur in the future.

Competition with weeds

The future prevalence of weed problems is likely to be related to (i) the future distribution, growth and competitive strength of the currently problematic weeds, and (ii) the potential of weeds that are either already present in New Zealand, but not yet widely distributed, or that could enter the country to become problem weeds, especially under changed climatic conditions.

The weed species that compete most strongly with *P. radiata* within New Zealand are tall woody weeds. Within this group, gorse (*Ulex europaeus*), Scotch broom (*Cytisus scoparius*), bracken (*Pteridium esculentum*), blackberry (*Rubus fruticosus*) and wilding conifers (e.g. *Pinus contorta* and *Pseudotsuga menziesii*) are the most competitive and invasive (Watt *et al.*, 2008). In addition, buddleja (*Buddleja davidii*), *Acacia* spp. and pampas (*Cortaderia* spp.) are problematic weeds in some specific regions. Tall shrubby species reduce plantation growth more than short species such as grasses and herbaceous species, as they compete more vigorously for both water and light and are not as effectively shaded out as trees grow taller (Richardson *et al.*, 1999; Watt, 2003).

Little research has investigated the future distribution of the most problematic weed species in New Zealand under climate change. Potter *et al.* (2009) found that changes in climate will have little effect on the potential distribution of broom, with all regions remaining suitable for the species. In contrast, it is expected that under future climate change, buddleja may expand its range within the southeast of New Zealand (Watt *et al.*, 2010; Kriticos *et al.*, 2011).

Expansion of 'sleeper weeds' is likely to pose a future threat to plantation forests. Sleeper weeds are weeds that are present in New Zealand, but whose distribution or vigour is limited under current climatic conditions. For instance, the exotic tree *Melaleuca quinquenervia*, which is currently established in Auckland and Northland, could become quite invasive if the species' thermal requirement for reproduction within northern areas of New Zealand is surpassed in the future (Watt *et al.*, 2009). Range expansion of this species could have significant consequences as *M. quinquenervia* has been found to be extremely difficult to control in exotic locations, such as Florida (Austin, 1978; Woodall, 1983).

Kudzu (*Pueraria montana*) is a perennial, semi woody, climbing leguminous vine, which is extremely invasive and damaging in the south eastern US. It has recently been found in northern New Zealand. Although we do not currently have an estimate of the potential distribution of this species, the distribution where it is invasive in the US is quite similar to that of *M. quinquenervia*. During the 1990s, kudzu has migrated northwards in the continental US from its original distribution, a shift which is in line with previous model predictions (Sasek and Strain, 1990). This change demonstrates the responsiveness of the weed to climatic conditions and highlights that the potential for range expansion under climate change should not be underestimated.

There is a risk that currently established exotic woody tree species native to Australia may become more dominant competitors in New Zealand under a warmer climate. *Acacia* spp. have very high growth rates and can rapidly occupy disturbed sites, vigorously competing with planted *P. radiata* seedlings (Turvey *et al.*, 1983). As tree species, they can compete further into the rotation than even tall weed species (Hunt *et al.*, 2006), which are predominantly shrubs. Some species have the ability to resprout after their stems have been severed which makes them hard to control. Seed germination is also often stimulated by fire. The likely increases in fire frequency and severity will make sites more predisposed to invasion by these species. Some *Acacia* species are already a localized problem in northern and eastern parts of the country (Watt *et al.*, 2008).

Climate change is also likely to affect growth rates of weeds through changes in CO_2, root zone water storage, temperature and changing length of the growing season. If relative growth of both plantation trees and weeds increases at the same rate then competition levels may not significantly change. However, in agricultural settings there is evidence that weeds exhibit a stronger positive response to CO_2 than crop plants which is likely to lead to reductions in crop yields (Ziska *et al.*, 2011; Ziska, 2011). The basis for this increased competitive behaviour of weeds is unclear but may be related to the vigorous and generally indeterminate growth habit of weeds and greater genetic and phenotypic plasticity associated with wild species (Ziska and McConnell, 2015). The growth response of different weeds to climate change has been shown to vary widely (Sheppard and Stanley, 2014). As a consequence, increases in CO_2 have been shown to preferentially select for more responsive invasive species within plant communities (Ziska and McConnell, 2015).

Discussion

Climate change impact assessments of forest systems are often dominated by a focus on biophysical factors, which generally show positive effects of climate change on forest productivity (Reyer, 2015). This is largely due to the growth response to elevated CO_2 (Hickler *et al.*, 2015; Reyer, 2015), and even temperature increases by a few degrees, or precipitation changes by a few per cent, especially when coupled with increasing CO_2 concentrations, may not be of great detriment to the physiological growth potential of many forest stands (e.g. Kirschbaum *et al.*, 2012).

Other factors impinging on the fate of forest stands, on the other hand, can be much more negative. This has been experienced most clearly by the expansion of the mountain pine beetle in North America (Hicke *et al.*, 2006; Marini *et al.*, 2012) that has the potential to lead to the death of susceptible stands that had previously been protected by mortality of the insect pests during severe winters (Cullingham *et al.*, 2011). Because of the tight linkage between temperature and distribution of the pest species, its range expansion under future warming can be antici pated with very high probability. This pattern is expected to pre dominate for many pest species (e.g. Logan *et al.*, 2003).

Similarly, wildfire risk is strongly linked to climatic factors such as temperature, humidity and wind speed which, together with stand attributes like fuel load and fuel moisture contents, largely control fire risks in forest systems. These factors are gen erally expected to change towards increasing fire risk in the future (e.g. Flannigan *et al.*, 2009; Pechony and Shindell, 2010). Forest stands are also at risk from wind damage, although cli mate change risks for wind are more nuanced and depend on changes in climatic factors as much as changes in stand proper ties (Moore and Watt, 2015).

