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INFLUENCE OF CLIMATE CHANGE AND FUEL MANAGEMENT ON BUSHFIRE RISK IN WESTERN AUSTRALIA

Mechanical Fuel Load Reduction Utilisation project

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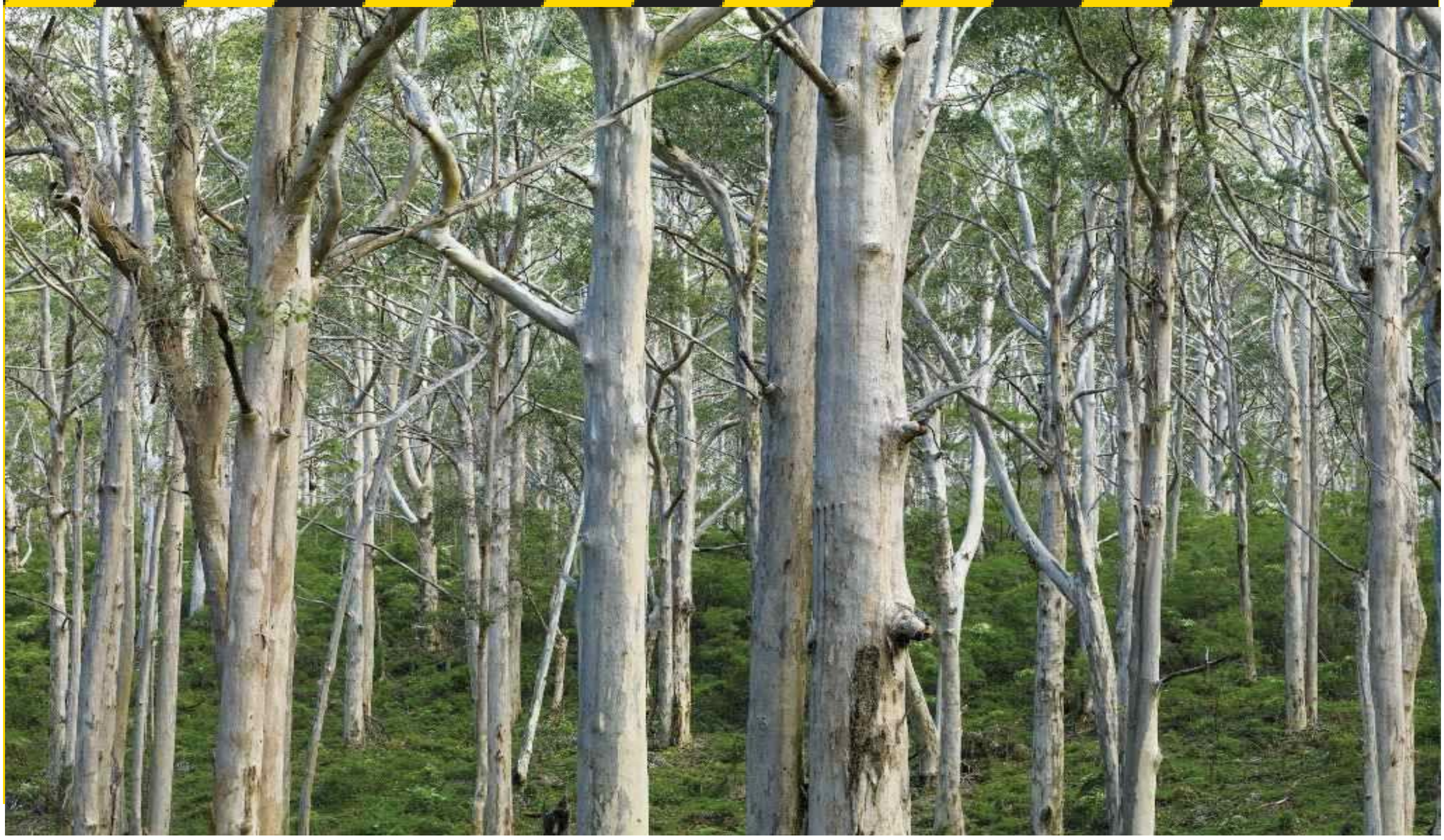

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ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Bushfire risk is likely to increase in the future due to the combined impacts of climate change and urban sprawl. This report presents the results of an analysis combining the outputs from stakeholder consultation with those from the *Unified Natural Hazard Risk Mitigation Exploratory Decision Support System* (UNHaRMED) to quantify increases in bushfire risk due to different population growth and climate change scenarios in four areas of emerging bushfire risk in Western Australia. Results indicate that increases in bushfire risks from 2018 to 2050 range between 23.9% and 59.7% (in terms of average annual loss), depending on the scenario and case study area considered. UNHaRMED is also used to assess the potential of mitigating these increases in risk via fuel load reduction.

Results indicate that fuel management can reduce future bushfire risk and that the decline in risk is positively correlated with an increase in the proportion of the landscape treated. However, our results suggest that in cases where fuel management does significantly reduce the risk of impacts posed by bushfires, this reduction was much less than an increase in risk from climate change.

It should be noted that this project focused on the rural-urban interface in alignment with the existing Bushfire Risk Management Planning approach adopted in Western Australia. As such, landscape-scale mitigation was not considered in this particular project, but would be an important consideration in future research.

END-USER PROJECT IMPACT STATEMENT

Tim McNaught, *Department of Fire and Emergency Services, WESTERN AUSTRALIA*

As state/territory jurisdictions adapt to the impacts a changing climate has on the vulnerability of communities and emergency service personnel, the role research plays to support a better understanding of mitigation measures before an event become increasingly important.

Whilst fuel management alone is not the only mitigation strategy it is none the less a crucial focus for land owners/occupiers and land managers in Western Australia. Importantly, given the potential benefit, the UNHaRMED software can offer in modelling future scenarios to inform planning, policy and investment decisions, an appreciation of the effect fuel management treatments can have in reducing costs and increasing benefits is necessary.

This research project, undertaken in a targeted way to test proof of concept, is useful in providing further foundation to how risk and vulnerability can be modelled within UNHaRMED and provide a greater appreciation of how a broader range of targeted fuel mitigation options at the rural urban interface can reduce losses or in the future other mitigation measures beside fuel management become increasingly effective.

1. INTRODUCTION

Bushfire risk is likely to increase in the future due to the combined impacts of climate change and urban sprawl. Planned burning is one of the most utilised fuel management activities, but the safe application of this method is being hampered by climate change (e.g. shrinking and shifting windows of opportunity) and potential adverse societal outcomes (e.g. smoke impact, risk of fire escape). In order to address this issue, this utilisation project is focused on assessing opportunities for using alternatives to planned burning to manage fuel load in areas of emerging bushfire risk in areas of interest to end-users in Western Australia.

As part of this project, areas of emerging bushfire risk in Western Australia (WA) were identified with the UNHaRMED Decision Support System (DSS) framework (Riddell et al., 2016), an integrated spatio-temporal model for analysing natural hazard risk within urban and rural environments, and discussion with end-users (see Jeanneau et al. (2021a) for more details). This report quantifies potential future losses due to bushfires under a range of climate and population growth scenarios in these areas and quantifies the possible reduction in risk with fuel management.

Section 2 presents a brief description of the regions of emerging bushfire risk identified by UNHaRMED and the WA end-users. Section 3 compares the change in regional bushfire risk to assess the impact of population growth and climate change on future losses. Section 4 provides an assessment of the potential reductions in future bushfire risk that fuel management activities can achieve, and Section 5 summarises the key findings.

2. IDENTIFICATION OF AREAS OF EMERGING BUSHFIRE RISK

We consulted end-users to identify key areas of emerging bushfire risk in Western Australia. We also consulted Bushfire Risk Management Plans (BRM Plans) from these areas of interest to compare the extent of current fire mitigation activities and the UNHaRMED bushfire risk outputs (see Jeanneau et al. (2021b) for details).

The discussions with end-users resulted in the selection of five major areas to focus on for this study. This selection was based on local knowledge and information presented in local BRM Plans. The five target areas for fuel management and risk reduction potential are the Gingin region, two regions in the Perth Hills (Kalamunda and Mundaring), Margaret River and the Jerramungup (Bremer Bay) region (Figure 1).

