PEOPLE ARE THE PROBLEM AND THE SOLUTION:

CHARACTERIZING WILDFIRE RISK AND RISK MITIGATION IN A WILDLAND-URBAN INTERMIX AREA IN THE SOUTHERN GULF ISLANDS

by

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ABSTRACT

People play an important role in both causing and mitigating risk in forest-urban intermix areas. We developed a wildfire risk assessment model that characterizes the nature and causes of wildfire risk and evaluates the effectiveness of risk mitigation strategies for a wildland-urban intermix area in the southern Gulf Islands, British Columbia, Canada. The risk maps produced highlight the significance of both human-caused fire ignitions and residential developments' vulnerability to wildfire in producing wildfire risk. Wildfire managers should recognize that people, as much or more than biophysical factors such as fuel type or topography, drive wildfire risk in wildland-urban intermix areas such as those found in the Gulf Islands. As such, successful wildfire mitigation strategies should be designed to encourage changes in human behaviour as it relates to fire ignition and residential development. Furthermore, a successful risk assessment must involve stakeholders, building their capacity to undertake ongoing risk mitigation initiatives.

Keywords: wildfire risk assessment; wildland-urban intermix; southern Gulf Islands; WUI; wildland-urban interface; wildfire risk mitigation; wildfire consequences; wildfire probability.

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1: INTRODUCTION

The social and environmental contexts for fire management are changing rapidly across North America. Climate change continues to increase the frequency and size of forest fires (Westerling et al. 2006) and, in historically low-severity fire regimes, fire intensity is increasing due to fire suppression and associated fuel build-ups (Agee 1998; Brown et al. 2004; Kauffman 2004; Noss et al. 2006). Associated with these record areas-burnt are record fire suppression budgets (Dombeck et al. 2004). Coupled with increasing fire suppression costs are diminishing returns for each additional dollar spent on fire suppression. Concurrently, rural development of previously forested areas is expanding the interface between forested and rural areas (Gude et al. 2008; Radeloff et al. 2005; Theobald and Romme 2007), increasing the *consequences* of wildfires when they do occur.

Whereas wildfire management has traditionally been understood as fire suppression and prevention, today's changing fire management conditions are prompting land managers to expand wildfire management practices to include forest fire risk assessment (Canadian Wildland Fire Strategy Assistant Deputy Ministers Task Group 2005; Filmon 2004; Union of British Columbia Municipalities 2005; United States Government 2002). Where it may not be possible to prevent or suppress all forest fires, a risk assessment guides the allocation of fire prevention, suppression, and asset protection resources by using a model to predict where forest fires are likely to do the most damage (Canadian Wildland Fire Strategy Assistant Deputy Ministers Task Group 2005; Filmon 2004; Haight et al. 2004; Johnson et al. 2005; Union of British Columbia Municipalities 2005; United States Government 2002). A risk assessment can also be used to evaluate the relative effectiveness of proposed forest fire risk mitigation strategies by simulating management actions in the model and then comparing the resulting changes in risk levels (eg. B.A. Blackwell and Associates Ltd. 2004; Ohlson et al. 2003). Most importantly, encouraging communities to identify and describe their own risk mitigation strategies is the best way to build a community's capacity to address wildfire risk and furnish sustainable wildfire mitigation projects (Steelman and Kunkel 2004).

In an effort to address the wildfire concerns of residents in the southern Gulf Islands, the Gulf Islands National Park Reserve (GINPR; on the southwest coast of British Columbia, Canada) chose to undertake a wildfire risk assessment as a first step in the wildfire management planning for the park. The assessment was intended to characterize wildfire risk and the effectiveness of selected risk mitigation strategies in the southern Gulf Islands. The risk assessment project also sought to formalize methods for incorporating expert and stakeholder opinion into the risk assessment.

The next two chapters describe the methods and findings produced from this wildfire risk assessment. Each chapter is a manuscript intended for academic journal publication. Chapter 2 is a description of the methods used to undertake the risk assessment and a description of the nature wildfire of risk and the most effective ways to mitigate risk in the southern Gulf Islands. Chapter 3 focuses on the portion of the risk assessment addressing how we might measure consequences , the nature of wildfire consequences in the southern Gulf Islands, and the importance of accurately measuring wildfire consequences.