For a balanced assessment of the combined climate change effects of all agents of change, it is therefore necessary to con sider all of the key aspects of change in an integrated assess ment. This requires collaboration between different science disciplines and the bringing together of different approaches and numeric evaluations. The present work took a first step in such an assessment by cataloguing the various changes that our forests might be subject to in the future. A further stage of development in an integrated assessment would see the differ ent processes combined in unified ecosystem models that can also quantitatively integrate these processes. Although linkages were included between predictions of productivity and wind damage, most effects that were assessed in this study were not linked in a dynamic way which is a limitation of our approach. For instance, by direct inclusion of pest and disease damage in a comprehensive model, the plant physiological status could be directly linked to plant susceptibility to certain diseases. Conversely, any pest or disease damage could directly affect plant growth, with consequences for future photosynthetic car bon gain or, vulnerability to wind or fire damage. However, this would require significantly greater system complexity and math ematical integration of very different model components. Such integration will ultimately be needed for a true assessment of climate change impacts and avoidance of any bias in climate impact assessments brought about by omission of any import ant aspects of system processes and interactions.

Sensitivities and areas for future research

This review identified the growth response to increasing CO_2 as a key sensitivity of the overall response of forest systems to future climate change, but there is still considerable uncertainty of the magnitude of this response. Some workers have focused on photosynthetic processes and expect large increases in CO_2 responsiveness, especially under water limited conditions (e.g. Lloyd and Farquhar, 1996; Franks *et al.*, 2013). Others have argued that stimulation of photosynthesis is inconsequential under many natural conditions and can be overridden by other growth limiting factors (e.g. Körner *et al.*, 2007; Fatichi *et al.*, 2014). Others have presented a more diverse picture, suggesting that CO_2 stimulated carbohydrate supply may stimulate growth under some conditions, especially under low light or water stress, but may have little effect on productivity in other circumstances, such as under severely nutrient limited condi tions (e.g. Ceulemans and Mousseau, 1994; Kirschbaum, 2011). Empirical evidence in support of these various positions is mixed (e.g.Norby *et al.*, 1999; Nowak *et al.*, 2004; Donohue *et al.*, 2013; Kirschbaum and Lambie, 2015), but a recent reanalysis of the results of past short term CO_2 growth experiments suggested that future growth enhancement may lie about half way between the values calculated with constant and increasing CO_2, respectively (Kirschbaum and Lambie, 2015). Clearly, more research is still needed to refine the likely growth response to increasing CO_2 of plantations in New Zealand and elsewhere. That single factor constitutes the largest single uncertainty in current modelling of plant responses to future conditions and makes it still difficult to confidently forecast changes to prod uctivity and risk of wind damage.

Current projections show that the risks to plantations from the two most damaging diseases in New Zealand are unlikely to change markedly. Nonetheless, further research should be undertaken to examine the potential impact of the damaging disease red needle cast (*P. pluvialis*) under current and future cli mates. Currently, there is also no significant damage to planta tions from insect pests. However, it would be useful to determine how climate change affects the climatic suitability of plantation forest regions for a range of high risk species such as bark beetles and defoliators. The impact of weeds on planta tions in the future is likely to depend on the degree to which current 'sleeper' weeds and naturalised aggressive woody tree species (e.g. *Acacia* spp.) can expand their range and increase in vigour. The future potential distributions of these key weed spe cies should be determined using process based weed distribu tion models. Further research is also required to determine how important weed species will respond to climate change and how effectively they will compete with plantations in the future. Given the potentially damaging role wind and fire are projected to have on future plantations, it would also be useful to refine our spatial understanding of the impacts of these factors.

Conclusion

Overall, our analyses showed productivity gains for *P. radiata* from the direct effects of climate change that ranged from rela tively minor to substantial depending on the response to increasing CO_2. These simulations suggest that the direct effects of climate change are likely to favourably affect forest product ivity even if the potential CO_2 response is only partly realized. Although fire risk is projected to increase in the future, most damage is likely to ensue from the greater vulnerability of plan tations to wind damage, that results from increased height growth.

Changes in trade and increased global travel are likely to influence the origin of future incursions of invasive pests, with invasions from regions in eastern Asia likely to constitute a growing risk. Currently, the most significant biotic disturbances of New Zealand plantations come from two needle cast dis eases, for which climate projections show very little change in damage over the course of this century. Although New Zealand does not currently have any damaging forest insect species, population levels and resulting damage are likely to increase in the future as warmer temperatures accelerate insect development and increase the susceptibility of host plants to attack. Competition within plantations from aggressive woody tree species, and in particular those originating from Australia is likely to increase as a result of climate change.

The effects of climate change present global plantation forests with many challenges but also new opportunities. This study quantifies the increases in productivity expected due to climate change. Changes in wind conditions will have implications for silvicultural practices, particularly for stands grown to maximize carbon, while there will be significantly increased wildfire risk to plantation forests. The future impact from biotic factors are complex and often species dependent, but this study highlights the major threat species and notes the highest risk source locations. The results from this ambitious synthesis of climate change threats should provide decision makers the foresight to mitigate against avoidable threats, adapt to committed future changes and capitalize on future opportunities.

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Conflict of interest statement

None declared.

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From: Media
To: s 9(2)(a)
Subject: Gore fire danger
Date: Wednesday, 13 January 2021 11:34:00 am

Kia ora s 9(2)(a),

Thanks for your questions yesterday.