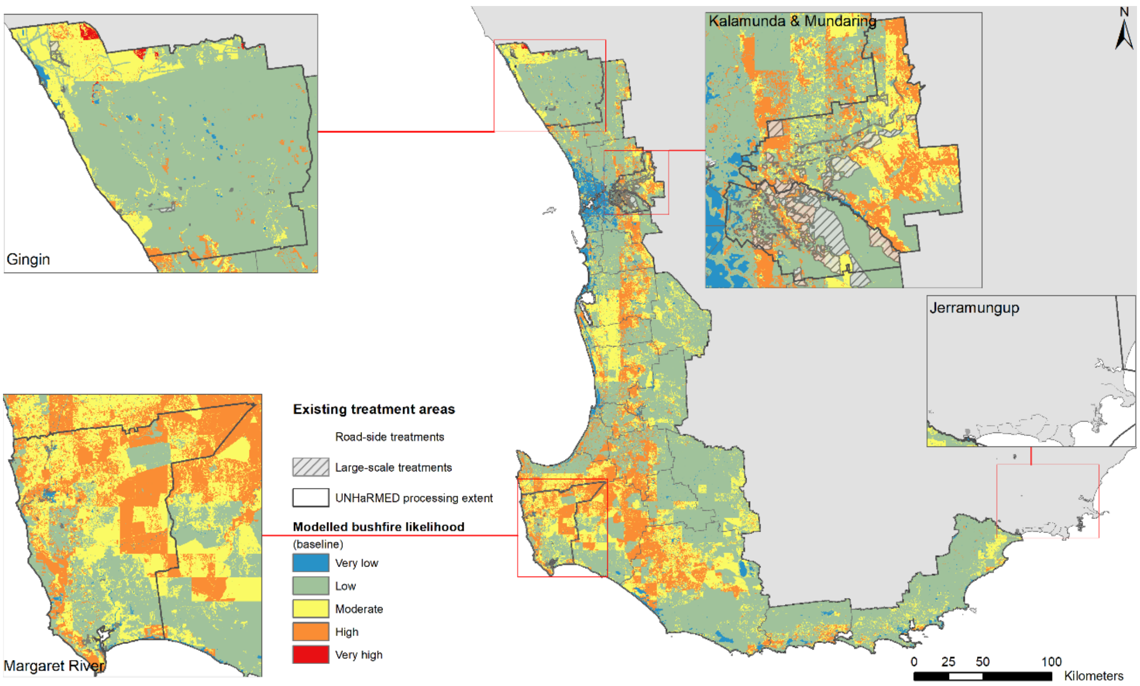

FIGURE 1. LOCATION OF THE FIVE TARGET REGIONS IN WA OVERLAYED WITH THE BASELINE BUSHFIRE LIKELIHOOD OBTAINED USING UNHARMED. NOTE THAT THE JERRAMUNGUP REGION IS CURRENTLY OUTSIDE OF THE UNHARMED PROCESSING EXTENT.

Figure 2 presents the change in bushfire risk simulated in UNHaRMED when considering population growth and severe climate change conditions (RCP 8.5). Our results indicate a likely low to moderate increase in bushfire risk for all four target regions. The City of Kalamunda and Shire of Mundaring will likely be the most impacted by severe climate change, as indicated by the proportion of these regions where bushfire risk will increase. This is consistent with current population growth projections as these two regions are part of the Perth Metropolitan area and are highly attractive[1] for residential dwellings.

[1] Western Australia Tomorrow population forecasts, Department of Planning, Land and Heritage

These results also indicate a good agreement between the level of bushfire risk simulated in UNHaRMED and the perceived levels of bushfire risk at the rural-urban interface by the relevant bushfire management agencies (represented by the location of fuel treatments (light grey patches) in Figure 2). This observation suggests that UNHaRMED is suitable for identifying future areas of emerging risk.

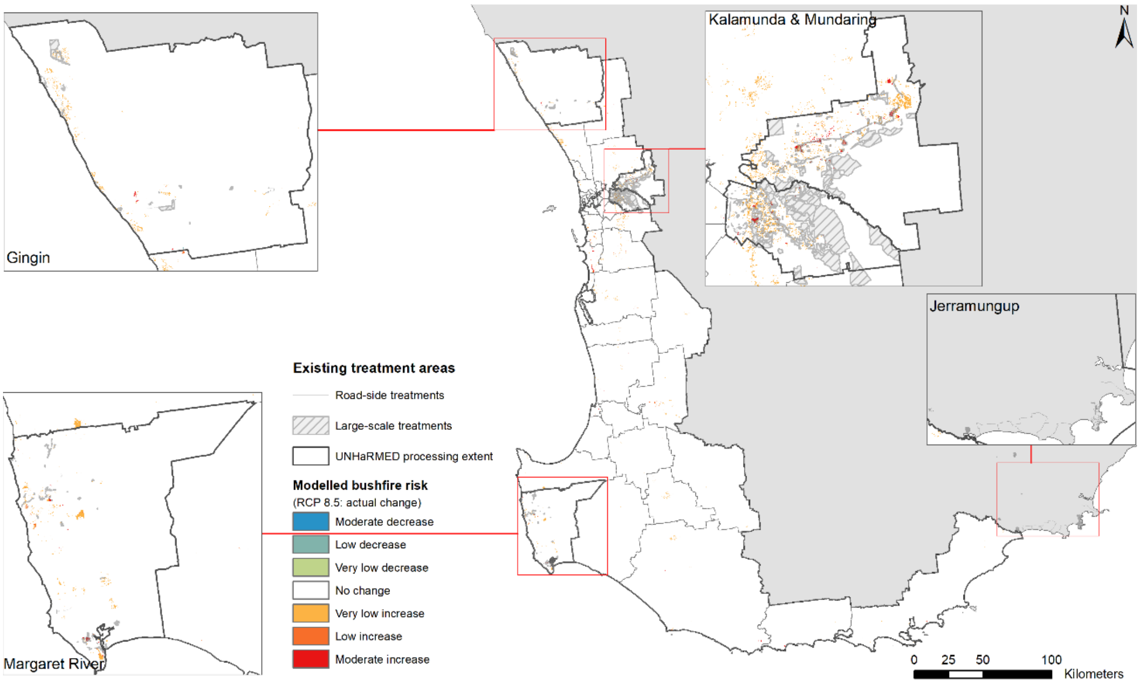

FIGURE 2. LOCATION OF THE FIVE TARGET REGIONS IN WA OVERLAYED WITH THE CHANGE IN BUSHFIRE RISK FROM POPULATION GROWTH AND SEVERE CLIMATE CHANGE (2018 VS 2050, RCP 8.5) OBTAINED USING UNHARMED. NOTE THAT THE JERRAMUNGUP REGION IS CURRENTLY OUTSIDE OF THE UNHARMED PROCESSING EXTENT.

3. DETERMINATION OF FUTURE LOSSES

We ran three simulation scenarios in UNHaRMED to test the influence of population growth and climate change on future losses due to bushfires (Table 1). Scenario 1 assumes that the climate remains the same as today and only looks at the impact of population growth. Scenario 2 and 3 include weather inputs accounting for moderate and severe climate change, respectively. All three scenarios accounted for population growth and an increase in area demand for a range of land uses (e.g. residential, commercial, industrial, etc.).

The resulting modelled bushfire risk (expressed in Average Annual Loss (AAL)) was then compared between the three simulations for each of the four areas of emerging bushfire risk, as discussed in the subsequent sections of the report.

TABLE 1. DETAILS OF THE UNHAMRED SIMULATION SCENARIOS. NOTE THAT ALL SCENARIOS ACCOUNT FOR POPULATION GROWTH AND AN INCREASE IN AREA DEMAND FOR A RANGE OF LAND USES.

Scenario	Climate Impact		
	None	*RCP 4.5 (moderate)*	*RCP 8.5 (severe)*
1a	X		
2a		X	
3a			X

3.1 INDIVIDUAL REGION ASSESSMENT

Figures 3 to 10 present the UNHaRMED simulation results for the land use at the beginning and end of the simulation (2018 and 2050, respectively) and compare the modelled AAL for 2018 with that in the year 2050 for each of the three scenarios. These results can be used to visualise where bushfire risk is located in each of the regions considered and how risk changes with population growth and climate change.

3.1.1 The Shire of Gingin

Several residential hubs are expected to grow in the Shire of Gingin along the coast (Figure 3). However, this did not significantly increase the modelled bushfire risk (Figure 4a). In contrast, if we consider the combined effect of population growth and climate change, the modelled bushfire risk increased by 5 to 10% (Figure 4b and c). The differences between the two climate change scenarios is difficult to observe. Still, closer inspection shows that bushfire risk almost doubled in the settlement north-east of Lancelin with severe climate change (RCP 8.5) compared to the moderate scenario (RCP 4.5). At the same time, it remained constant in other areas.