2: PEOPLE ARE THE PROBLEM AND THE SOLUTION: CHARACTERIZING WILDFIRE RISK AND RISK MITIGATION IN A WILDAND-URBAN INTERMIX AREA IN THE SOUTHERN GULF ISLANDS

2.1 Introduction

Fire management conditions are changing rapidly across North America. Climate change continues to increase the frequency and size of forest fires (Westerling et al. 2006) and, in historically low-severity fire regimes, fire intensity is increasing due to fire suppression and associated fuel build-ups (Agee 1998; Brown et al. 2004; Kauffman 2004; Noss et al. 2006). Associated with these record areas-burnt are record fire suppression budgets (Dombeck et al. 2004). Coupled with increasing fire suppression costs are diminishing returns for each additional dollar spent on fire suppression. Concurrently, rural development of previously forested areas is expanding the interface between forested and rural areas (Gude et al. 2008; Radeloff et al. 2005; Theobald and Romme 2007), increasing the *consequences* of wildfires when they do occur.

These changing fire management conditions are particularly pronounced in WUI areas. A WUI is the interface where forests meet urban development (USDA and USDI 2001); they may also contain intermix regions where forest areas are intermixed with urban areas (USDA and USDI 2001). Intermix regions are often the rural periphery between urban and wildland areas. Forests in intermix areas can be highly disturbed for a variety of reasons ranging from logging and residential development to an absence of fire (Radeloff et al. 2005). Combined with these changing forest fuels and fire regimes is the pronounced dominance in WUIs of human-caused fire ignition over lightning-caused ignition (Romero-Calcerrada et al. 2008; Syphard et al. 2008). Intermix areas host dramatically escalated wildfire consequences as forest fires can cause the destruction of residential homes and frequently result in the loss of life.

Whereas wildfire management has traditionally been understood as fire suppression and prevention, today's changing fire management conditions are prompting land managers to expand wildfire management practices to include forest fire risk assessment (Canadian Wildland Fire Strategy Assistant Deputy Ministers Task Group 2005; Filmon 2004; Union of British Columbia Municipalities 2005; United States Government 2002). Where it may not be possible to prevent or suppress all forest fires, a risk assessment guides the allocation of fire prevention, suppression, and asset protection resources by using a model to predict where forest fires are likely to do the most damage (Canadian Wildland Fire Strategy Assistant Deputy Ministers Task Group 2005; Filmon 2004; Haight et al. 2004; Johnson et al. 2005; Union of British Columbia Municipalities 2005; United States Government 2002). A risk assessment can also be used to evaluate the relative effectiveness of proposed forest fire risk mitigation strategies by simulating management actions in the model and then comparing the resulting changes in risk levels (eg. B.A. Blackwell and Associates Ltd. 2004; Ohlson et al. 2003). Most importantly, encouraging communities to identify and describe their own risk mitigation strategies is the best way to build a community's capacity to address wildfire risk and furnish sustainable wildfire mitigation projects (eg. Steelman and Kunkel 2004).

In an effort to address the wildfire concerns of residents in the southern Gulf Islands (on the southwest coast of British Columbia, Canada), the Gulf Islands National Park Reserve (GINPR) chose to undertake a wildfire risk assessment as a first step in the wildfire management planning for the park. The assessment was intended to characterize wildfire risk and the effectiveness of selected risk mitigation strategies in the southern Gulf Islands. The risk assessment project also sought to formalize methods for incorporating expert and stakeholder opinion into the risk assessment. In this paper, we summarize the results of this risk assessment, characterizing the nature of wildfire risk in the southern Gulf Islands and describing the methods we developed for incorporating stakeholder opinion into the wildfire risk assessment.

2.2 Case Study

The Gulf Islands are located in south-western British Columbia between the city of Vancouver and Vancouver Island (Figure 1). The southern Gulf Islands include Mayne Island, Saturna Island, North and South Pender Island, as well as many smaller surrounding islands, totalling 304 km^2 of islands spread out over approximately 700 km^2. The Gulf Islands National Park Reserve (GINPR) was established in 2003 and holds parcels of land scattered throughout the southern Gulf Islands. The risk assessment was completed for all of the islands that hosted at least one GINPR managed property. Thus, the wildfire risk assessment study area encompassed Mayne Island, Saturna Island, North and South Pender Island as well as many smaller islands.

The GINPR is in the Coastal Douglas-fir biogeoclimatic zone (Meidinger and Pojar 1991), characterized by a mediteranean climate regime with mild winters and dry, hot summers, and Douglas-fir (*Pseudotsuga menziesii* var. menziesii) and salal (*Gaultheria shallon*) on zonal sites. The resulting landscape is largely a mosaic of rural residential areas and second-growth mixed-species forests, including Douglas-fir, Arbutus (*Arbutus menziesii*), Grand fir (*Abies grandis*), western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), Rocky Mountain Juniper (*Juniperus scopulorum*), bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra*).

