

Summer growth rates and annual yields of perennial ryegrass (*Lolium perenne* L.) in the Upper North Island are expected to decline as a result of climate change

Andrea M. BABYLON^{1*}, Simon J. R. WOODWARD¹ and Pierre C. BEUKES¹

¹DairyNZ, Private Bag 3221, Hamilton 3240, New Zealand

*Corresponding author: Andrea.Babylon@dairynz.co.nz

Abstract

Evaluating the ability of perennial ryegrass to continue underpinning New Zealand's low-cost dairy production systems under future climate change scenarios requires a modelling approach. In this study, climate projections for different climate change scenarios were used in the BASGRA pasture model to predict changes in annual yields and seasonal pasture growth rate patterns of perennial ryegrass. These predictions, including uncertainty, were made for the years 2010-2014, 2040-2044 and 2090-2094 in 14 dairy-dominant subregions in the Upper North Island of New Zealand. The suitability of perennial ryegrass is expected to decline in the future across all subregions, with worse outcomes expected under higher atmospheric greenhouse gas levels. Winter is expected to be the season least affected by climate change and summer the most affected. Late-winter/spring is predicted to become the main growing season, followed by late-autumn/early-winter. The ability of farmers to adapt their farming practices is essential in remaining profitable and internationally competitive.

Keywords: BASic GRAssland model, pasture yield, perennial ryegrass resilience

Introduction

The competitive advantage of New Zealand's dairy industry relies on matching the seasonal supply of pasture to the seasonal feed requirements of cows for milk production and pregnancy (Holmes et al., 1987; Chikazhe et al., 2017; Roche et al., 2017). Changes in local climate may result in commonly-used pasture species (particularly perennial ryegrass, *Lolium perenne*) becoming more, or less, suitable for supporting livestock systems. This can occur if temperatures rise and/or rainfall patterns change (Ausseil et al., 2019), for example if winters become warmer or summers become drier (Clark et al., 2012).

Predicting climate change impacts on pasture growth and persistence requires a mechanistic modelling approach to estimate the immediate and flow-on effects of local climate predictions on pasture growth and survival. Previously, the European grass model BASGRA (BASic GRAssland model; Höglind et al., 2016) was adapted by Woodward et al. (2020) to

match the pasture growth and tiller populations in the 2011-2017 grass persistence trial described by Lee et al. (2018). Trial sites were located in the Northland, Waikato and Canterbury regions of New Zealand. Beukes et al. (2021), together with the current study, utilised this work by predicting pasture responses to climate change in the Upper North Island (UNI) region of New Zealand (including the Northland and Waikato sites from the previous trial).

In the current study, historical weather data and climate projections (described below) for the Upper North Island of New Zealand from 1980 to 2100 were used as input into the BASGRA pasture model to simulate daily perennial ryegrass growth and annual yield. Results were compared for two climate change scenarios (described below) for the 2010-2014, 2040-2044 and 2090-2094 half-decades for 14 subregions of the Upper North Island of New Zealand. The 2010 half-decade was used as a baseline with which to compare the future half-decades. This allowed for the assessment of suitability of perennial ryegrass for dairy farming in this region in the next 70 years.

Materials and Methods

Climate Data

Climate projections (projected daily weather data) from six general circulation models (GCMs), representing two future climate scenarios (representative concentration pathways RCP4.5 and RCP8.5), were obtained from NIWA for the 1980-2100 period for each point on a 5 km x 5 km grid covering the Upper North Island (UNI) region (NIWA 2022). Only grid points within dairy-dominant districts north of Tokoroa in South Waikato (-38.22 latitude) and west of 176.975 longitude were included (Figure 1).

Climate for 1980-2005 was determined from historical weather data, while projections from 2006 onwards were based on the GCMs. The two concentration pathways (RCPs) represented climate scenarios in which greenhouse gas concentrations either stabilise (RCP4.5) or continue to increase at present rates (RCP8.5). The effect of greenhouse gas concentrations on climatic variables varies with region, but in general, average temperatures are expected to increase into the future, with larger increases expected

under higher greenhouse gas concentrations, especially during the summer/autumn seasons. Conversely, rainfall in the UNI region is expected to decrease overall, particularly during spring.

Since the climate data did not include extreme events such as severe storms, floods or droughts, the results presented only represent responses to general climatic trends. The potential failure of a perennial ryegrass sward as a result of such events was not considered.

The 315 grid points (Figure 1) were grouped to represent the 14 major dairy subregions in the UNI. Grid points in the 'Other' category were not included in the analysis.