The following can be attributed to Drew Bingham, the lead scientist for the *Our atmosphere and climate 2020* report:

- The sites discussed in OAC2020 were not ranked in order of rate of change in days with very high or extreme fire danger.

- The fire danger at the Gore site has remained low, though it is one of six sites identified as having a very likely increasing trend. Of those six, further analysis shows Gore had the lowest increase in the number of days per year with very high or extreme fire danger. The data shows this increase was very likely between 0 and 1.7 days per decade from 1997 to 2019.

- Gore and Invercargill had three or less days per year on average with very high or extreme fire danger between 1997-2019. In comparison, sites like Tara Hills, Lake Tekapo, and Blenheim had an annual average of more than a month's worth of days with very high or extreme fire danger

For further background:

- *Our atmosphere and climate 2020* (Figure 22 includes a map on the annual average number of very high and extreme fire risk days, 1999–2019): https://www.mfe.govt.nz/publications/environmental-reporting/chapter-3-changes-in-our-climate-and-environment-observed

Cheers,
Marcus

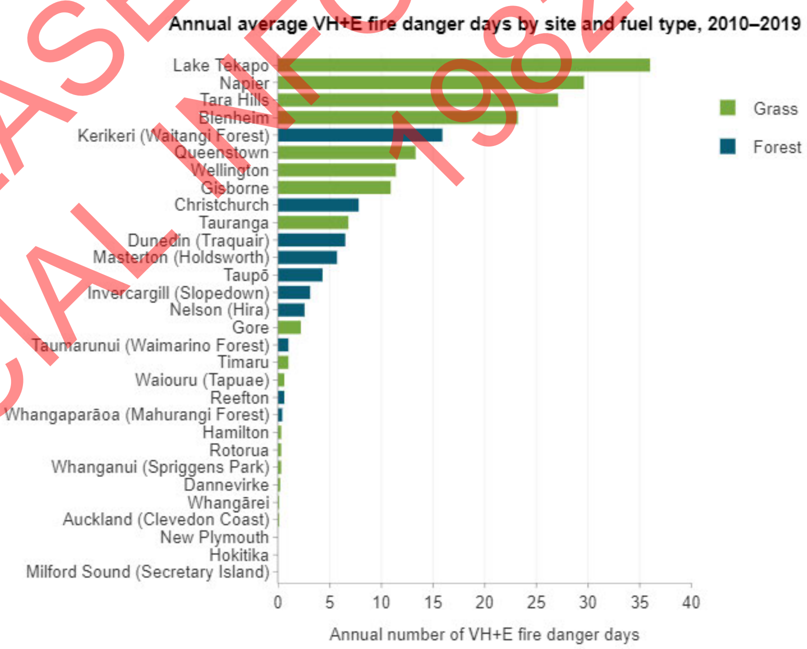
From: s 9(2)(a)
Sent: Thursday, 11 March 2021 3:02 pm
To: Drew Bingham <Drew.Bingham@mfe.govt.nz>; s 9(2)(a)
s 9(2)(a)
Cc: s 9(2)(a) Nancy Golubiewski <Nancy.Golubiewski@mfe.govt.nz>
Subject: RE: Recent NIWA-led research on wildfire risk

Kia ora Drew, s 9(2)(a)

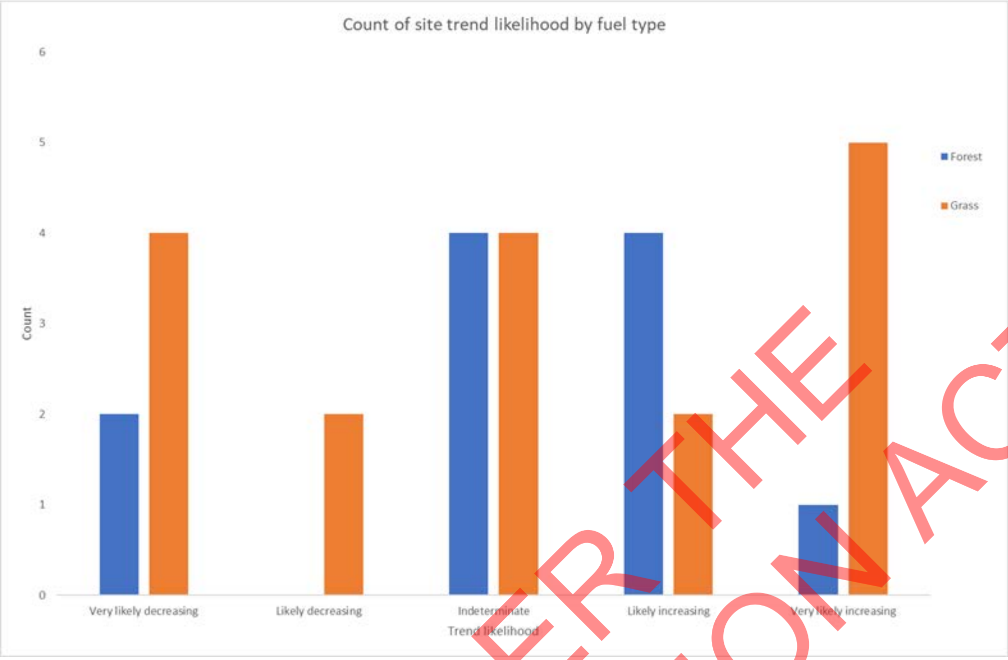
s 9(2)(a) and I have discussed the edits to the wildfire risk webpage suggested in s 9(2)(a) email (1 December 2020) below. We also note Drew has already corrected the citation in the *Atmosphere and Climate 2020* report.