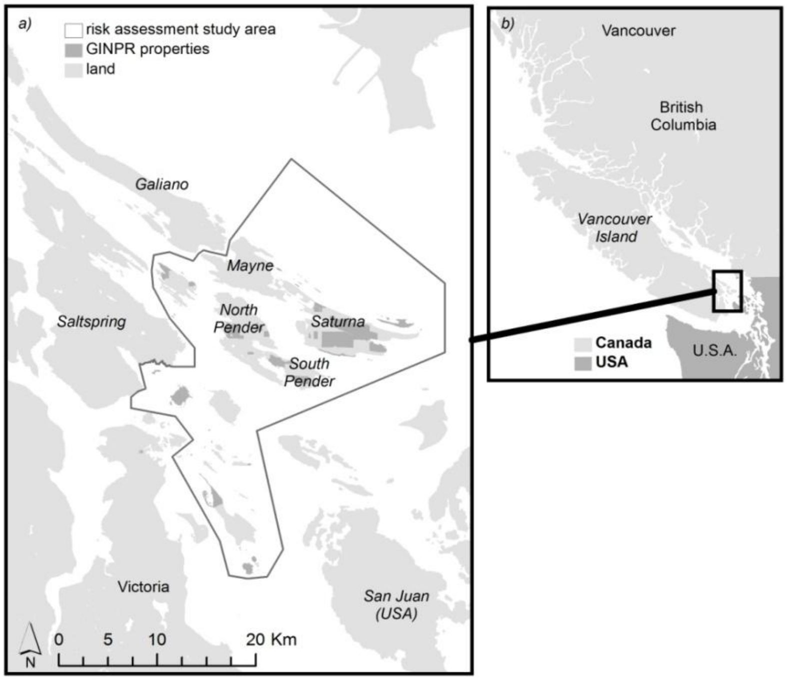

Figure 1. The southern Gulf Islands *a)* are located between the mainland and Vancouver Island *b).* The wildfire risk assessment study area encompassed Mayne Island, Saturna Island, North and South Pender Island as well as many smaller islands. The risk assessment was completed for all of the islands within the study area boundary with the exception of the evaluation of the mitigation scenarios which were limited to North Pender Island. For layout reasons only results for North Pender are shown in future figures in this paper.

Within a wildfire management context, the southern Gulf Islands provide an interesting study of wildland-urban intermix areas. The study area's island geography eliminates the possibility of a wildfire arriving from outside the study area, creating a wildland urban intermix area which is more isolated than in many situations. In contrast, a typical wildland-urban interface planning scenario must also be concerned with fires originating in the wildlands outside the WUI which then encroach on urban areas. The presence of local fire halls scattered across the study area means that local fire hall response times are low (usually less than

30 minutes) and the fire fighting capacity that can quickly be brought to bear on any ignition is higher than in many wildland areas. Accentuating these quick response times and rapid availability of fire equipment are rapid detection times and the presence of a provincial forest fire fighting base able to reach the study area within 40 minutes of fire detection.

Also important to wildfire management in this intermix area are such elements as values at risk, fire ignition, forest fuels, and stakeholders. Extensive rural development in a matrix of forest land that hosts a variety of endangered species, plant communities, archaeological sites, and national park facilities (Figure 2) equates to a complex mosaic of values at risk. Human-caused ignitions in the form of escaped campfires, backyard burns, house fires, and downed power lines are far more common than lightning ignitions and are concentrated around roads and residential areas (see Results section). Extensive rural development, fire suppression, agriculture, and small-scale forestry have transformed forests and forest fuels such that historical fire regimes and fire behaviour are likely very dissimilar to present conditions. Stakeholder representation was complex, ranging from local fire hall chiefs to provincial and federal government park wardens and fire managers.

The result of all these fire management conditions is that local fire managers are most concerned about human-caused fires originating in a residential area and moving into the surrounding matrix of forest. The worst-case scenario is that the fire front will grow within the forest and then move back into a residential area. Such a situation contrasts the typical wildland-urban interface settings where managers may be concerned with large fires that originate in the wildland, then move into urban areas (eg. Haight et al. 2004).