Pasture Model

Details of the New Zealand adaptation of the BASGRA pasture model are given in Woodward et al. (2020). The BASGRA pasture model simulates daily perennial ryegrass herbage mass and tiller population for a single grass paddock in a rotational grazing system. Other species (such as white clover) are not simulated. When calculating total dry matter cover (DM), it was assumed that the basal area not covered by perennial ryegrass was covered by other associated species, which produced the same amount of DM per area as perennial ryegrass. Thus, total DM was a scaled-up amount of perennial ryegrass dry matter. Harvesting was assumed to occur once the total (as opposed to perennial ryegrass only) dry matter (DM) reached 2850 kg DM/ha, and the post harvesting residual was set at 1500 kg DM/ha. This regime represented a simplified grazing regime and did not simulate the complexities of harvesting decisions on a real farm (e.g., Macdonald and Penno 1998).

Competition experienced by perennial ryegrass from other species (sown or non-sown), which may be more resilient to extreme weather, was not included (Kalaugher et al., 2017). Instead, the basal area of perennial ryegrass was simulated for each five-year period, beginning each five-year period as a newly sown 100% perennial ryegrass pasture with 100% basal coverage, typically declining thereafter in response to climatic and harvesting stresses (Woodward et al., 2020).

As described in Woodward et al. (2020), Bayesian calibration was used to infer credible model parameter sets that simultaneously fitted the Northland, Waikato and Canterbury data sets described in Lee et al., (2018). The single most likely parameter set (the *maximum a posteriori* (MAP) parameter set) was then chosen to represent perennial ryegrass swards in the simulations in the current paper.

Differences between sites were driven by latitude, soil plant available water (PAW, mm, the maximum amount of soil water accessible to plants), and daily weather data (daily rainfall, mean temperature, global solar radiation and potential evapotranspiration).

A PAW value of 60 mm (to 30 cm soil depth) was used for all simulations in the current study, representing a typical value for the Upper North Island region (based on data provided by Manaaki Whenua Landcare Research, MWLR).

Atmospheric CO₂ concentration influences leaf light-use efficiency in BASGRA, which in turn is used to calculate photosynthesis. The model was originally parameterised with an atmospheric CO₂ concentration of 350 ppm (BASGRA 2014). CO₂ fertilisation is a very complicated process and the opinions on the effects of CO₂ on plant growth in the literature are varied (Hovenden et al., 2019). Given that BASGRA does not include a soil C:N (carbon:nitrogen) component to provide potential feedbacks through progressive N limitation, CO₂ was held constant for all simulations in the current study.

Simulations

Simulations were carried out for the five-year periods (starting in May of the first year) for 1980-1984, 1990-1994, 2010-2014, 2040-2044, 2070-2074 and 2090-2094 for each grid point, climate model (GCM), and climate change scenario (RCP). Each simulation began with a newly-sown perennial ryegrass sward covering 100% of the paddock area, and simulated growth and population dynamics of the perennial ryegrass fraction of the pasture for five years (a 'half-decade'). This was based on results from Beukes et al. (2021), who found that the basal half-life (time in which a pasture declined from 100% basal cover to 50% basal cover) under future climates was typically around five years.

Average monthly perennial ryegrass pasture growth rates (kg DM/ha/d) and annual perennial ryegrass pasture yields (t DM/ha/y) were calculated for each half-decade. The annual pasture yields were then scaled for comparison to the baseline half-decade 2010-2014. The perennial ryegrass pasture growth rate results of each simulation were pooled across subregion, half-decade and climate models (GCM) to calculate a variety of statistical measures. The Jarque-Bera normality test (Trapletti and Hornik 2022) indicated that the results in each group were non-normal, so the median was used as the measure of central tendency and interquartile range as the measure of uncertainty. To simplify the presentation of the monthly perennial ryegrass pasture growth rates, only the results for the 2010-2014, 2040-2044 and 2090-2094 half-decades are presented, except for annual pasture yield results which are presented for all half-decades.

Results

Seasonal Perennial Ryegrass Pasture Growth Rate

Figure 2 shows the predicted seasonal pasture growth curves for each of the 14 subregions under climate