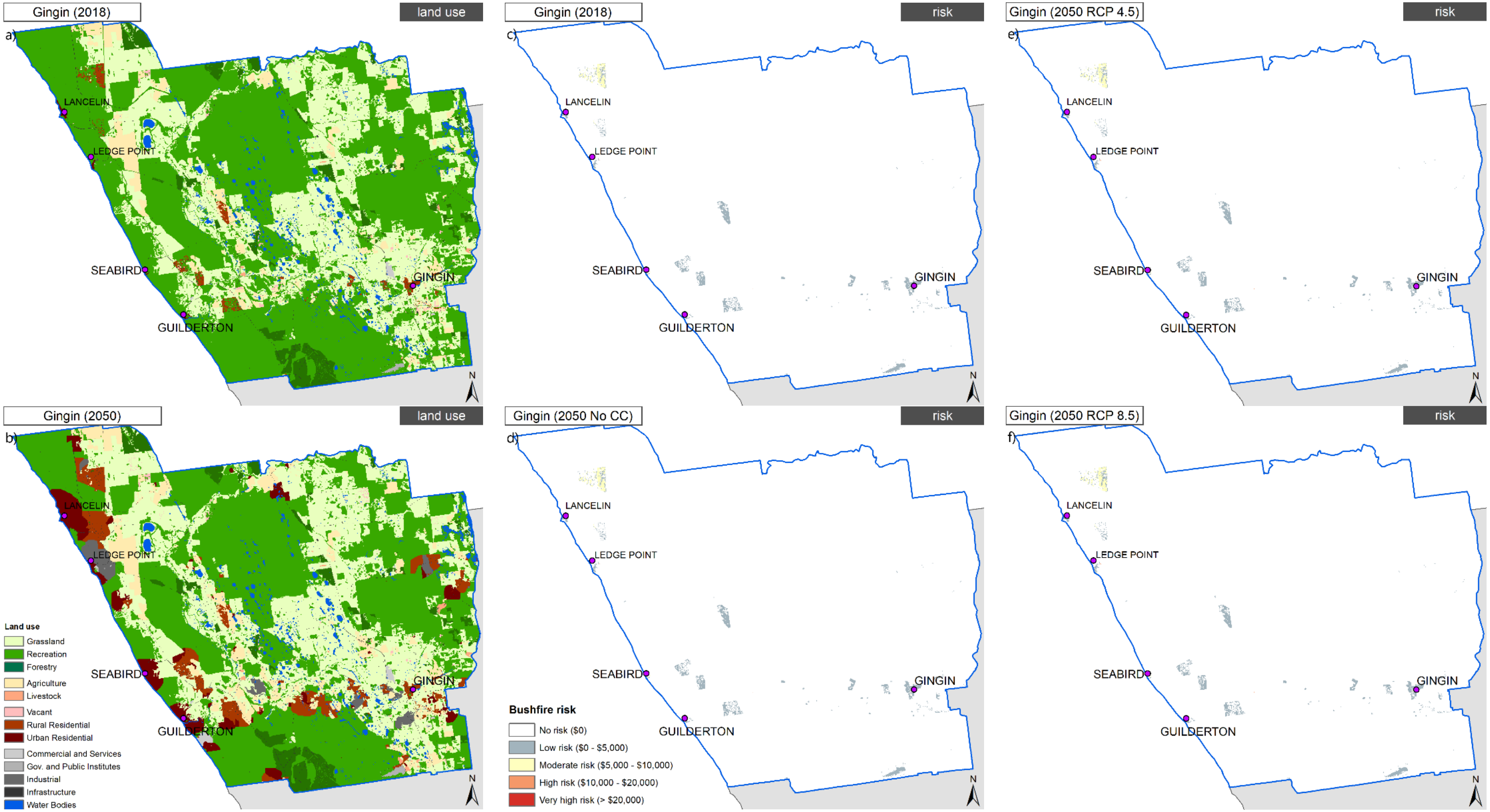

FIGURE 3. GINGIN – LAND USE 2018 VS 2050 (FIRST COLUMN) AND BUSHFIRE RISK FOR THE THREE FUTURE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5) VS 2018.

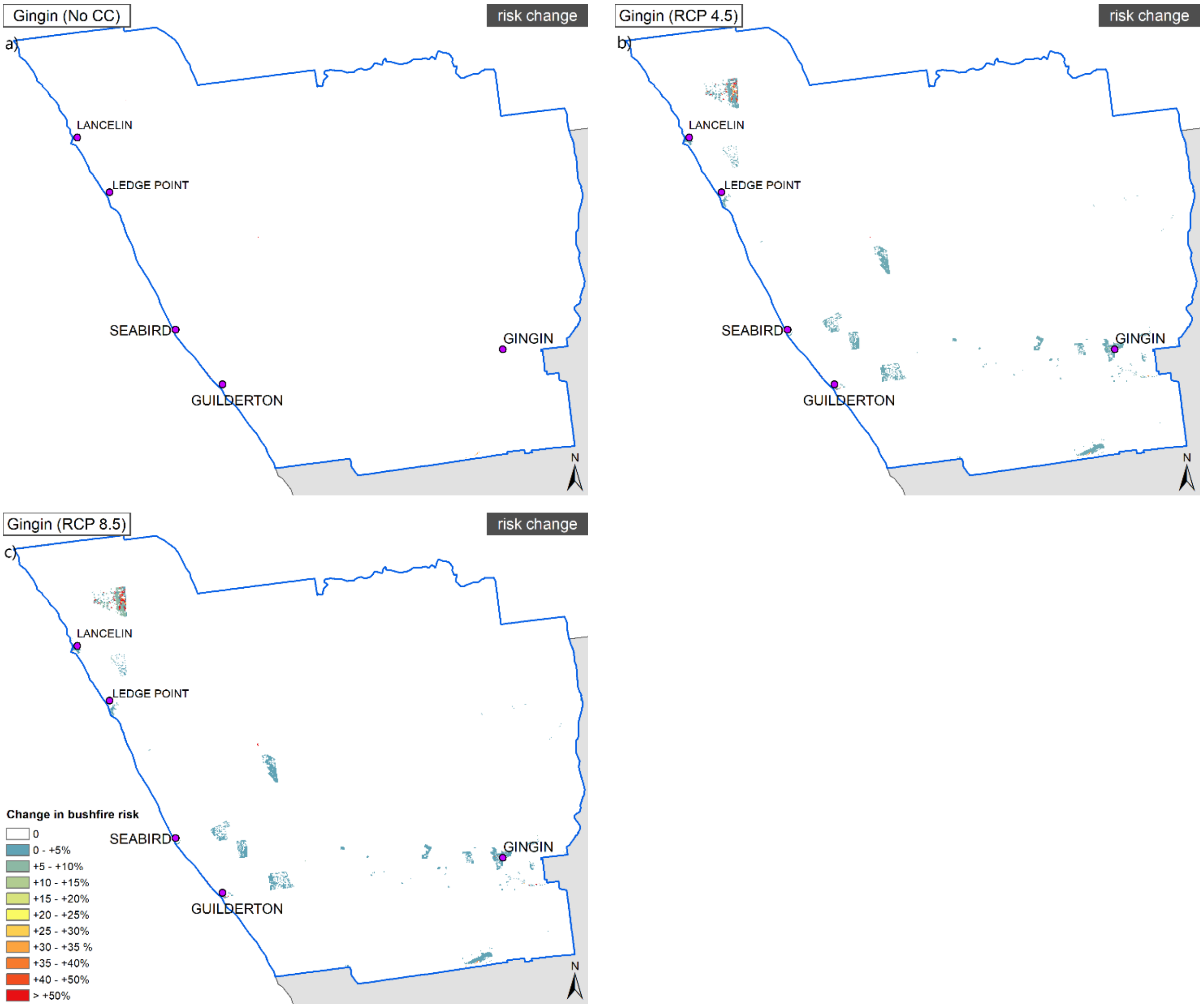

FIGURE 4. RISK CHANGE (IN %) BETWEEN 2018 AND 2050 FOR THE THREE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5)

3.1.2 The Shire of Augusta Margaret River

UNHaRMED predicted an expansion of most of the existing settlements in the Shire of Augusta Margaret River, particularly around Margaret River, Prevelly, Augusta and Gracetown (Figure 5b). This residential expansion increased modelled bushfire risk in excess of 50%, where new settlements emerged (Figure 6a). Further increases in bushfire risk were forecasted around Augusta, Margaret River and Prevelly with the consideration of climate change, with increases in risk ranging from +10% to above +50% with severe climate change (Figure 6b and c).