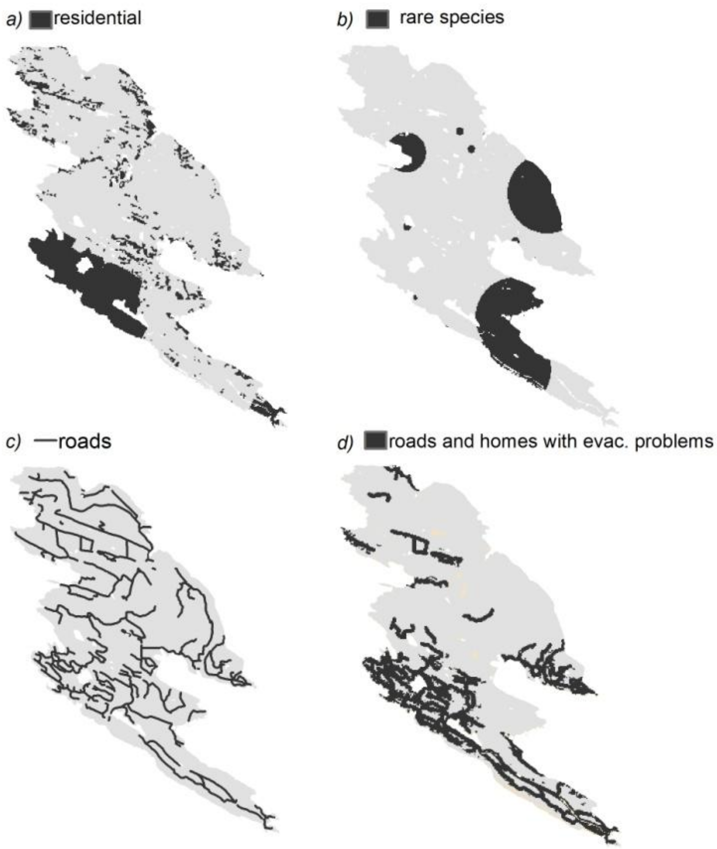

Figure 2. The wildland-urban intermix on North Pender Island is illustrated here by maps showing *a)*residential properties, *b)*known rare species locations, *c)*roads, and *d)*roads and residential properties with evacuation problems.

2.3 Methods

2.3.1 Risk Assessment Model Structure

It is common in forest fire management to use the term *fire risk* to mean the *probability* of a fire (National Wildfire Coordinating Group 2008). However, within the broader field of risk assessment, *risk* is defined as the probability of an event multiplied by the consequences associated with the event. This latter definition has been applied successfully in such fields as health sciences (Lee et al. 2006), environmental engineering (Bernatik et al. 2008), conflict resolution (Maguire and Boiney 1994), and wildlife conservation (Drechsler 2000). Thus, we define *wildfire risk* as *wildfire probability x wildfire consequences* (Ager et al. 2007; Allison et al. 2004; Bachmann and Allgower 2001; Cohan et al. 1984; Fairbrother and Turnley 2005; Finney 2005; Kerns and Ager 2007).

In our model, Wildfire Probability is expressed as the product of Ignition Probability and Escape Probability. Due to data limitations described in subsequent sections Ignition Probability and Escape Probability are expressed as relative probabilities, illustrating changes in relative event probability across the landscape rather than absolute probabilities of events. The term *risk element* is used to refer to factors that contribute to the evaluation of Wildfire Risk, such as fuel type, slope, or the presence of residential homes (Sampson and Sampson 2005). In practice, risk elements are used as input data to the Wildfire Risk assessment, providing the data needed to calculate Ignition Probability, Escape Probability, and Wildfire Consequences. Figure 3 shows the structure of our wildfire risk assessment model, listing the risk elements used to model Ignition Probability, Escape Probability, and Wildfire Consequences. It also illustrates how these probabilities and consequences are combined to produce Wildfire Probability and Wildfire Risk.