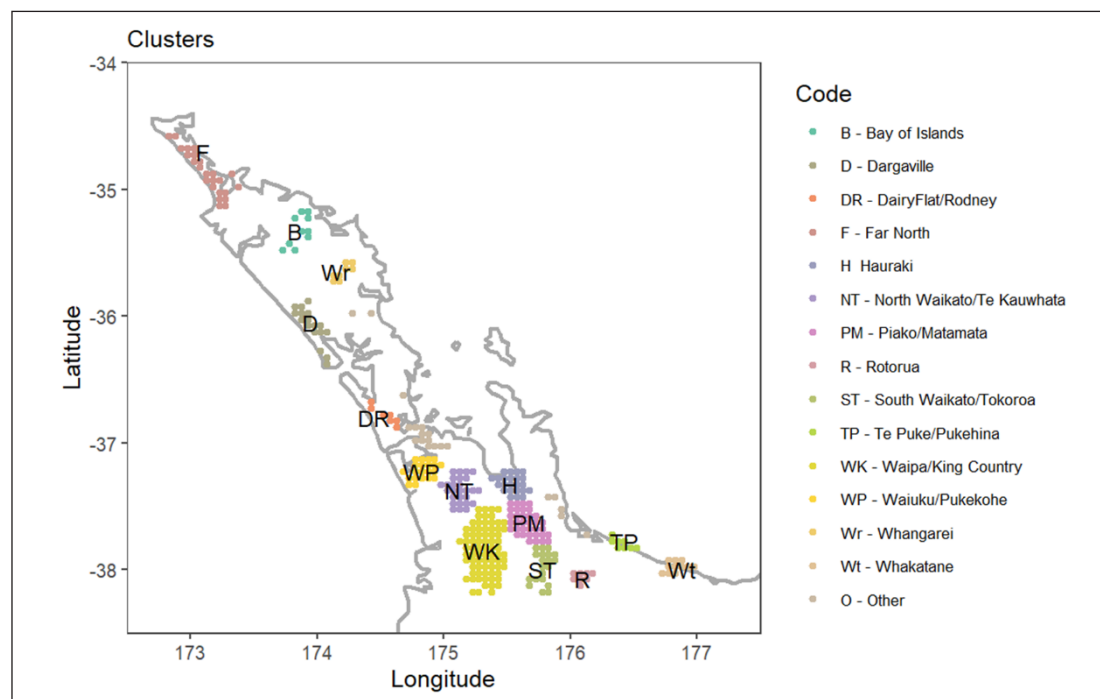


Figure 1 Map of Upper North Island climate projection locations used in this study to represent the 14 dairy subregions (Reproduced from Beukes et al., 2021)

scenarios RCP4.5 and RCP8.5 for the 2010-2014, 2040-2044 and 2090-2094 half-decades. Median monthly perennial ryegrass pasture growth rate (calculated across GCMs and across the grid points of each subregion) is shown as a bold curve and the interquartile range (50% uncertainty range) as a shaded band.

The model predicts that median perennial ryegrass pasture growth rates will tend to become lower in the future over the spring-summer-autumn months (from September until April). For many subregions, such as South Waikato/Tokoroa, median perennial ryegrass pasture growth rates (PGRs) will also tend to be marginally higher during winter, especially by the end of the century, but this is unlikely to compensate for the large losses expected during the rest of the year.

The end-of-century medians were generally lower than the mid-century medians, but there were exceptions, such as for Whangarei, where the 2090 medians were predicted to be higher than the 2040 medians. The high uncertainty around all of the predictions means that these differences may not be realised in practice.