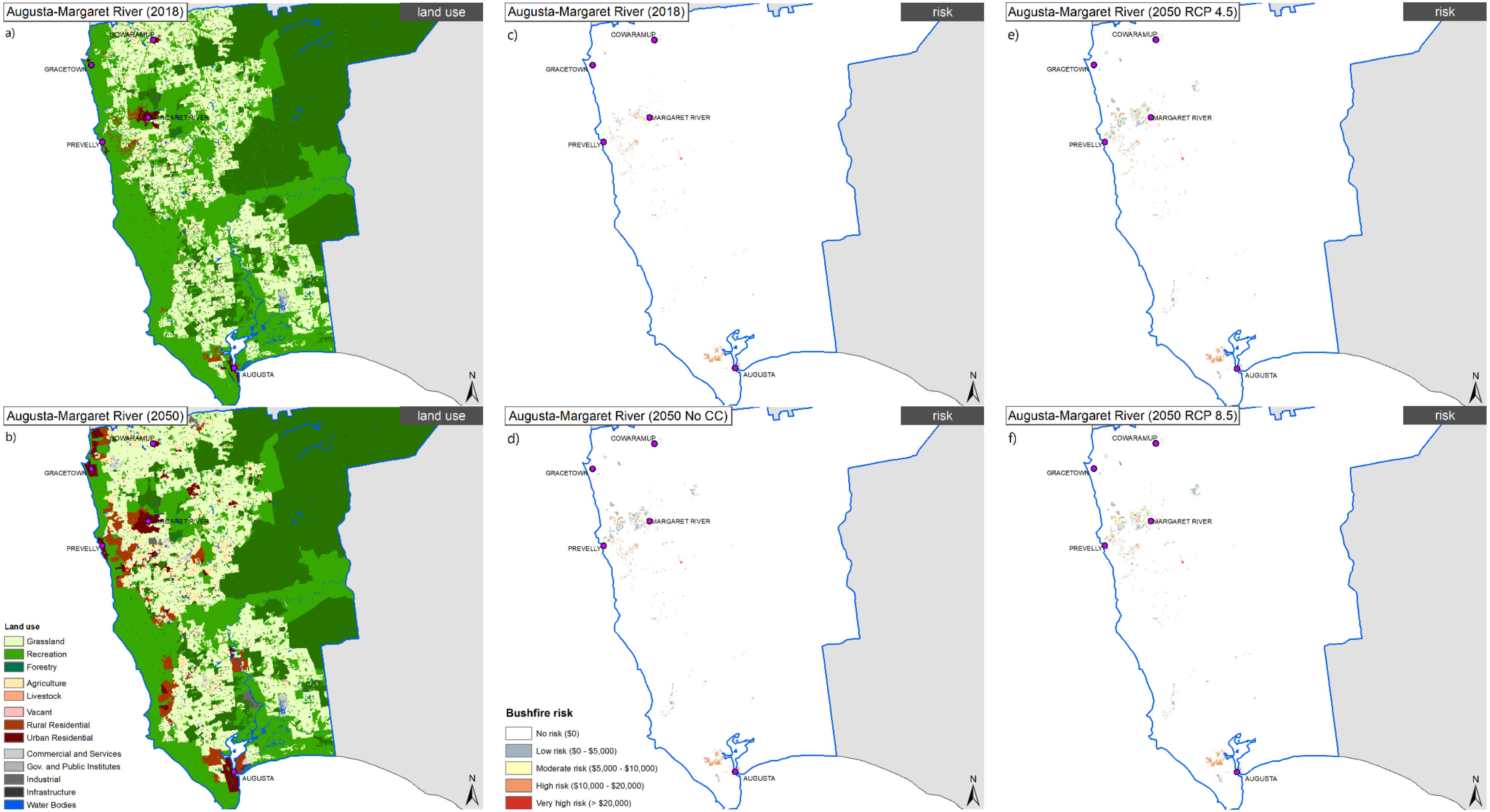

FIGURE 5. AUGUSTA-MARGARET RIVER – LAND USE 2018 VS 2050 (FIRST COLUMN) AND BUSHFIRE RISK FOR THE THREE FUTURE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5) VS 2018.

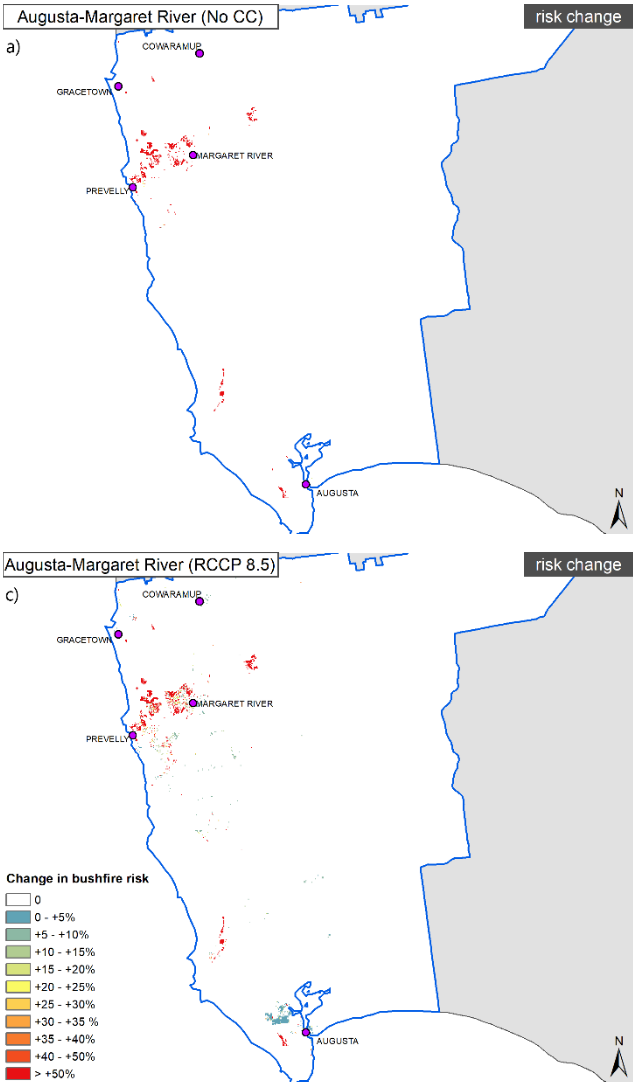

FIGURE 6. RISK CHANGE (IN %) BETWEEN 2018 AND 2050 FOR THE THREE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5)

3.1.3 The Shire of Mundaring

The majority of the existing residential centres were predicted to expand and create an interconnected hub around commercial forests (Figure 7b). This increase in population led to a sharp increase in bushfire risk (> 50%) where new settlements developed, for instance, in the south of Glen Forest and North of Mundaring (see red areas in Figure 8a). However, bushfire risk dramatically increased around existing settlements with the two climate change scenarios (Figure 8b and c). Bushfire risk increased from about 0 to 5% with the moderate climate scenario to 10 to 15% with severe climate change.

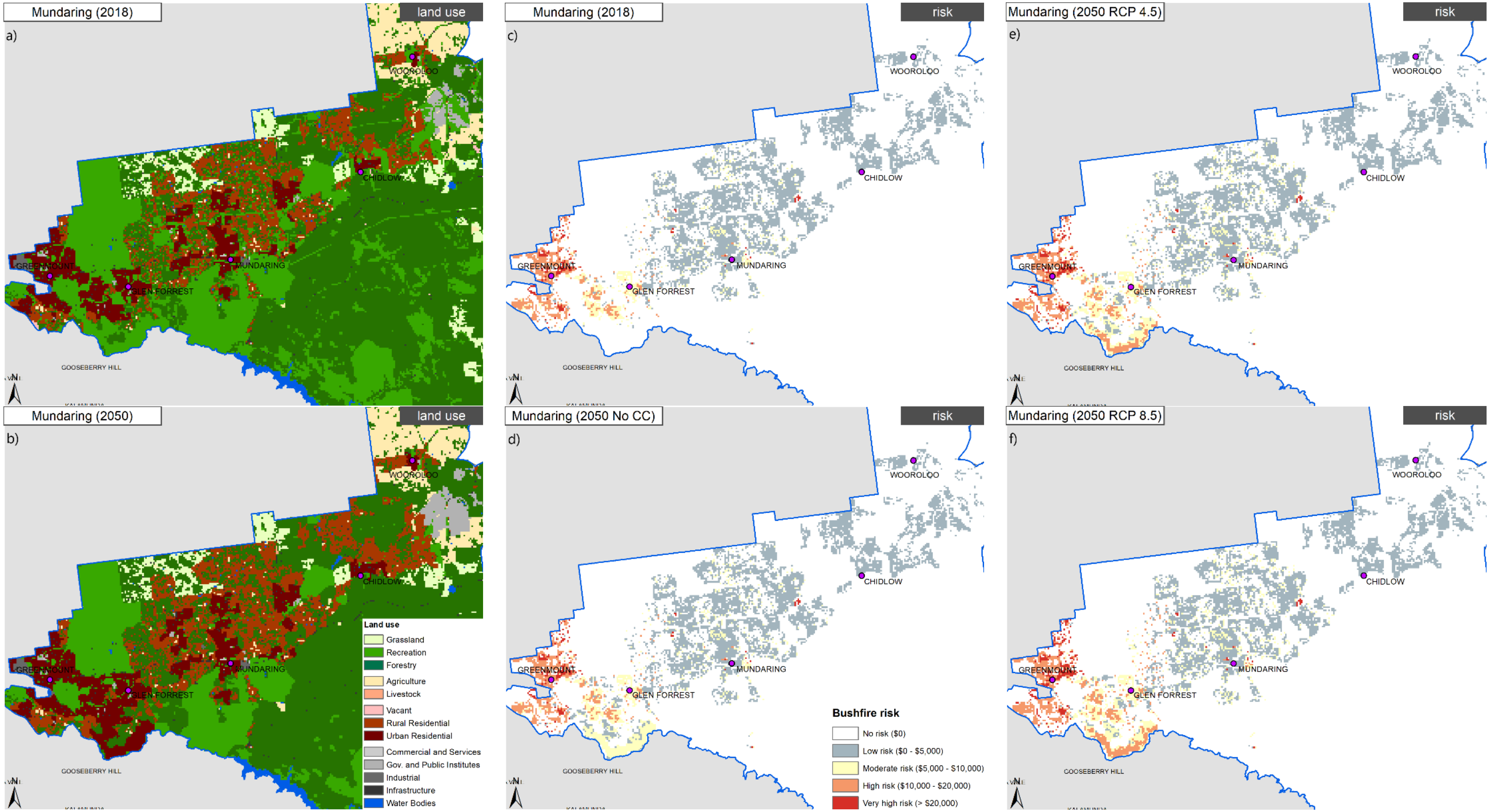

FIGURE 7. MUNDARING – LAND USE 2018 VS 2050 (FIRST COLUMN) AND BUSHFIRE RISK FOR THE THREE FUTURE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5) VS 2018.