- From s 9(2)(a) email: Request StatsNZ to edit their wildfire risk webpage section *Where this data comes from* to state "NIWA and FENZ Fire Weather System".
    - We haven't made the suggested change. We use the 'Where this data comes from' section to name the data provider ie., the organisation(s) the data comes from. Currently, the page states that the data was been provided by NIWA and the National Rural Fire Authority. The suggested change to 'FENZ Fire Weather System' doesn't name an organisation. Therefore, we're unsure what change to make - should 'National Rural Fire Authority' be changed to FENZ'?

- From s 9(2)(a) email: We support your suggestion to engage with Stats NZ to better convey the nuance with the forest / grass fire risk data. One way could be to edit their ShinyApp so that it is the location name, not the associated bar, is coloured according to the fuel type. We suggest a more prominent disclaimer needs to be included in the StatsNZ website stating that data is based on different fuel types and that care should be taken when comparing results from different locations.
    - We haven't made these suggested changes.
        - We note that there is no error to be corrected but there is the suggestion to better convey nuances with the fuel types. We've looked at our ShinyApp again.
            - For all sites for state, fuel type is already clear in the graph.



- We've also looked at the trend data and it doesn't seem that fuel type has much influence on the trends (see graph below). Because of this, we don't think it's necessary to make the changes suggested (i.e., to colour the site name by fuel-type)



- Given these results, we're unclear about the need to act on the following suggestion: '*a more prominent disclaimer needs to be included in the StatsNZ website stating that data is based on different fuel types, and that care should be taken when comparing results from different locations*'.
  - We are happy to have further conversations about this, but until that time we will leave the ShinyApp as is.

We contacted s 9(2)(a) and s 9(2)((FENZ) in December about meeting, but were unable to connect. We are happy to talk with FENZ again if you think our approach to the webpage could cause some issues.

Otherwise, we have noted the suggestions above for future development of the wildfire risk webpage, and suggest we all work more closely in future (e.g., everyone being 'in the room' when changes to content are discussed) so we can resolve issues at the time.

Nga mihi,

s 9(2)(a)

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Unleashing
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From: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Sent: Thursday, 3 December 2020 4:06 PM
To: s 9(2)(a)
Cc: Nancy Golubiewski <Nancy.Golubiewski@mfe.govt.nz>; John Robertson <John.Robertson@mfe.govt.nz>; s 9(2)(a)
Subject: RE: Recent NIWA-led research on wildfire risk

Kia ora s 9(2)(a)

Thanks for the update, it sounds like you had a productive discussion.

We'll go ahead and correct the citation in the report.

I'm also including s 9(2)(a) in this chain, as she will need to lead the response to the changes on the indicator website. I expect she will contact you to work out exactly what the changes should look like.

Thanks for your time on this, I'm glad we were able to come to a resolution that all could agree upon.

Kind regards,

Drew

From: s 9(2)(a)
Sent: Tuesday, 1 December 2020 3:01 PM
To: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Cc: Nancy Golubiewski <Nancy.Golubiewski@mfe.govt.nz>
Subject: RE: Recent NIWA-led research on wildfire risk

Hi Drew,

s 9(2)(a) and I had a productive meeting with s 9(2)(a) from SCION yesterday. Ultimately we have come to the consensus that the data presented in OAC2020 are of sufficient quality and appropriateness and therefore recommend that an error correction process does not need to be initiated. It appears some of the original concerns resulted from the mistaken conflation of observed/historic index data with modelled projections. The key recommended actions resulting from our meeting are largely the same as those I outlined in my previous email to you specifically:

- Request StatsNZ to edit their wildfire risk webpage, section *Where this data comes from*, to state "NIWA, and FENZ Fire Weather System".
- We support your suggestion to engage with StatsNZ to better convey the nuance with the forest / grass fire risk data. One way could be to edit their ShinyApp so that it is the location name, not the associated bar, is coloured according to the fuel type. We suggest a more prominent disclaimer needs to be included in the StatsNZ website stating that data is based on different fuel types, and that care should be taken when comparing results from different locations.
- We recommend that a minor correction is required in the OAC2020 report; such that the MAF report from 2011 and the results it presents (attached) are used as the citation on pg 64 of OAC2020. According to s 9(2)(a), these are the most recent and relevant research results available on this topic.

As a result of our productive meeting yesterday, we feel an additional meeting with the three of us, plus yourself and s 9(2)(a) is no longer required. However, if you wish to speak with me to clarify anything I am of course available for that. I would appreciate it if you can let me know if you're happy to pursue the recommended actions bulleted above.

For future iterations of such work, we (NIWA) have agreed to engage with s 9(2)(a) SCION to check and/or develop an improved methodology for deriving these data.

Kind regards, s 9(2)(a)

From: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Sent: Thursday, 19 November 2020 12:09 p.m.
To: s 9(2)(a)
Cc: Nancy Golubiewski <Nancy.Golubiewski@mfe.govt.nz>
Subject: FW: Recent NIWA-led research on wildfire risk

Hi s 9(2)(a)

Thanks for sharing this feedback.

FENZ have reached out to us as well, and we had an initial meeting last week (including Stats and s 9(2)(a) for them to convey their issues with the how we reported on wildfire risk in the report and website. They indicated that they would prefer to reach out to you (NIWA) directly, so good to hear they've been in touch.