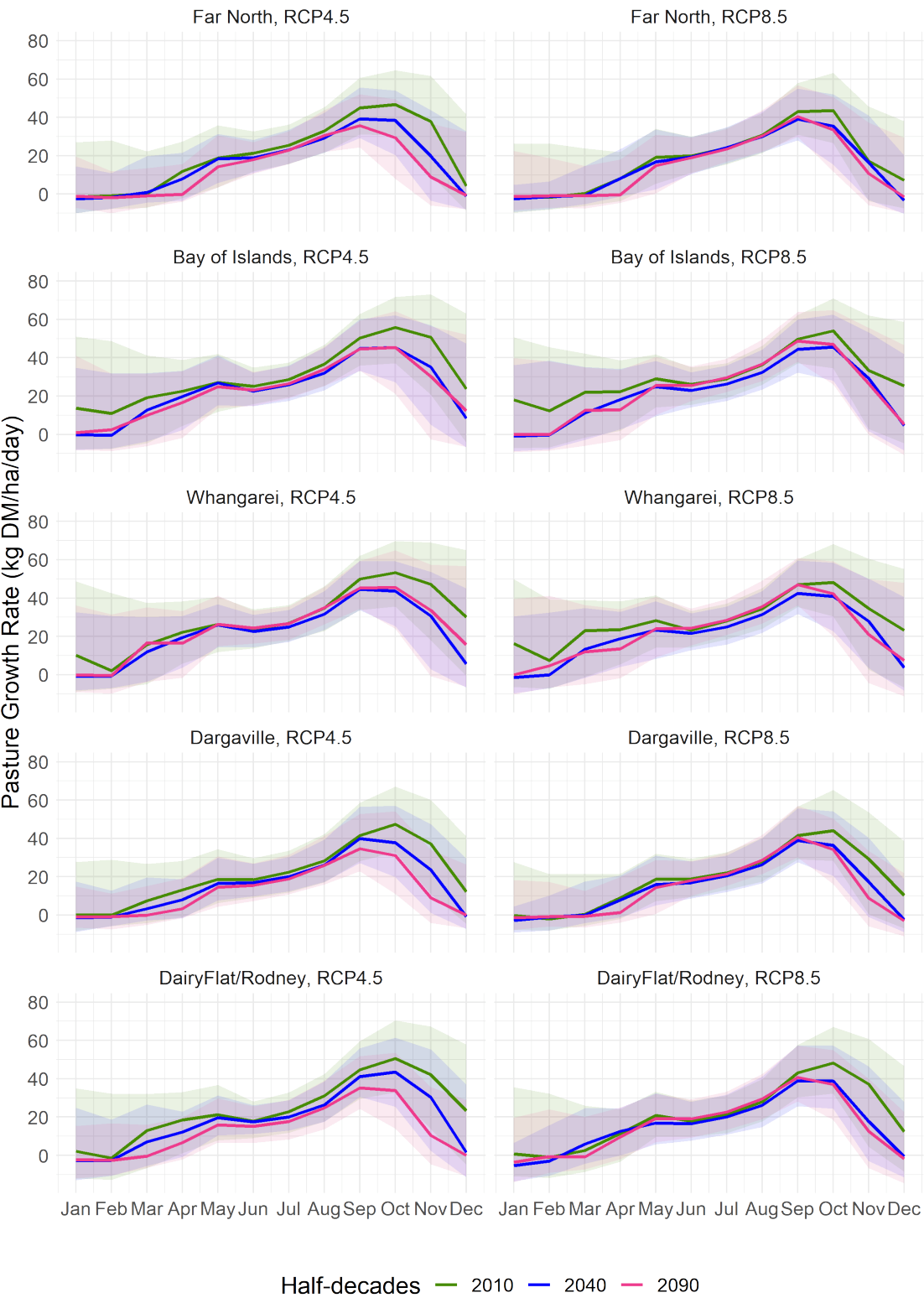
The PGR curves for Rotorua and Te Puke/Pukehina are unusual. Compared to other subregions, Rotorua was predicted to experience very high PGRs during summer, with a large dip in winter. For Te Puke/Pukehina, the curves were significantly lower and flatter