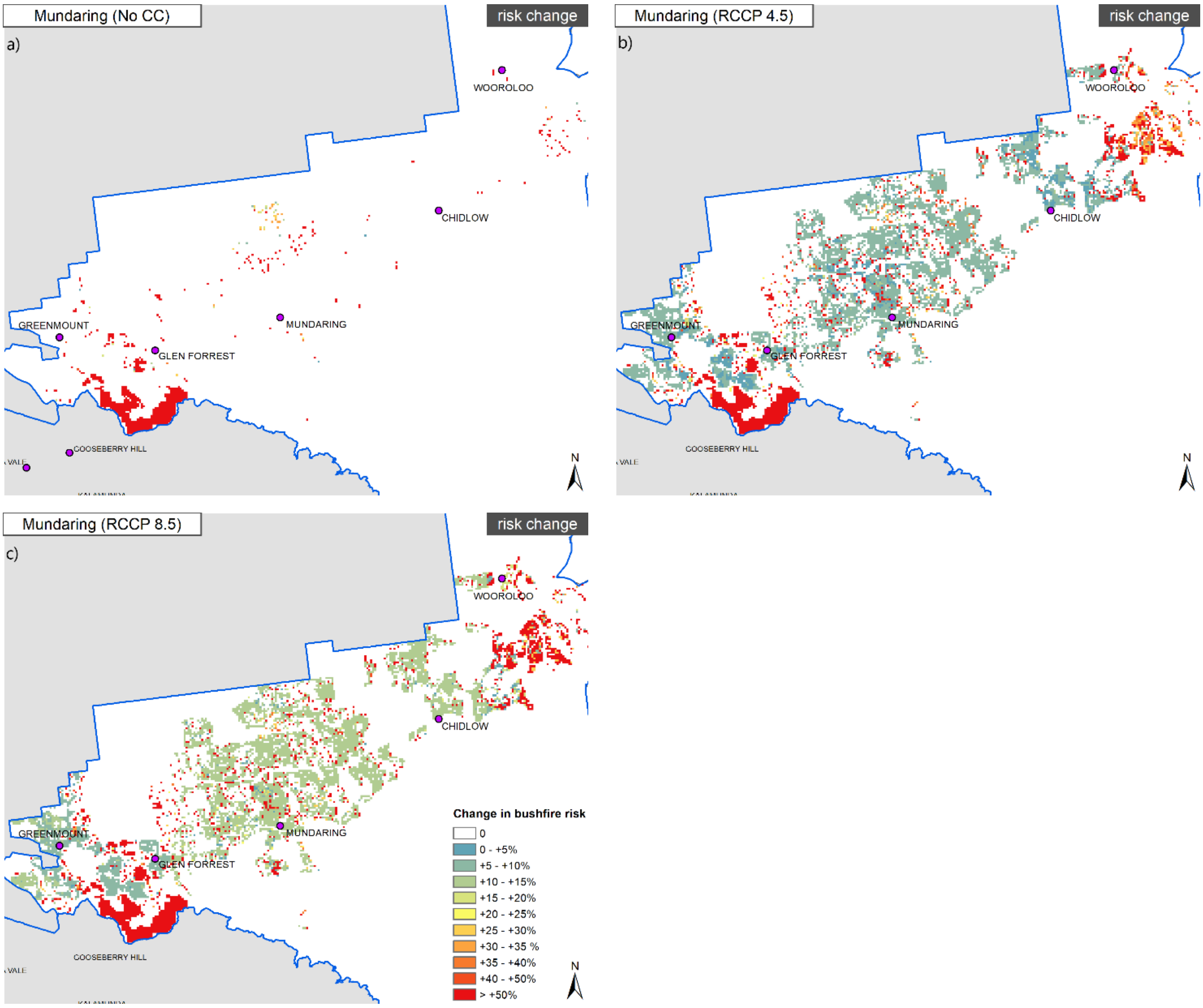

FIGURE 8. RISK CHANGE (IN %) BETWEEN 2018 AND 2050 FOR THE THREE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5)

3.1.4 The City of Kalamunda

Similarly to the Shire of Mundaring, in the City of Kalamunda, most residential areas expanded into recreational lands to create inter-connected cities as part of the population scenarios considered (Figure 9b). As expected, the creation of these new settlements increased bushfire risk compared to the initial conditions (see red areas in Figure 10). Bushfire risk was also predicted to increase further as a result of the impacts of climate change, with two-thirds of the region (between Maida Vale and Kalamunda) expecting an increase in bushfire risk from between 0-5% to 10-15% (Figure 10b and c).

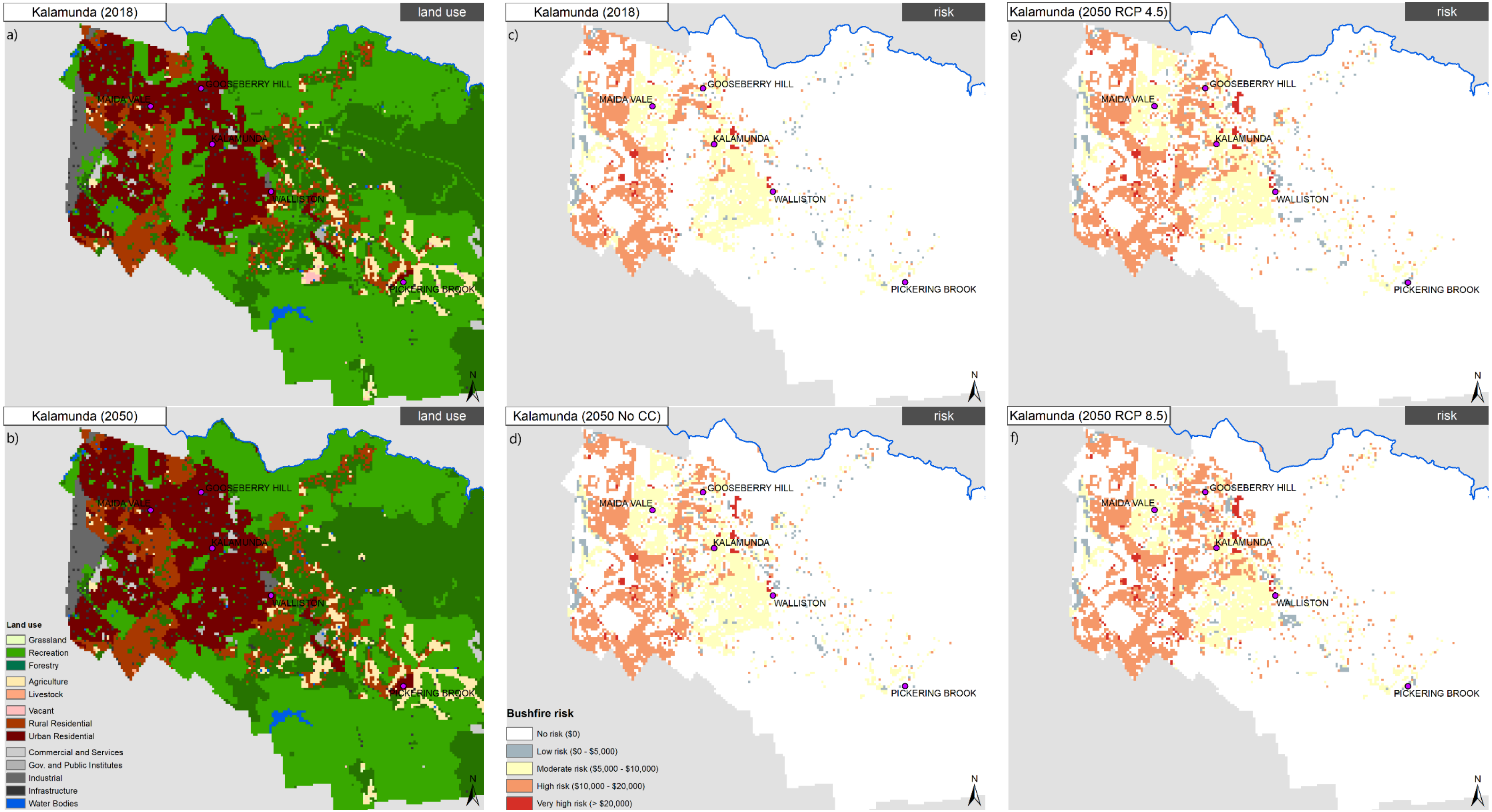

FIGURE 9. KALAMUNDA – LAND USE 2018 VS 2050 (FIRST COLUMN) AND BUSHFIRE RISK FOR THE THREE FUTURE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5) VS 2018.