The main issues they raised in the meeting with us were around interpretation and analysis of the data (the forest/grass presentation of the data on the website in particular), and that our findings conflicted with theirs (we reported decreasing trends in some areas where their modelling indicates increasing wildfire risk), and the communication issues with the public and government this is causing. They also identified the outdated agency name (National Rural Fire Authority), which we have updated in the report. And as with their communication with you, they also voiced frustration at not having been consulted during the report production.

Our next steps from the meeting was for Stats and s 9(2)(a) to work with you to verify the quality and appropriateness of the data used for our reporting. If it's found that there are errors we would initiate an error correction process, however, if it is the case that our data are fine, and the historical data are providing a different view than their modelled risk projections, we would work together on communications that would help the public and policy-makers to understand the differences, and to work with Stats to update their web page to better convey the nuance with the forest / grass fire risk data. We also agreed to work together on reporting in the future, given the ongoing nature and prominence of wildfire risk as an ER indicator.

Hopefully that helps inform your understanding of where we're at, and we'll look forward to hearing from you about a time to meet.

Kind regards,
Drew

From: s 9(2)(a)
Sent: Wednesday, 18 November 2020 3:27 PM
To: Drew Bingham <Drew.Bingham@mfe.govt.nz>
Cc: s 9(2)(a)
Subject: FW: Recent NIWA-led research on wildfire risk

Hello Drew,

I hope this finds you well. I am reaching out to let you know we (NIWA) have received some critical feedback on the Wildfire Risk data presented in OAC2020 via s 9(2)(a) at SCION (see below for his email). s 9(2)(a) and I plan to organise a meeting involving ourselves, you, s 9(2)(a) (StatsNZ) and s 9(2)(a) (SCION) at some point prior to Christmas so we can work through and resolve s 9(2)(a) concerns. In addition, s 9(2)(a) will be speaking to s 9(2)(a) directly in the near-future.

In the meantime, we are working through this internally at NIWA, and I wanted to let you know some of our thinking in response to s 9(2)(a) criticisms:

- *Are FENZ aware their data was being used?*
  - Fire Danger ratings were provided for 30 locations. As shown in Macara & Sutherland (2017) and Macara et al. (2020), FENZ (Raws) stations were selected for 11 of these locations.
  - NIWA has a data sharing agreement in place where we can provide FENZ data to the public provided i) FENZ is acknowledged as its source, in the following manner "FENZ Fire Weather System", or otherwise as approved. ii) any Web based products that use FENZ RAWS observations will need to acknowledge the source as FENZ."
  - As per Section 4 of Macara & Sutherland (2017), NIWA obtained explicit permission to use the data: "The authors wish to acknowledge Stuart Waring from the New Zealand Fire Service (NZFS) for permission to use NZFS data in this investigation". Based on NIWA's data agreement as above, such explicit permission isn't required.
  - For the 2020 iteration of this work, NIWA note we haven't explicitly acknowledged FENZ Fire Weather System in the Macara et al (2020) Client Report, although that report refers the reader to the Macara & Sutherland (2017) report where explicit permission was acknowledged. The StatsNZ webpage (https://www.stats.govt.nz/indicators/wildfire-risk) does acknowledge the data source, however it does so inaccurately ("National Rural Fire Authority").
  - **Proposed action:** Ask StatsNZ to edit their wildfire risk webpage, section *Where this data comes from*, to say "NIWA, and FENZ Fire Weather System".

- *Disappointing that NIWA didn't come to SCION for advice, assistance, or peer review of their methods and results*
  - The data NIWA provided are simply generated using methodology as applied and running operationally via *EcoConnect* (software used for the provision of weather and climate data to the public) and as presented online and publicly available (https://fireweather.niwa.co.nz/). As far as we are aware, there has been no change to the original methodology and shared IP with SCION.

- *Flawed results NIWA authors inadvertently compared Fire danger rating frequencies of forest vs grassland fire danger at different sites*
  - NIWA are well aware that stations have different fuel types (of our 30 locations, 28 stations have grass, and 2 stations have forest). Fire danger ratings at each of the 30 locations are based on the primary fuel type that is selected for each station. Macara and Sutherland (2017) and Macara et al (2020) describe the Fuel type that applies to each of the stations in the station metadata tables.
  - On the StatsNZ webpage (https://www.stats.govt.nz/indicators/wildfire-___), when viewing the Graph of *State* for *All sites*, the different fuel types for each site are distinguished by the colour of the bars ... the bars are indistinguishable (New Plymouth, Hokitika, Milford Sound). Additionally, detailed methods including fuel type selection are provided on the StatsNZ website.
  - **Proposed action:** Ask StatsNZ to edit their ShinyApp so that it is the location name, not the associated bar, which is coloured according to the fuel type. Suggest a more prominent disclaimer needs to be included in the StatsNZ webpage stating that data is based on different fuel types, and that care should be taken when comparing results from different locations.

- *NIWA authors are unaware of the major errors and gaps that exist in underpinning grass curing data within the FWSYS required to calculate grassland fire danger*
  - NIWA simply provided historic observed data which is based on the operational calculation per EcoConnect and the publicly available website (https://fireweather.niwa.co.nz/). Therefore the data are the 'best' available, contemporarily relevant and used operationally. It is beyond the scope of the present work to account for/update the calculations in light of such errors and gaps.

- *The study utilises only a limited time period (~20 years) compared to the longer time series usually required to observe climate changes*
  - NIWA provided the data ..., MFE and StatsNZ interpreted the data and calculated trends. The trend calculations by StatsNZ are rigorous and based on statistical significance/certainty, with the criteria (e.g. very likely increasing, likely decreasing, etc.) clearly defined in the *Our Atmosphere and Climate 2020* report; "Measuring and reporting trends and anomalies" infobox on page 28.