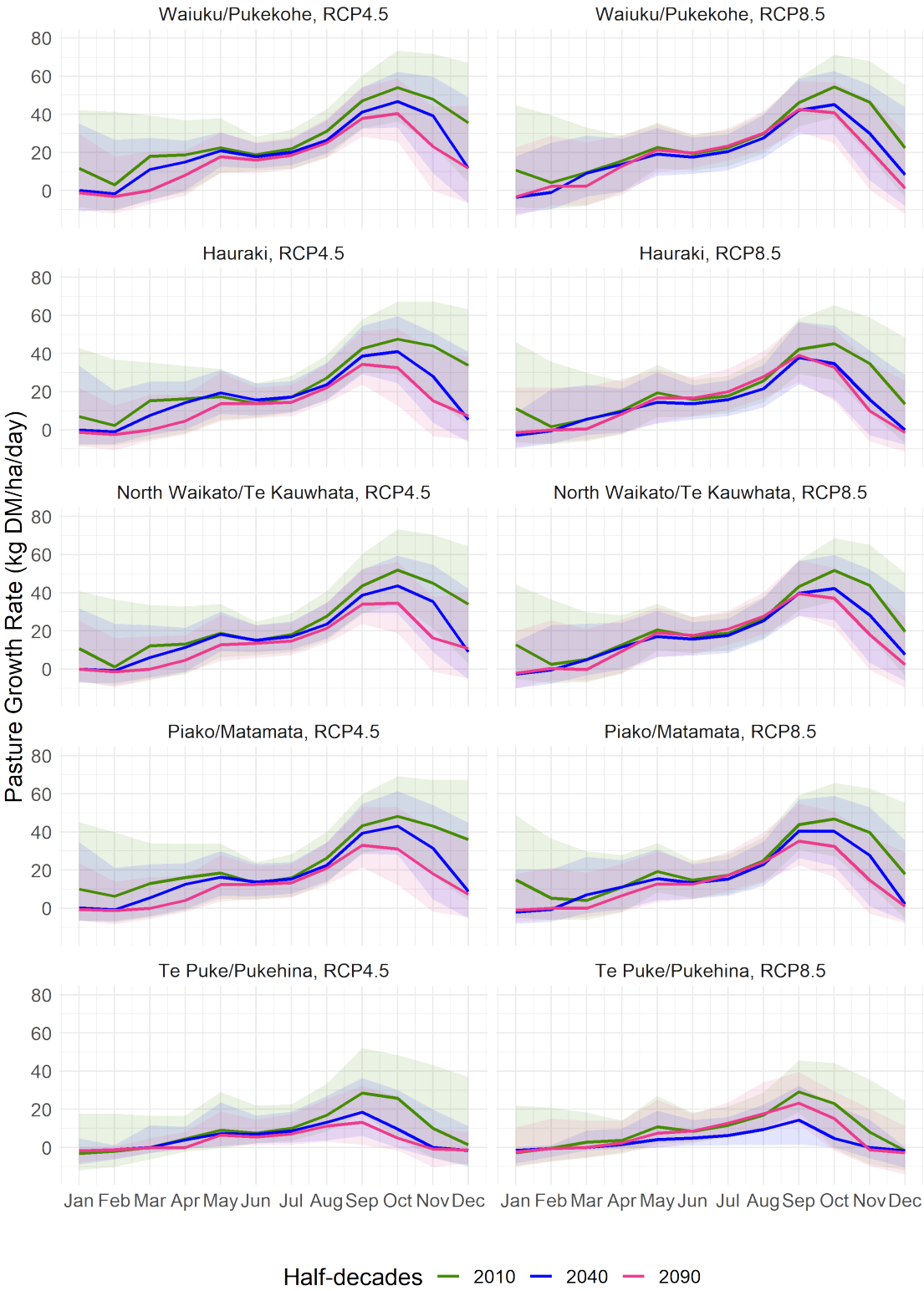
than those of the other subregions, which suggested an unpromising outlook for perennial ryegrass. Future work is planned to explore the predicted climate drivers responsible for these patterns.