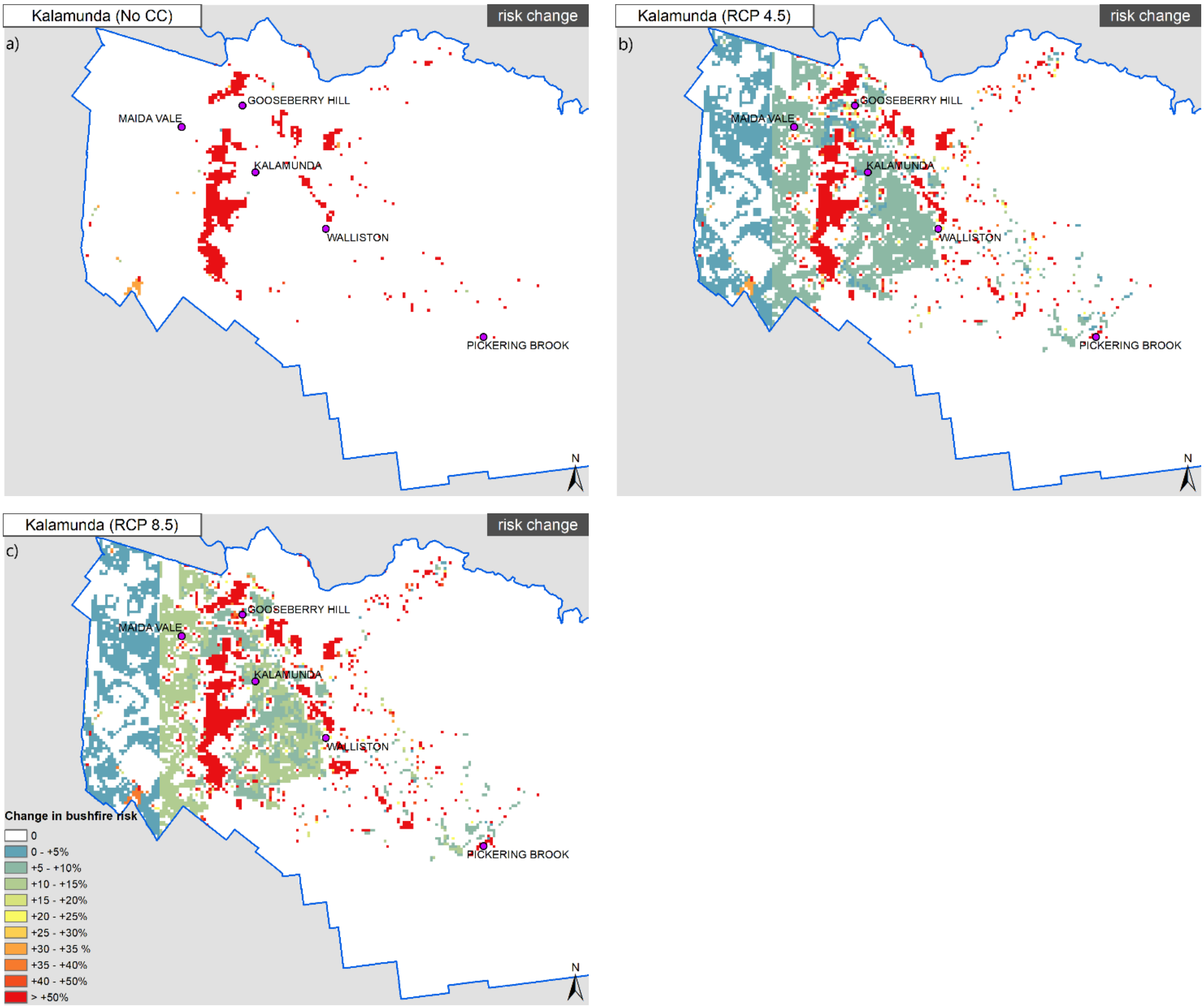

FIGURE 10. RISK CHANGE (IN %) BETWEEN 2018 AND 2050 FOR THE THREE CLIMATE SCENARIOS (NO CHANGE, RCP 4.5, RCP 8.5)

3.2 AGGREGATED ESTIMATION OF BUSHFIRE RISK

The simulation results indicate that bushfire risk is likely to increase dramatically due to the influence of climate change in three out of the four target regions (Margaret River: 42 - 57%; Mundaring: 34 - 51%; Kalamunda: 42 - 60%) (Figure 11). For the Gingin region, bushfire risk is likely to increase slightly in both climate change scenarios (RCP 4.5: 27%; RCP 8.5: 32%) compared to the first year of the simulation (Figure 11).

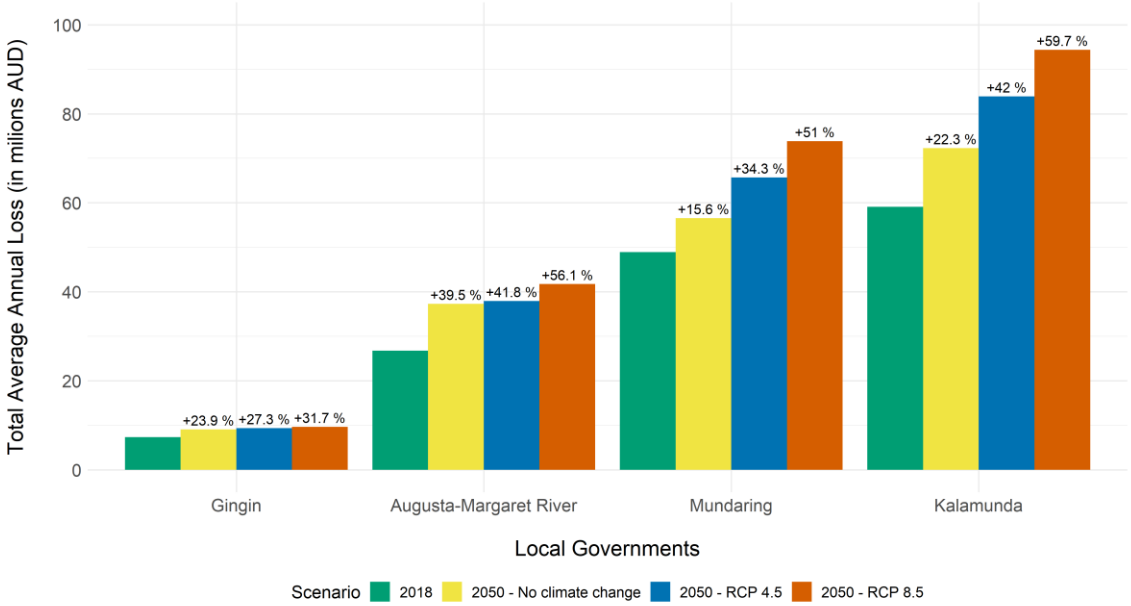

FIGURE 11. SCENARIOS 1A, 2A, AND 3A: TOTAL AVERAGE ANNUAL LOSS FROM BUSHFIRES (IN MILIONS AUD) FOR THE FOUR TARGET REGIONS. NOTE THE PERCENTAGE DISPLAYED ON TOP OF EACH DIAGRAM REPRESENTS THE INCREASE IN TOTAL AAL FROM THE BASELINE YEAR OF 2018.

The "no climate change scenario" results indicate that even if the climate conditions remained the same as today, three out of the four target regions would likely observe an increase in total Average Annual Loss of around 24 to 40% compared with the first year of the simulation. This observation can be correlated with urban sprawl into natural reserves, increasing the length of the rural-urban interface.

Figure 12 indicates that the total AAL from bushfires was about ten times higher in the Perth Hills than that of the other two more rural regions (Gingin and Augusta – Margaret River). However, the total AAL was within the same order of magnitude for all four regions if only rural residential areas were considered. This observation highlights the need for better quantification of bushfire risk in UNHaRMED to also account for the loss of ecosystem services and other non-market value resources (see Jeanneau et al. (2021c) for more details).