- *Projections of future fire danger inappropriately acknowledged*
  - At present in the OAC2020 report, pg 64, Scion (2019) are cited for the fire danger projection information.
  - **Proposed action:** The OAC2020 report is corrected, such that the MPI report from 2011 and the results it presents (attached) are used as the citation on pg 64. Check with Grant Pearce to see if any more recent research results are available.

Additional point for clarification

- For the overall body of work contributing to the *Our Atmosphere and Climate 2020* report, NIWA are simply the providers of the data (and implicitly the data custodians, hence we were approached by MFE for this work). s 9(2)(a) at times appears to have conflated this data provision role with the data reporting role led by MFE and StatsNZ. That said, myself (and several others; s 9(2)(a) s 9(2)(a) s 9(2)(a) not to mention the comprehensive internal reviews at MFE and StatsNZ) were involved in reviewing the report and webpages.

Please standby for any updates from us, as well as arranging a mutually agreeable time to hold our meeting. I anticipate that among other topics, we will discuss the proposed actions (bolded above) in that meeting.

Kind regards, s 9(2)(a)

From: s 9(2)(a)
Sent: Wednesday, 11 November 2020 1:11 p.m.
To s 9(2)(a)
Subject: Fwd: Recent NIWA-led research on wildfire risk

From: s 9(2)(a)
Sent: Wednesday, 21 October 2020 2:31 PM
To: s 9(2)(a) s 9(2)(a)

Subject: Recent NIWA-led research on wildfire risk

Hi s 9(2)(a)

As discussed, I'd like to highlight some issues with recent research on wildfire risk undertaken by NIWA for MfE and Stats NZ.

The research formed the basis of a section of the just released MfE & Stats NZ report, Our Atmosphere and Climate (see pp 44-45, and also pp. 64). The NIWA research, described in contributory reports by Macara & Sutherland (2017) and Macara et al. (2020), quantified the number of days of VH & E fire danger and trends for 30 locations over the period 1997-2020, using data obtained (and quality checked and corrected where necessary) from FENZ's Fire Weather System which NIWA maintains for them.

As well as questioning whether FENZ were aware that NIWA were using their data (or at least some of it for FENZ fire weather stations, vs NIWA or MetService's stations in main centres), it is most disappointing that NIWA did not come to Scion for advice or assistance to complete this study, or at least for peer review of the methods and results. Scion was a partner with NIWA in the development of the Fire Weather System for FENZ, and shared considerable IP with NIWA via equations and methods for calculating fire danger ratings for NZ.

It is disappointing to see that as a result, some of the results from the study are **flawed** and are being circulated widely in the mainstream national media (e g. RNZ, NZ Herald, Stuff, Newshub) and via national indicator data sets for wildfire risk managed by **Stats NZ** (as part of their broader national indicators). In calculating the frequencies of days of VH & E fire danger, the NIWA authors have inadvertently compared forest fire danger against grassland fire danger for different sites, and unaware of the major errors and gaps that exist in underpinning grass curing data within the FWSYS required to calculate grassland fire danger. The study also utilises only a limited time period (~20 yrs), compared to the longer time series usually required to observe climate change (30+ yrs) and for which data are available for many of the stations.

The report, and associated media, also merge the results from this latest NIWA research with those from previous work led by Scion in collaboration with NIWA (for MPI in 2011). In fact, the headline that fire dangers will increase by 70% comes from this previous Scion-led research, not this latest NIWA study, although is not appropriately acknowledged as such in the NIWA or MfE & Stats NZ reports (NIWA actually cite a Scion Connections article, not the main project reports).

This potential errors in this latest NIWA study are critical given that the study results have also now formed the basis of the national indicator for wildfire risk posted on the Stats NZ website, and will form the basis for subsequent future monitoring and updates. The study also has potential to go against national guidance and advice from FENZ to Government e.g. through the wildfire risk profile being updated by FENZ for Dept. of Prime Minister and Cabinet as part of the National Risk Register.

Perhaps though what is more worrying is that neither MfE or Stats NZ knew to come to Scion as the subject experts around wildfire risk, or at least to approach FENZ to ask who the experts were in this area. So there is likely some work required to better communicate this around the various government departments with an interest in climate change.

I believe these issues with this research warrant discussion with FENZ as the owner of the FWSYS and lead agency in NZ for wildfire, but also with NIWA management given the lack of collaboration with Scion in this case given the strong history of working together previously.

Thanks, s 9(2)(a)

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Scientist, Fire Research
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19 February 2021
s 9(2)(a)

Vicky Roberston
Secretary for the Environment
PO Box 10362
Wellington 6143

Concerns Re Reporting on Forest and Rural Fire Danger Levels

Introduction

The Ministry for Environment/Stats NZ 'Our atmosphere and climate 2020' report published in October 2020 includes a number of failings in the methods used to support the commentary on 'The Risk of Wildfires Changing'. These include;

1) The 17 year period used, from the 30 sites is from 2020 to 2017, is insufficient to support such findings. To use such a short period to assess changes in fire danger levels do not fully reflect the history on changes if any in the fire danger levels throughout the New Zealand forest and rural landscape. The statements made in the report relating to "the Risk of Wildfires Changing' has resulted in misleading the discussions on the impacts of changes in climate to fire danger levels. This has also allowed flawed statements to be made by media on this topic.