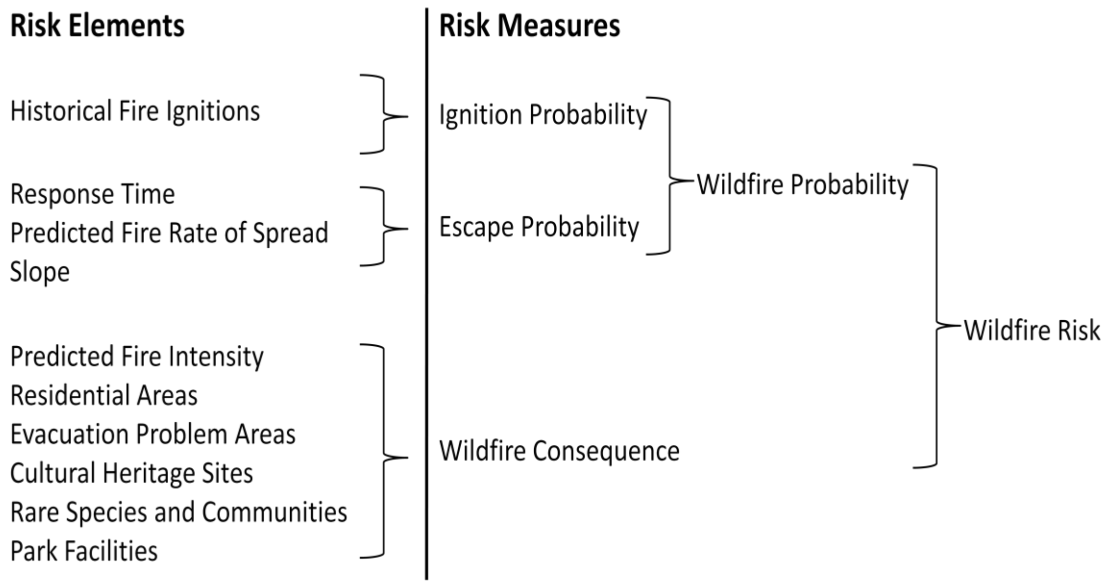

Figure 3. An illustration of the Wildfire Risk model we developed. Each risk element is listed and how it contributes to Wildfire Risk. Because the risk model is mapping-based, each risk element is represented as a map layer in ArcGIS 9.2.

The multiplicative structure of the model means that a given location must have values for relative Ignition Probability, Escape Probability and Wildfire Consequence greater than zero to host a non-zero Wildfire Risk value. The result is a risk map that is bimodal in character: the majority of the landscape will host very low Wildfire Risk and some areas will host greater risk. This reflects the nature of multiplicative wildfire risk models where, for example, a location with high ignition probability, excessive fuel build-up, and high consequences next to the local fire hall would not be a high wildfire risk location because escape probability is low. In contrast, *additive* wildfire risk models (B.A. Blackwell and Associates Ltd. 2004; Davies and Coulthard 2006; Lane County Land Management Division 2005) might assign a similar site moderate to high risk because the majority of the parameters that comprise wildfire risk are rated high. The multiplicative model clearly focuses attention on areas with higher wildfire risk. It is also useful because the Wildfire Risk values produced are on interval scales, clearly illustrating relative changes in Wildfire Risk.

We use a Geographic Information Systems-based approach where Wildfire Risk is evaluated for each 25 meter by 25 meter raster cell across the study area. Risk elements were mapped in ArcGIS 9.2 as vector data and then input into the risk model as rasters. ARcGIS 9.2 Spatial Analyst tools were then used to generate Ignition Probability, Escape Probability, Wildfire Probability, Wildfire Consequence, and Wildfire Risk.

2.3.2 Establishing Expected Fire Behaviour

Predicting expected fire behaviour for the second growth mixed conifer forests that dominate the study area presented several challenges. A near absence of wildfires in recent decades in the Gulf Islands (Poffenroth 2009) made prediction of expected fire behaviour based on empirical observations infeasible. In addition, the federal government's standard fire behaviour prediction model, Fire Behaviour Prediction (FBP) System, does not have a fuel type that matches the fuel characteristics typical of the second growth Douglas-fir leading forests in the Gulf Islands (Forestry Canada Fire Danger Group 1992). This lack of alignment between the FBP System fuel types and local fuel conditions had made mapping local fuel types for input into the FBP System very difficult. Most of the study area had been mapped as the FBP C3 fuel type, a mature Lodgepole Pine forest with complete crown closure, relatively high height to live crown, and light surface fuels. Preliminary conversations with local fire managers also indicated a lack of consensus on expected fire behaviour; Parks Canada fire behaviour specialists felt there were lower fire intensities and crowning potential than did local fire chiefs (Boyte 2007; Walker 2007).

To address this lack of consensus, we convened two fire behaviour workshops whose objective was to create consensus among local stakeholders regarding expected fire behaviour predictions that we could use to calibrate our fire behaviour prediction modelling. The workshops consisted primarily of visiting sites representative of several common fuel types and discussing expected fire behaviour. Local government fire management staff, fire hall staff, and provincial and federal fire behaviour specialists attended the first workshop. Provincial government fire behaviour specialists from across the province of British Columbia attended the second workshop. We used the results of these two fire behaviour workshops and a literature review on fire behaviour in coastal Douglas-fir forests to calibrate our modelling of fire behaviour in the Canadian Forest Service's Fire Behaviour Prediction Model. This model produced predicted fire intensity and rate of spread for each unique combination of slope, aspect, and fuel type in the study area.