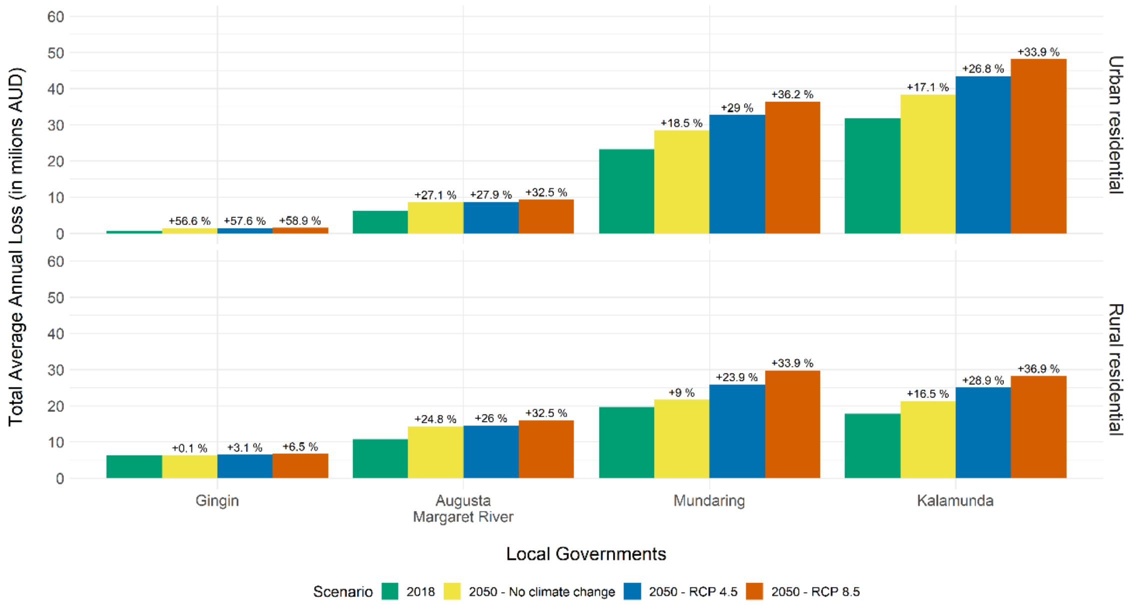

FIGURE 12. SCENARIOS 1A, 2A, AND 3A: TOTAL AVERAGE ANNUAL LOSS FROM BUSHFIRES (IN MILLIONS AUD) FOR THE FOUR TARGET REGIONS DISTINGUISHING BETWEEN RURAL AND URBAN RESIDENTIAL LAND USES. NOTE THE PERCENTAGE DISPLAYED ON TOP OF EACH DIAGRAM REPRESENTS THE INCREASE IN TOTAL AAL FROM THE BASELINE YEAR OF 2018.

4. IMPACT OF FUEL MITIGATION ON FUTURE LOSSES FROM BUSHFIRES

4.1 METHOD DESCRIPTION

The same three simulation scenarios as outlined in Section 3 in UNHaRMED were run to test the influence of fuel management on future losses from bushfires (Table 2). Fuel management activities were conducted as a one-off treatment applied in the year before the end of the simulation (2049). The main aim was to quantify the potential benefit of fuel management at the rural-urban interface and identify if fuel management could reduce future bushfire risk.

TABLE 2. DETAILS OF THE UNHAMRED SIMULATION SCENARIOS WITH FUEL MANAGEMENT. NOTE THAT ALL SCENARIOS ACCOUNT FOR POPULATION GROWTH AND AN INCREASE IN AREA DEMAND FOR A RANGE OF LAND USES.

Scenario	Fuel management	Climate Impact		
	Yes	*None*	*RCP 4.5 (moderate)*	*RCP 8.5 (severe)*
1b	X	X		
2b	X		X	
3b	X			X

Fuel management in UNHaRMED is currently intended to reset the time since last fire (fuel age) to zero. This option should then reduce the fire behaviour on the treated and neighbouring cells and reduce the AAL the year following the treatment application. Currently, the DSS does not distinguish between different fuel management approaches and defines all fuel management activities as a direct reduction in fuel load. We acknowledge that only applying a fuel treatment at the end of the simulation (year 2049) would lead to an artificially high bushfire risk due to the accumulation of fuel load over time (growth of vegetation). In a real-world environment, vegetation growth would be controlled by natural or planned burns and other fuel management activities over the years.

In this exercise, the plausible future fuel management strategies were developed based on information from future land use and bushfire risk maps produced by UNHaRMED, a geospatial dataset combining existing treatments undertaken by DFES[2] and standard practices commonly used to define fuel management strategies.

[2] DFES Bushfire Risk Management System (BRMS) Assets & Treatments. https://catalogue.data.wa.gov.au/dataset/dfes-bushfire-risk-management-system-brms-assets-treatments

The choice of the location for treatment cells was decided by the following rules:

- Treatments can be applied on the following land uses
  - Vacant
  - Recreation (e.g. conservation and natural environments)
  - Plantation forests if they are close to urban and residential land uses
- Treatments are preferred on cells close to urban or rural residential land uses
- Treatments are preferred on cells where the bushfire risk modelled in UNHaRMED is high

4.2 RESULTING CHANGE IN BUSHFIRE RISK WITH FUEL MANAGEMENT

Following the rules described above, about 0.3 - 0.4% of the landscape was treated for the Shires of Gingin and Augusta-Margaret River (Table 3). This is consistent with the fact that residential hubs represent a very small proportion of the land uses in these two regions. On the other hand, fuel management was applied to about 3.4% of the landscape for the Shire of Mundaring and about 10.5% of the landscape for the City of Kalamunda (Table 3). These values are consistent with those reported in the literature (Clarke et al., 2020a). For example, the *Prescribed Burning Atlas* reports that fuel management treatments are generally applied to 0 to 15% of the landscape (Clarke et al., 2019, Clarke et al., 2020b).

Overall, the total AAL reduced slightly (between 0.3 to 4%) compared to the no-mitigation scenarios for all regions, demonstrating the benefit of fuel management in reducing bushfire risk at the rural-urban interface (Table 3, Figure 13). The higher reduction in bushfire risk in the Shire of Mundaring and the City of Kalamunda also indicates that treating a larger proportion of the landscape was more effective for bushfire risk management (Table 3 and Figure 13).

TABLE 3. CHANGE IN TOTAL AAL FOR THE THREE CLIMATE CHANGE SCENARIOS AND IMPACT OF FUEL MANAGEMENT. * THE PROPORTION OF THE LOCAL GOVERNMENT AREA TREATED IN PERCENT IS PRESENTED IN PARENTHESIS. ** THE ABSOLUTE CHANGE IN TOTAL AAL (IN AUD) IS PRESENTED IN PARENTHESIS (i.e. TOTAL AAL SCENARIO b - TOTAL AAL SCENARIO a)

Local Government	Scenario	Fuel management	Total area (ha)	Total area treated (ha)*	Total AAL (in millions AUD)	Change in total AAL compared to no-mitigation option (%)**
Gingin	1a	No	320,705	0	9.11	
	1b	Yes		1,048 (0.3%)	9.08	-0.3 (-$28,727)
	2a	No		0	9.36	
	2b	Yes		1,048 (0.3%)	9.33	-0.3 (-$29,220)
	3a	No		0	9.68	
	3b	Yes		1,048 (0.3%)	9.65	-0.3 (-$30,754)
Augusta - Margaret River	1a	No	212,129	0	37.33	
	1b	Yes		857 (0.4%)	37.05	-0.7 (-$276,087)
	2a	No		0	37.95	
	2b	Yes		857 (0.4%)	37.67	-0.7 (-$275,429)
	3a	No		0	41.76	
	3b	Yes		857 (0.4%)	41.47	-0.7 (-$287,744)
Mundaring	1a	No	64,297	0	56.53	
	1b	Yes		2,386 (3.4%)	54.18	-4.2 (-$2,346,283)
	2a	No		0	65.66	
	2b	Yes		2,386 (3.4%)	63.09	-3.9 (-$2,570,843)
	3a	No		0	73.86	
	3b	Yes		2,386 (3.4%)	71.27	-3.5 (-$2,589,386)
Kalamunda	1a	No	32,394	0	72.30	
	1b	Yes		3,414 (10.5%)	70.32	-2.7 (-$1,974,400)
	2a	No		0	83.92	
	2b	Yes		3,414 (10.5%)	81.76	-2.6 (-$2,158,317)
	3a	No		0	94.35	
	3b	Yes		3,414 (10.5%)	92.23	-2.3 (-$2,129,036)

Although the proportional change in bushfire risk between the mitigation (scenarios b) and no-mitigation scenarios (scenarios a) decreased slightly with more severe climate change, the increase in absolute change in risk was non-negligible (Table 3). Moreover, the absolute change in total AAL with the application of fuel management was greater in the climate change scenarios (2b and 3b) than in the no-climate change scenario (1b) (Table 3). These observations suggest that fuel management can be used to reduce the impact of climate change on future bushfire risk.

However, our results suggest that in the settings used, where the fuel treatment was only applied in the last year of the simulation, even if fuel management reduced the risk of impacts posed by bushfires, this reduction was much less than the increase in risk from climate change (scenarios 2b and 3b). These results could be explained by the fact that fuel load reduction was only applied to a very small fraction of the landscape (0.3 – 10%) on a single year (2049). Another potential explanation for this limited reduction could be that fuel reduction activities were not always located directly adjacent to valued assets, which the fire spread and risk calculation model in UNHaRMED might not have picked up.

Nonetheless, these observations indicate that other mitigation options will likely be needed to reduce bushfire risk in the future. For example, the level of fuel management will likely need to increase in light of climate change (e.g. higher revisit frequency to specific sites, increase to the surface treated on a given year, etc.). Another mitigation strategy could combine different zoning strategies to limit development into high-bushfire risk areas with fuel reduction activities.