2) In the Ministry for Environment/Stats NZ section of the report it refers to a 2017 NIWA Fire Risk Assessment Report. From the thirty sites referenced in this NIWA report eighteen sites involved a fire risk assessment using the Grasslands Fire Danger Class outputs from the NZ Fire Danger Rating System (NZFDRS). The use of the Grassland Fire Danger Classes raises a number of concerns. The Grassland Fire Danger Class involves the use of the Initial Spread Index (ISI) from the NZFDRS, and the degree of grassland curing. This degree of curing is a manual assessment at a representative grassland site near the Remote Automatic Weather Station (RAWS). It needs to involve a detailed weekly inspection of changes in the dry matter levels along a 100 meter grasslands transect.

Media Reports

An example of what was reported as alarmist and distorting statements by the media on the Ministry for Environment/Stats NZ Report was on TV3 News on 15th October 2020. TV3 suggested there would be a 70% increase in fire danger levels by 2040;

In addition Stuff also report on the 15 October 2020 that "By 2040, days with very high or extreme fire danger periods are projected to increase by an average of 70 percent, due to hotter, drier and windier conditions, the report says. The largest increases are projected for areas that are not accustomed to fire. Wellington could experience a doubling to 30 days a year and coastal Otago a tripling to 20 days a year." Such statements cannot be supported by the facts.

Degree of Curing

The Degree of Curing component of the NZ Grassland Fire Danger Class required the assessment of levels of grassland curing at a site near each RAWS. The most satisfactory means of estimating the Degree of Curing is by direct observations for an area which represents the "typical situation" in which most wildfires are expected to occur; ideally, the location should be within a few kilometers of a fire weather station. Obviously this will require considerable judgement on the part of local fire managers. A permanent transect 100 metres in length should be established for the Degree of Curing assessment rather than relying on a roadside check or observations from a distance. Ideally, the transect should be marked with a steel post at each end as this permanent installation will allow comparisons to be made not only during the current fire season, but also from one fire season to another.

The sampling should be done by the same person. Observations are not required to be made on a daily basis but should be done at least every week or 10 days. Ten evenly spaced out samples (@ 10 m, @ 20 m, etc.) should be evaluated along the transect line Care and judgement must be exercised in making the visual estimates of Degree of Curing. The best method is to locate a 1.0 metre by 1.0 metre sized frame (made out of small diameter wooden dowelling, light-weight aluminum or similar material) immediately in front of the toe where the sampler has paced the required distance. Mentally estimate, by volume not cover, the cured (i.e., dormant) or dead material in each quadrat to the nearest 5 percent. Often the grass must be pried apart to determine the amount of dead material underneath the current season's growth, but still undecomposed. Following this, determine an average for the entire transect.

Estimates of cured or dead material less than 50 percent should be considered very carefully. These situations occur only when no litter (excluding decomposed material) or standing dead stems remain from the previous season's growth. Initially, when the observer is "calibrating" his/her visual assessment, and then periodically, as a check, all the material within the frame should be clipped, the dead and live material separated and the volume of each determined by ocular means or by drying in a forced-air drying oven and weighed on a electronic balance if such equipment is readily available. If a camera is available, a photo be taken at the time of each visit to the site from the starting post looking down the transect and perhaps of a "representative quadrat" or two. A permanent record of the degree of curing assessments along with this photographic record should be kept giving the name of the assessor, date of the assessment, the estimated percentages and the mean value. Before the use of the Grassland Fire Danger Class, in any formal assessment/study, confirmation is required to ensure the correct process is use to assess the degree of curing at any of the sites used in the study.

The impact of recent climate on fire danger levels in New Zealand

Further research to determine the impacts of recent climate on fire danger levels in New Zealand has recently been completed (Dudfield, Pearce, Cameron - February 2021). Using a number of outputs from the Fire Danger Rating System the research question was "Is the fuel available to burn over the past 20 years any greater than for the period prior to the year 2000". The research involved the analyses of fire weather data for up to 60 years from 15 sites throughout NZ. This study looked to analyse three key components of Drought Code (DC), Build Up Index (BUI) and Initial Spread Index (ISI) from the daily outputs from the NZ Fire Danger Rating System. These historical data sets ranged in length from 24 to 59 years. The results from this largely qualitative analysis shows a trend that fuel availability for combustion has seen an overall reduction over the past 20 years when compared with the period prior to 2000.

This study uses daily climatology records from 15 weather stations located within different regions throughout New Zealand. Data was obtained from the Fire Weather System managed for Fire and Emergency New Zealand by the National Institute of Water and Atmospheric Research (NIWA), and records for discontinued Meteorological Service of NZ stations updated to June 2020 with synoptic data provided by MetService.

The study looked at two groups of fire danger indicators. These included:

1) The monthly maximum BUI, DC and ISI values from historical data sets for the 15 weather stations ranging in length from 24 to 59 years. For stations with data available for more than 20 years prior to 2000, this was trended against the 20 year period following 2000. For those stations with historical indicators covering a 24 year period only, this data was split to compare two 12-year periods

2) The number of days with DC greater than 300, BUI greater than 60 and ISI greater than 10 were identified, and a five-year rolling average was then applied to each station.

The high level-results of this assessment are outlined in Table 1. For the 90 fire danger indicators across the 15 weather stations, 68 (77%) of the indicators showed a no change to a nominal or notable decrease, versus 22 (23%) of the indicators showing a nominal to notable increase.