Annual Yield

The annual DM yield results were expressed as a percentage of the 'baseline' median 2010 DM yields. Using this approach, median annual yields predicted for each period for each subregion are shown in Figure 3 for RCP4.5 and RCP8.5. In all cases, the 2040 and 2090 median annual yields were less than the 2010 yield. Predictions for past half-decades, while generally lower than the 2010 baseline, still tended to be higher than for future half-decades. For RCP4.5, most subregions were predicted to have their worst future yield in the 2090 half-decade, whereas for RCP8.5, yields were predicted to decline until the 2040 half-decade and improve thereafter.

In terms of individual subregions, Rotorua fared fairly well under both RCPs, with median yield percentages staying above 70% of the 2010 baseline. In Bay of Islands and Whangarei, median annual yields remained consistently above 70% of the 2010 median annual yield under the RCP4.5 scenario, but fell below 70% in the RCP8.5 scenario. The opposite result was observed in Dargaville, Far North and North Waikato/





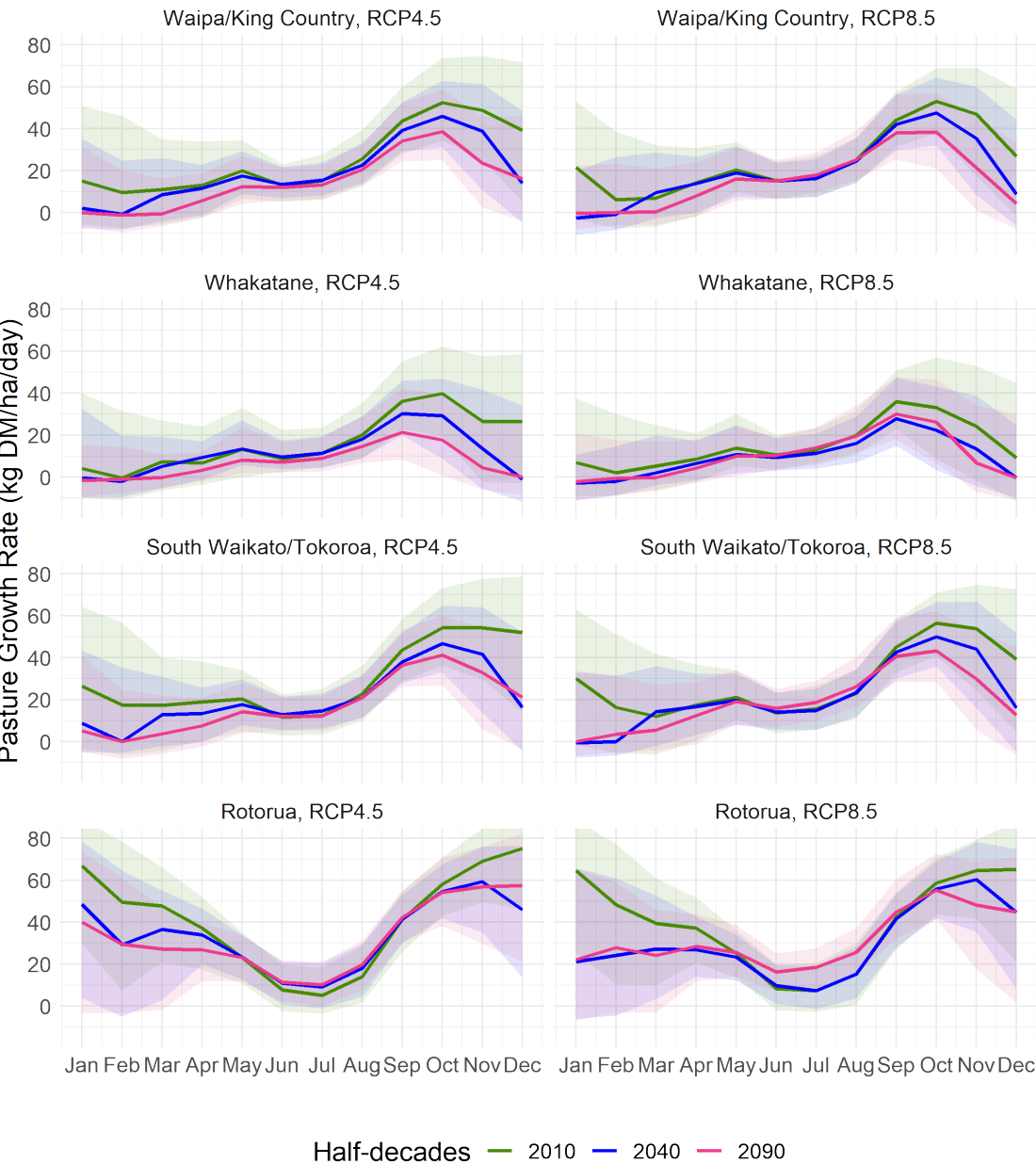


Figure 2 Predicted median monthly perennial ryegrass pasture growth rate and interquartile range over half-decades starting 2010, 2040 and 2090 for 14 subregions in the Upper North Island under two climate scenarios (RCP4.5 and RCP8.5).

Te Kauwhata, where median annual yields remained above 70% of the 2010 median annual yield under the RCP8.5 scenario and fell below 70% during the RCP4.5 scenario. Annual yields in Te Puke/Pukehina and Whakatane were predicted to decrease drastically under both RCP scenarios. In Whakatane, median yields decreased to between 38-68% of the 2010 yield under RCP4.5 and to 48-59% under RCP8.5. In Te Puke/Pukehina the median annual yield decreased to

39-55% of the 2010 yield under RCP4.5 and to 30-68% under RCP8.5. In the remaining locations and scenarios, while median annual yield remained above 50%, and in some cases overtook the 70% mark, the results were not consistent over time.

Discussion

Simulation of perennial ryegrass performance in the Upper North Island of New Zealand under future