2.3.3 Establishing Probability of Ignition

We define Ignition Probability as the probability of fire ignition over a one year period for each 25 meter by 25 meter location in the study area. Historical ignition density (see below) was used as a surrogate estimate of Ignition Probability. Ignition probabilities reported are considered relative probabilities because we do not know the baseline probability of a fire for each future year. To generate a map of relative ignition density across the study area, we applied the ArcGIS 9.2 kernel density function to a map of historical fire incident points. Fire extent polygons are a better method for measuring Ignition Probability (Finney 2005) because they are influenced by local topography and wind, however, there have been very few forest fires in the southern Gulf Islands since the turn of the century (Poffenroth 2009). The historical fire incident dataset was a combination of fire hall dispatch summaries and the Gulf Islands National Park Reserve fire incident log, including both human and lightning-caused ignitions. Combined, they represented between 53 and 141 ignition events for each major island and enough data to characterize relative changes in ignition density across the study area. On Saturna Island, for instance, where residential and tourism development is limited, 11 years of data (1996 – 2007) were used for a total of 53 ignition incidents. Mayne Island is more populated and has more ignition incidents, thus only 4 years (2003 – 2007) of data were necessary to digitize 60 ignition incidents. On the Pender Islands, only two years worth of ignition incidents (2005 – 2007) were used, resulting in 141 ignition events. Over 95% of all ignitions incidents were human-caused.

2.3.4 Establishing Wildfire Escape Probability

Local fire managers felt that escape probability played a key role in determining wildfire probability. Because the islands are all relatively small and developed areas are spatially diffuse and well distributed, fire managers are primarily concerned with a fire igniting in a residential area and escaping into neighbouring properties or forest. We defined Escape Probability as the probability that the fire would not be under control within 4 hours or that the fire would escape the property, location, or structure of origin.

In the absence of objective measures for this risk element the escape probability was derived in expert interviews with local fire chiefs, who had agreed earlier that fire rate of spread, fire hall response time, slope, and fire type as the four most important conditions determining fire Escape Probability. For each condition, we assigned levels such as slope at <35%, 35–70%, or 70%>, and then combined these attributes to hypothetical scenarios (Figure 4). For each fire scenario, each of the nine respondents (fire chiefs or assistant fire chiefs in the study area) were asked to complete three tasks: pick the condition that contributed most to an escape, pick the condition that contributed least to an escape, and predict the Escape Probability (Figure 4; please note that the first two tasks amount to a maximum difference conjoint approach, and the third task was not used in this analysis). A total of 24 such scenarios were evaluated by each expert, which is the minimum number of replications required in a fractional factorial design to run a statistical analysis for main effects. This method is novel in the area of risk analysis, but has been applied successfully in consumer research and health sciences when multiattribute phenomena need to be understood (Cohen 2003; Haider 1997; Marley and Louviere 2005). Compared to other methods that have been used to determine consequences in the past, this method has several advantages (see Chapter 2). The most important of these are that it is easier cognitively for respondents to identify the most distinct pair (Marley and Louviere 2005) and it better simulates the respondent's natural way of making trade-off decisions (Aas et al. 2000; Oh et al. 2005).

Question A Which condition causes an escape the **least?**	**Fire Scenario 4**	**Question B** Which condition causes an escape the **most?**
☐	*Fire Type:* Structure Fire, Chimney Fire, Appliance Fire	☐
☐	*Rate of Spread:* >16 m/min	☐
☐	*Slope:* >70%	☐
☐	*Response Time:* >60 minutes	☐

Question C: What is the probability (%) of the fire escaping? (not being under control within 4 hours or escapes the property/location of origin or structure)

.1 1 10 20 30 40 50 60 70 80 90 100

Figure 4. For each survey question, respondents were asked to imagine they were called to the given fire scenario and answer Question A, B, and C. This question format was repeated 24 times, each question having a unique combination of fire conditions for the respondent to compare.

The statistical analysis of such a maximum difference survey (tasks 1 and 2) assumes that the relative choice probability of a given pair is proportional to the distance between the two attribute levels on an underlying latent scale of preference (Finn and Louviere, 1992). The statistical analysis of the best and worst responses uses a multinomial logistic regression, and the resulting estimates represent relative utilities or preference measures, scaled along one interval scale.

2.3.5 Calculating Wildfire Probability

We define relative Wildfire Probability as the probability of a fire during one fire season for each 25 meter by 25 meter cell in the GIS data set. Wildfire Probabilities reported are considered relative probabilities because they are the product of Ignition Probability and Escape Probability which are both relative probabilities. Ideally, Wildfire Probability is defined as the probability of a wildfire of a given fire intensity for each location (Finney 2005), because wildfire consequences depend on fire intensity. Our fire behaviour model does not predict the probability of each fire intensity, and therefore our analysis does not account for the uncertainty associated with predicting fire intensity and the disparity in consequences that may arise from different fire intensities.

2.3.6 Establishing Wildfire Consequences

Establishing wildfire consequences is challenging because consequences can range from damage to market goods such as residential homes, to loss of non-market values such as human life, ecosystem services, and endangered species. Consequently, establishing a common metric for wildfire consequences has been problematic (Finney 2005). We solved this problem by using another maximum difference conjoint survey similar to the expert survey on wildfire escape probability (see Establishing Wildfire Escape Probability section above). This time we used a stakeholder survey to determine the relative importance of specific consequences, thereby establishing a common metric for measuring wildfire consequences.