	Kaitaia	Auckla	Gisbor	Napier	Rotor	Taupo	Wangai	Para-ur	Master	Nelson	Blenhei	Chch	Q-town	Dunedi	Inv-gill
Number of years/period:	59	54	24	24	24	24	24	24	24	24	24	24	41	55	58
Days of Build Up Index > 60	↑	↑	↓	↓	↑	O	⬆	O	↑	O	O	↓	↑	O	O
Days of Drought Code > 300	O	O	O	↑	↑	⬆	O	↓	O	↓	⬇	↓	↑	O	O
Days of Initial Spread Index > 10	⬇	O	⬇	O	O	O	O	O	↓	↓	↓	O	O	↓	⬇
Number of years/period:	59	54	56	28	54	46	41	56	28	56	27	58	41	55	58
Maximum BUI by Month for period	↑	↑	⬇	O	O	⬆	⬆	↓	O	↓	⬇	⬇	↑	↓	O
Maximum DC by Month for Period	↑	↑	⬇	↑	↑	↑	⬆	O	O	⬇	⬇	⬇	O	↑	O
Highest ISI per month for the period	⬇	↓	⬇	O	↓	O	↓	O	⬇	⬇	⬇	⬇	O	O	⬇

Key

Notable Increase	⬆	5
Nominal increase	↑	17
Overall no change	O	34
Nominal decrease	↓	16
Notable decrease	⬇	18
		90

Each arrow generally shows the movement between the cluster of years prior to 1999 compared with the 2000 to 2020 cluster of years.

The BUI, DC and ISI referred to above are defined as:

1) The BUI is a numeric rating of the total amount of fuel available for combustion. It combines the Duff Moisture Code and the DC.
2) The Drought Code (DC) is a numeric rating of the average moisture content of deep, compact organic layers. This code is a useful indicator of seasonal drought effects on forest fuels and the amount of smoldering in deep duff layers and large logs.
3) Initial Spread Index (ISI) is a numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC on rate of spread without the influence of variable quantities of fuel.

Table 1: Summary of changes in fire danger for 15 weather station locations across New Zealand

In fact, more stations showed decreases in fire dangers for the period since 2000 compared to the period prior to 2000, whether nominal or notable. Gisborne, Nelson, Blenheim and Christchurch mainly showed decreases, including many notable decreases, plus Invercargill and Paraparaumu also showing no change or decreases. Only two stations (Taupo, Wanganui) showed notable increases, with significant increases for the number of days of DC >300 and maximum monthly BUI and DC values since 2000. The remaining stations showed more variable trends, with a mix of increases, decreases and/or no changes in fire danger indicators for the two comparison periods.

Conclusions

There is little evidence to show that there would be a 70% increase in fire danger level by 2040. To use such statements is misleading, emotional and indicates a lack of understanding of the management of fire in the New Zealand forest and rural landscape.

The NZFDRS provides a sound scientific basis for answering key questions in the management of fire in the forest and rural landscape, as well as supporting fire management decision-making. What has emerged in a recent research project into the number of days with fuel available for combustion at an intense level – as indicated by elevated values of the BUI and DC components of the NZFDRS – it has shown that this has remained the same or actually reduced since 2000 for almost all of the weather station locations analysed in the fifteen weather sites. Similarly, indicators of increased fire spread potential – based on the ISI component of the NZFDRS – show even more widespread decreases. Along with the BUI and DC changes, this may be explained in part by changing wind patterns and associated increases in rainfall along the Southern Alps associated with natural seasonal climate variability, as well as longer-term climate change.

Based on this study, involving up to 60 years of fire weather data for a range of locations across the country, it will take a major swing in current weather patterns to suggest that the average annual frequency of elevated fire danger levels across New Zealand will increase dramatically over the next 20 to 40 years.

s 9(2)(a) [redacted]

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s 9(2)(a)

Dear s 9(2)(a)

Concerns regarding reporting on forest and rural fire danger levels

Thank you for your letter of 19 February 2021 about concerns with reporting on forest and rural fire danger levels in *Our atmosphere and climate 2020*. The Ministry for the Environment (the Ministry) places a high value on the quality of our analysis, and we always welcome feedback on our reports.

I acknowledge your comments about the appropriateness of the data used in relation to trends and fuel types, and the resulting media interest. Particularly since the Ministry received similar feedback on the wildfire risk discussion in the report from other interested parties.

To address the matters raised, the Ministry worked with officials from Fire and Emergency New Zealand (FENZ), NIWA and Scion. We were able to satisfy concerns that the data, analysis, and statements in the report were correct, and that the data and trends in the report were interpreted and presented correctly.

We think some of the confusion may have stemmed from the use of two different data sources in the report. Data on days with very high and extreme wildfire danger were used to analyse trends in the past (and identified six sites with very likely increasing trends, and six sites with very likely decreasing trends). Although the Ministry determined that the analysis was correct, we acknowledge the need to better convey the nuance with the forest/grass fire risk data in the future.

Working with scientists at Scion, the Ministry also addressed a concern around the statement about a projected 70% increase in fire danger levels by 2040. This statement is taken from a modelling study (Watt et al., 2019), and is not extrapolated from the wildfire risk indicator data. Following discussion, the Ministry updated the citation in the report so that it references the most current and relevant research results that calculate this statistic.

These changes were considered sufficient to address concerns around messaging and data handling stemming from the report, and the Ministry has committed to work more closely with FENZ on wildfire risk data, analysis, and communications in our future reporting. While the study you published (Dudfield, Pearce & Cameron, 2021) was not available to the Ministry during publication of this report, it will be considered along with any other recent findings in our next wildfire reporting.

Yours sincerely

Vicky Robertson
Chief Executive and Secretary for the Environment