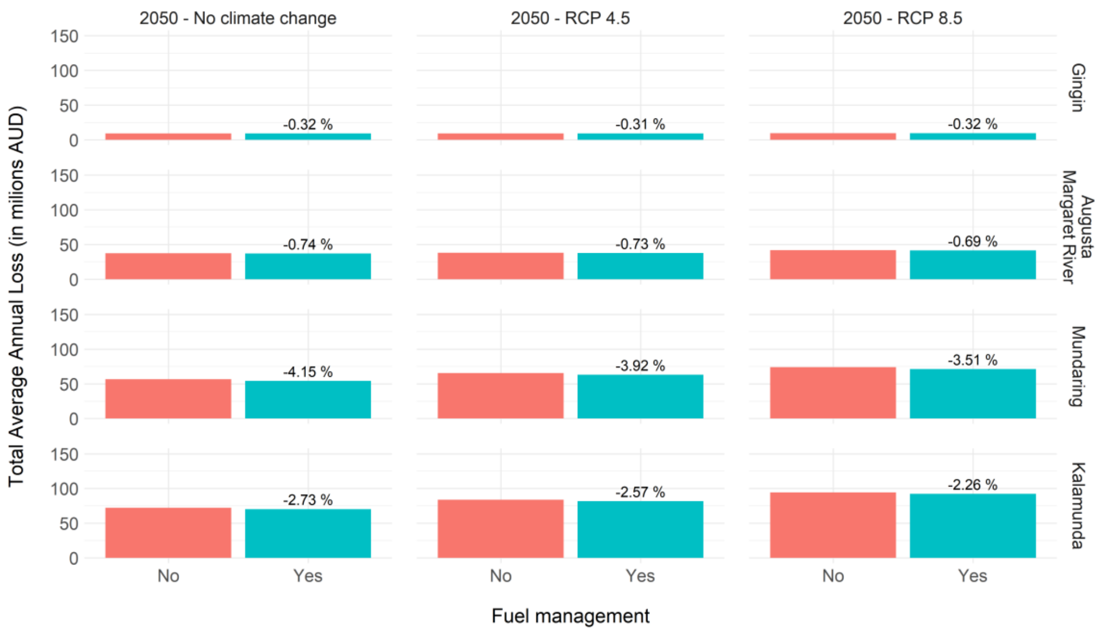

FIGURE 13. IMPACT OF FUEL MANAGEMENT ON THE TOTAL AVERAGE ANNUAL LOSS FROM BUSHFIRES (IN MILIONS AUD) FOR THE FOUR TARGET REGIONS UNDER THREE FUTURE CLIMATE SCENARIOS. NOTE THE PERCENTAGE DISPLAYED ON TOP OF EACH DIAGRAM REPRESENTS THE RELATIVE CHANGE IN TOTAL AAL DUE TO FUEL MANAGEMENT.

5. SUMMARY

Overall, this report demonstrated that UNHaRMED could be used to (i) identify areas for emerging bushfire risk, (ii) quantify the impact of climate change on future losses due to bushfires, and (iii) quantify to what extent fuel management strategies could mitigate future bushfire losses.

Our results indicate that increases in bushfire risk from 2018 to 2050 (in terms of Average Annual Loss) range between 23.9% and 59.7%, depending on the scenario and case study area considered. UNHaRMED was also used to assess the potential of mitigating these increases in risk via fuel load reduction. Results indicate that fuel management can reduce future bushfire risk and that the decline in risk is positively correlated with an increase in the proportion of the landscape treated. However, our results suggest that in cases where fuel management does significantly reduce the risk of impacts posed by bushfires, this reduction was much less than the increase in risk from climate change. This observation indicates that other mitigation options will be needed to reduce bushfire risk in the future such as targeted zoning policies, increased level of fuel management or a combination of both.

In this report, plausible future fuel management strategies were developed based on information from future land use and bushfire risk maps produced by UNHaRMED, a geospatial dataset combining existing treatments undertaken by DFES and standard practices commonly used to define fuel management strategies. In the future, a general conceptual approach could be developed to identify locations for fuel management strategies based on local knowledge of conditions under which fuel management activities are suitable. This work would ensure that fuel management locations are selected more objectively and correspond more closely to local conditions.

This research mainly focused on fuel management at the rural-urban interface to closely represent the current Bushfire Risk Management Planning approach adopted in Western Australia. Further work could also explore the influence of landscape-scale mitigation strategies on future bushfire risk to increase the resilience of future bushfire risk management planning. For instance, the area where fuel management is conducted could be modulated to create a range of treatment mosaics across the landscape. Similarly, the distance from specific assets could also be adjusted to test this hypothesis.

The integration of fuel mitigation in UNHaRMED could also be improved in the future. New input data, an improved understanding of bushfire modelling and the combination of existing approaches could be explored to modify how fuel mitigation is integrated in the software. For example, physically-based dynamic bushfire models such as Phoenix (Tolhurst et al., 2008), Spark (Miller et al., 2015) and Aurora (Steber et al., 2012) could be coupled with Monte Carlo Simulations (MCS) to identify the most likely fire paths and fire front direction for a set of environmental conditions. Results from the MCS approach could help us design new fire spread functions to improve how fuel management is implemented in UNHaRMED.

TEAM MEMBERS

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Dr Aaron Zecchin (University of Adelaide): Key Researcher

A/Prof Hedwig van Delden (Research Institute for Knowledge Systems (RIKS) / University of Adelaide): Key Researcher, UNHaRMED development

Roel Vanhout: UNHaRMED software development

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End-user organisation	End-user representative
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Department for Environment and Water (DEW)	Mike Wouters Simeon Telfer
Tasmanian Fire Services (TFS)	Louise Mendel

REFERENCES

1 CLARKE, H., BRADSTOCK, R., PRICE, O., CIRULIS, B., PENMAN, T. & BOER, M. 2020a. The Prescribed Burning Atlas: a new system to plan effective prescribed burns. Melbourne: Bushfire and Natural Hazard CRC.

2 CLARKE, H., CIRULIS, B., BRADSTOCK, R., BOER, M. M., PENMAN, T. & PRICE, O. 2019. A new decision support tool for prescribed burning risk assessment. *Bushfire and Natural Hazards CRC & AFAC conference*. Melbourne.

3 CLARKE, H., CIRULIS, B., PENMAN, T., PRICE, O., BOER, M. M. & BRADSTOCK, R. 2020b. From hectares to tailor-made solutions for risk mitigation – Final report. Melbourne: Bushfire and Natural Hazards CRC.

4 JEANNEAU, A., ZECCHIN, A., VAN DELDEN, H., MCNAUGHT, T. & MAIER, H. 2021a. Identification of Fuel Management Locations and Risk Reduction Potential - Milestone M3 for Mechanical Fuel Load Reduction Utilisation Project for the Bushfire and Natural Hazard CRC. Melbourne: Bushfire and Natural Hazards CRC.

5 JEANNEAU, A., ZECCHIN, A., VAN DELDEN, H., MCNAUGHT, T. & MAIER, H. 2021b. Influence of climate change and fuel management on bushfire risk in Western Australia - Milestone 2 and Deliverable 2 for the Mechanical Fuel Load Reduction Utilisation Project. Melbourne: Bushfire and Natural Hazards CRC.

6 JEANNEAU, A., ZECCHIN, A., VAN DELDEN, H., MCNAUGHT, T. & MAIER, H. 2021c. Opportunities for alternative fuel load reduction approaches - Summary report - Milestone 6 and Deliverable 4 for the Mechanical Fuel Load Reduction Utilisation Project.

7 MILLER, C., HILTON, J., SULLIVAN, A. & PRAKASH, M. SPARK – A Bushfire Spread Prediction Tool. *In:* DENZER, R., ARGENT, R. M., SCHIMAK, G. & HŘEBÍČEK, J., eds. Environmental Software Systems. Infrastructures, Services and Applications, 2015// 2015 Cham. Springer International Publishing, 262-271.

8 RIDDELL, G. A., MAIER, H. R., VAN DELDEN, H., NEWMAN, J. P., ZECCHIN, A. C., VANHOUT, R., DANIELL, J., SCHÄFER, A., DANDY, G. C. & NEWLAND, C. P. A Spatial Decision Support System for Natural Hazard risk reduction policy assessment and planning. Research Forum 2016: Proceedings from the Research Forum at the Bushfire and Natural Hazards CRC & AFAC Conference, 2016. Bushfire and Natural Hazards CRC ISBN: 978-0-9941696-6-2 September 2016, 133.

9 STEBER, M., ALLEN, A., JAMES, B. & MOSS, K. Aurora: Enhancing the capabilities of Landgate's FireWatch with fire-spread simulation. Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum, 2012.

10 TOLHURST, K., SHIELDS, B. & CHONG, D. 2008. Phoenix: development and application of a bushfire risk management tool. *Australian journal of emergency management,* 23**,** 47-54.