To design the survey, we first identified the five most important types of values at risk in the southern Gulf Islands through a process of stakeholder consultation. These are residential homes, human life, endangered species, national park assets, and cultural heritage sites. We then separated each value-at-risk into specific Wildfire Consequences levels (eg. Major damage to 10 houses, Minor damage to 10 houses, Major potential for loss of life, Minor potential for loss of life). Each survey question followed the same format as the escape probability survey questions (shown above) by listing 5 wildfire consequences and asking the respondent to choose the one worst wildfire consequence and the one best wildfire consequence (see Chapter 2 for greater detail). Twenty four questions were needed to have the respondent evaluate each unique combination of wildfire consequences. The same analytical procedure (multinomial logistic regression) as described in the Estimating Wildfire Escape Probability section was used for the analysis.

In order to map fire consequences, we assigned a wildfire consequence based on each location's values-at-risk and predicted fire intensity. For example, a location with residential housing predicted to sustain a fire intensity of '4,000 Kw/min would be assigned a consequence of "Minor Damages to 10 houses", whereas, the same location with Moderate or High predicted Fire Intensity would be assigned a consequence of "Major Damage to 10 houses". The Wildfire Consequence value assigned is the relative importance score as determined by the multinomial logistic regression. The total fire consequence for each location is the sum of fire consequences present at that location (eg. Major potential for loss of life + major damage to 10 houses).

2.3.7 Evaluating Management Scenarios

We used the completed wildfire risk assessment to evaluate the effectiveness of four risk mitigation strategies at reducing total Wildfire Risk. Risk mitigation strategies were selected through consultation with local fire managers and were thought to be realistic, albeit ambitious, approximations of mitigation options being considered. To simplify the comparison, the analysis was limited to North Pender Island. The four wildfire mitigation management scenarios evaluated were:

1. FireSmarting (Province of British Columbia 2005) residential homes in evacuation problem areas
2. Fuel treatment in evacuation problem areas
3. A 50% reduction in fire ignitions
4. Building an effective escape route from the Magic Lakes Estates development. Magic Lakes Estates is the highest density residential development in the study area and was not designed with adequate evacuation routes.

Each mitigation strategy was evaluated by revising risk element maps so they simulated the proposed mitigation strategy and then running the risk model, producing new risk maps. The fuel treatment scenario assumed that all forests in evacuation problem areas were thinned to the FBP C7 fuel type (ie. the fuel type map was revised). The C7 fuel type is a Ponderosa Pine – Douglas-fir multiaged stand with an open canopy and high height to live crown distance (Canadian Forest Service 2007) and best matches the fuel characteristics of potential fuel treatments. We chose to locate the fuel treatments in evacuation problem areas because they hosted the highest consequence levels according to the consequence maps. The FireSmart scenario assumed that all residential homes and residential properties in evacuation problem areas were treated to BC FireSmart standards (Province of British Columbia 2005). Thus, treated houses were assumed to have non-flammable roofing and siding and no flammable material adjacent to the house. FireSmarted locations were assumed to have reduced damage to houses and potential for loss of life. The Magic Lakes evacuation scenario assumed that an effective evacuation route and evacuation plan was developed for Magic Lake Estates on North Pender. The Magic Lakes Estates are the highest density residential development in the southern Gulf Islands and only have one access road. The reduced ignitions scenario assumed a 50% reduction in fire ignitions across the study area. Total Wildfire Risk associated with each mitigation scenario was derived by adding up the Wildfire Risk for each 25 meter by 25 meter raster cell in the study area.

2.4 Results

2.4.1 Expected Fire Behaviour

At the outset of the project there was a lack of consensus on expected fire behaviour and the relative importance of values at risk. Local fire chiefs felt the second growth mixed conifer (Douglas-fir leading) forests typical of much of the study area would produce intense crown fires during drought conditions common in the summer. In contrast, National Parks fire behaviour specialists expected surface fires with minimal crowning. After the two fire behaviour workshops, participants agreed that during typical summer drought conditions (90^{th} percentile conditions) expected fire intensities were low with no crowning potential. It was then agreed that crown fires would be sustained by all fuel types except deciduous stands when lower relative humidity associated with outflow conditions (interior air mass moving onto coastal areas) met with moderate to high winds and drought conditions. These findings were congruent with early literature on fire behaviour in the coastal Douglas-fir (Charles Dague 1930; George Joy 1923). We decided to model fire behaviour based on outflow conditions because fire managers were looking for guidance on managing for "worst case" wildfire scenarios.