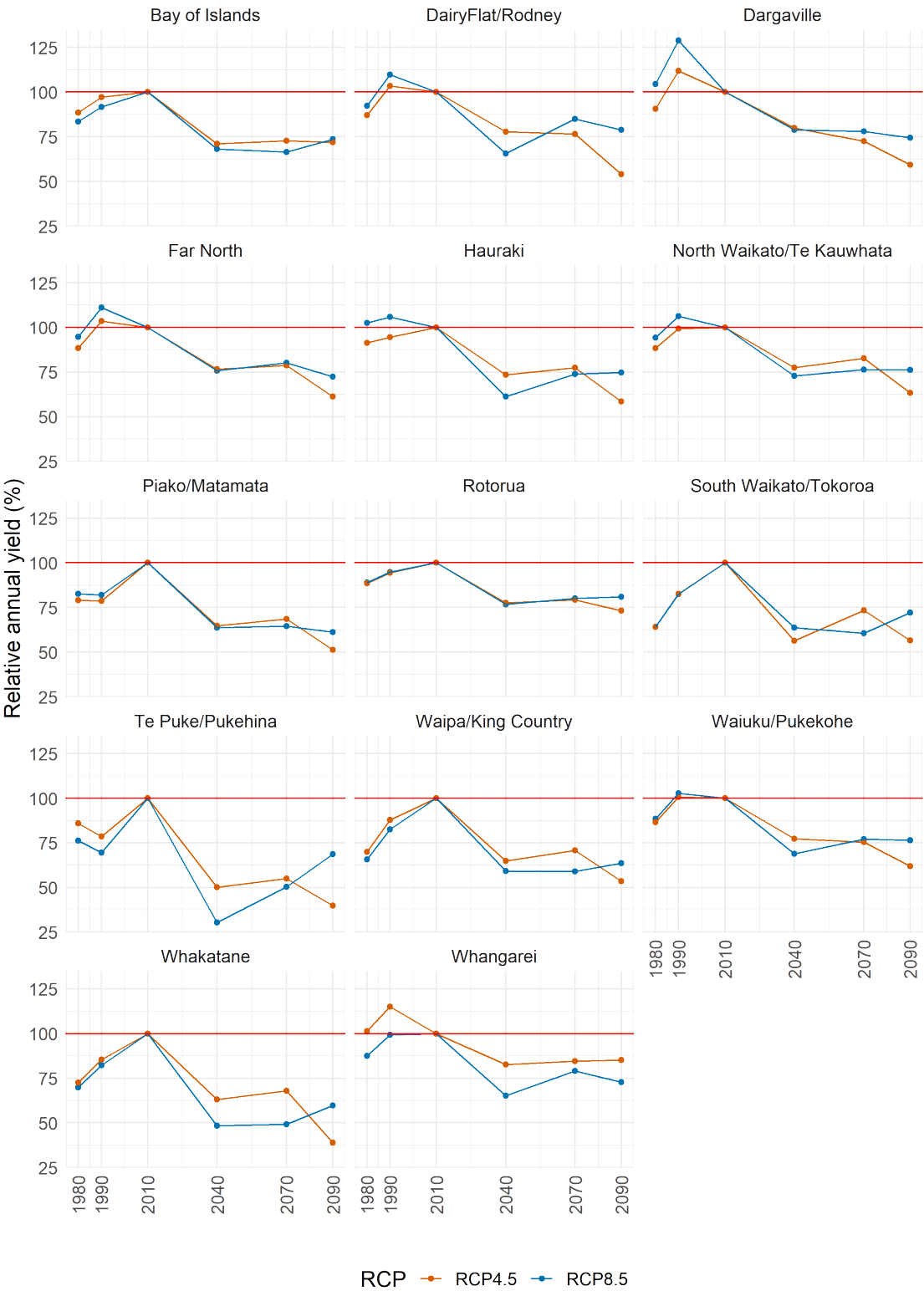


Figure 3 Median annual perennial ryegrass yield expressed as a percentage of the 'baseline' median 2010 yield (red line), for RCP4.5 (orange) and RCP8.5 (blue).

climate scenarios suggested that pasture growth rates will generally decrease throughout most of the year, with possible increases only in winter. Improved winter growth rates were previously predicted by Liewffering (2016), who compared pasture growth rates from the APSIM model for the 1980–1999 and 2030–2049 periods for Southland and Hawkes Bay sites. Improved winter growth rates could potentially be taken advantage of by farmers by moving to a winter milking schedule (Chikazhe et al., 2017). Several studies (Newton et al., 2014; Liewffering 2016; Ausseil et al., 2019) predicted higher growth rates in spring under climate change, but this was not corroborated in the current study. Their findings could have been due to the inclusion of other pasture species in their models, compensating for perennial ryegrass when growth rates were low. These studies also included a CO₂ fertilisation effect, which could lead to elevated growth responses (Li et al., 2013; Keller et al., 2014; Hovenden et al., 2019; Pers. comm. Mark Liewffering, AgResearch).

The response of perennial ryegrass pasture to changing climate is complex, since moisture, radiation, potential evapotranspiration and temperature all change simultaneously and the pasture response, as modelled in BASGRA, combines these drivers in a complex way. Teasing out the contributions of individual environmental factors is difficult and was beyond the scope of the current study.

Despite predicted improvements in perennial ryegrass pasture growth rate in winter into the future, annual yields are expected to decrease towards the end of the century, as observed in the Hawkes Bay site by Liewffering (2016). While the Southland site in Liewffering (2016) experienced an increase in annual yields into the future, it should be noted that negative daily pasture growth rates were excluded from their calculations, which could result in an overestimation of pasture yields. An increase in annual yields was also calculated by Newton et al. (2014); however, this was for the period 1960–2004 and is in line with the 1980, 1990 and 2010 annual yield predictions presented here.

A decline in annual pasture yields could result in farm systems with lower stocking rates, lower milk production, or a greater reliance on imported feed (e.g., palm kernel expeller). It could also increase dependence on crops such as maize, fodder beet and turnips, that are already widely used as supplementary feed in this region and would be likely to reduce farm profitability (Neal and Roche 2019).

It should be noted that although yields tended to vary more in the RCP4.5 scenario, they were, nevertheless, expected to be higher than in the RCP8.5 scenario. Reductions in greenhouse gasses should therefore continue to be encouraged.

Across most subregions, mid/early-autumn to mid-

spring PGR appeared to experience the least variability, while growth curves from mid-spring to mid/early-autumn had the largest variability. In agreement with this, high summer variability was predicted by Ausseil et al. (2019) and would likely result in this time of year becoming even more challenging for farmers than it already is, in terms of predicting the amount of feed available for their livestock (Glassey 2011). On the other hand, the lower variability of winter perennial ryegrass pasture growth rates supported the validity of the option to move to winter milking, as suggested by both Chikazhe et al. (2017) and Glassey et al. (2021). Either way, farmers will need to become more adaptable and resilient to feed supply variability changes in the future. Furthermore, thinning pastures can be subjected to weed and pest infestation, requiring more intervention or complete renewal (Beukes et al., 2021). The latter is costly and increases the risk of damage to the underlying soil structures.

Based on future annual yield predictions for the RCP4.5 scenario, Bay of Islands, Rotorua and Whangarei, may be able to adapt farm systems to remain perennial ryegrass-based into the future, along with Dargaville, Far North and North Waikato/Te Kauwhata for RCP8.5, as these locations are expected to retain over 70% of their 2010 yields. Te Puke/Pukehina and Whakatane, on the other hand, may suffer significant perennial ryegrass failure, in some predictions producing only up to 30% of their 2010 yields in both RCP scenarios. In these subregions, it may be best to consider alternative species to perennial ryegrass. The other subregions and scenarios modelled showed inconsistent results into the future. Yield varied from above 70% in some half-decades, to close to 50% in others. These subregions and scenarios should be prepared for periods during which perennial ryegrass performs adequately, and other periods during which it does not. Alternative species may also be considered based on the individual farmer's tolerance to risk and access to external resources.

The results for Dargaville, Far North and North Waikato/Te Kauwhata for RCP8.5 differed from those predicted in Beukes et al. (2021), which classified these regions as becoming unsuitable for perennial ryegrass-based pastoral farming into the future. In Beukes et al. (2021), ryegrass persistence in these three regions was predicted to fall from medium, to medium-low or low, which matched the decrease in annual yield in the current study. Ryegrass suitability in Beukes et al. (2021) was measured, in part, by the amount of dry matter produced in each region during the five-year period. In Dargaville, Far North and North Waikato/Tokoroa, the annual yield amounts were found to be less than 10 t DM/ha and when compared with other regions (the same regions as in the current study), these

clusters were found to be unsuitable.

For locations expected to be resilient to climate change, a farm systems adaptation approach may be necessary. Although these areas (barring Rotorua) were predicted to retain over 70% of their 2010 annual yields, their perennial ryegrass growth during summer was expected to be very low, so that farm system changes may be necessary to achieve reliable profit in the future (e.g., moving to autumn calving, incorporating alternative crops).

As well as predicting median growth rates, this study has added to the picture of the future by estimating the variability of perennial ryegrass growth rates, providing farmers with expected ranges of pasture growth throughout the year. This is an area of interest for farmers where other modelling approaches have been lacking (Kalaugher et al., 2017).

Conclusions

The mechanistic pasture model BASGRA was used with input from six NIWA climate model projections (GCMs), for two climate change scenarios (RCPs), in order to calculate future perennial ryegrass pasture growth rates for the half-decades 2010-2014, 2040-2044 and 2090-2094 in 14 dairy-dominant subregions in the Upper North Island of New Zealand (UNI). The results differed from others in the literature as they included both expected median pasture growth rates, as well as the variability around those medians.

The main perennial ryegrass growing season was predicted to occur in late-winter/spring in the future, with a secondary growing season in late-autumn/early-winter. The largest changes in pasture growth were predicted to occur during spring-summer-autumn and the smallest in winter. Summer was predicted to experience the largest variability in expected growth rates, and winter the smallest.

The current research predicts a deterioration of perennial ryegrass pasture growth rates in the UNI as a result of climate change. Worse outcomes were expected in the higher greenhouse gas scenario (RCP8.5) than in the lower greenhouse gas scenario (RCP4.5). For the RCP4.5 scenario, the subregions expected to remain suitable for perennial ryegrass are Bay of Islands, Rotorua and Whangarei. For the RCP8.5 scenario, Dargaville, Far North and North Waikato/Te Kauwhata were expected to remain suitable. Te Puke/Pukehina and Whakatane were expected to become unsuitable to support perennial ryegrass pastures in the future in both scenarios. The remaining locations and scenarios were expected to vary in suitability over time. The results highlight the need for farmers to adapt their farming practices in the future in order to remain profitable and internationally competitive.

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