2.4.2 Wildfire Probability

Wildfire Probability values ranged from 0 to 1.0 (Figure 5) and should be considered relative probabilities as they are the product of two relative probabilities: Ignition Probability and Escape Probability. Wildfire Probability is highest where areas with a history of human-caused ignitions overlap with steeper terrain and longer fire hall response times. Some risk assessments choose to normalize parameters that contribute to wildfire probability (eg. B.A. Blackwell and Associates Ltd. 2004), however, we deemed this inappropriate given that Ignition Probability and Escape Probability were based on empirical measurement. In addition, local fire managers felt that Wildfire Probability and

Wildfire Risk values produced by the assessment were an appropriate reflection of their understanding of local wildfire risk conditions.

Historical ignition densities were used as a surrogate measure of Ignition Probability and ranged from 0.10 to 2.65 ignitions/year (Figure 5). All Ignition Probabilities are considered relative probabilities. Higher Ignition Probabilities were clustered around residential areas with a history of human-caused ignitions. There were very few lightning-caused ignitions.

Escape Probability values ranged from 0.05 to 1.00 (Table 1 and Figure 5) and were generally higher on less-populated islands such as Saturna and Portland islands. Higher Escape Probability values were associated with high response times, steeper terrain, and more rapid rates of spread. Changes in fuel type had minimal impact on Escape Probabilities as predicted rates of spread were consistently high due to the extreme fire weather conditions used. Comparison with anecdotal historical information on escaped fires indicates that predicted Escape Probability values are 30-50% higher, though the fire weather conditions used in our model are much drier than normal summer drought conditions. Without additional observed fire escapes the accuracy of predicted Fire Escape values will remain unknown.

Table 1. Shows the predicted escape probability (%) for each combination of slope, response time, and fire rate of spread.

Slope (%)	Response Time (minutes)	Rate of Spread (meters/min)	Prob. Escape (%)	Slope (%)	Response Time (minutes)	Rate of Spread (meters/min)	Prob. Escape (%)
35	20	7	10	70	60	15	80
35	30	7	20	70	90	15	70
35	60	7	50	100	20	15	40
35	90	7	50	100	30	15	50
70	20	7	10	100	60	15	80
70	30	7	30	100	90	15	80
70	60	7	90	35	20	20	10
70	90	7	70	35	30	20	20
100	20	7	10	35	60	20	60
100	30	7	50	35	90	20	70
100	60	7	80	70	20	20	30
100	90	7	70	70	30	20	90
35	20	15	20	70	60	20	90
35	30	15	20	70	90	20	100
35	60	15	20	100	20	20	80
35	90	15	70	100	30	20	80
70	20	15	40	100	60	20	80
70	30	15	50	100	90	20	100

2.4.3 Wildfire Consequences

The wildfire consequences survey established the relative importance of specific wildfire consequences (Table 2). An arbitrary zero point for the scale was designated at ‘no damage to houses’ simply because it represents a useful reference point. Respondents felt that a fire with a ‘major potential for loss of life’ (-16.6) was approximately three times worse than ‘major damage to 10 houses’ (-5.5) and 4.5 times worse than ‘a rare element is lost due to the fire eg. rare flower, old growth forest ’ (-3.7). A fire which has a ‘minor potential for loss of life’ (-10.3) was twice as bad as ‘major damage to 10 houses’ (-5.5). ‘Major net ecological losses’ has a positive score because the zero point for the scale was set at ‘no damage to houses’, a consequence that was perceived to be slightly worse than ‘major net ecological losses’.

Table 2. Shows the relative scores assigned to each Wildfire Consequence as derived from the analysis of the wildfire consequences survey results.

Consequence	Score
major potential for loss of life	-16.604
minor potential for loss of life	-10.2885
major damage to 10 houses	-5.5008
rare element is lost	-3.7067
rare element is damaged	-3.3862
minor damage to 10 houses	-2.9403
major damage to cultural heritage sites	-2.8977
damages > $40,000	-0.9093
minor damage to cultural heritage sites	-0.7317
damages < $40,000	-0.2482
no damage to houses	**0**
major net ecological losses	1.0737
ecological benefits are unclear or net benefit is zero	3.5146
major net ecological benefits	6.581

A divergence of opinion was expected regarding the relative importance of endangered species and residential homes. Parks Canada staff were expected to value endangered species to a greater extent than fire hall staff. Fire hall staff were expected to be more concerned with the protection of residential homes and Gulf Island residents. The consequences survey found no such divergence of opinion among stakeholders.

When the mapped values at risk were assigned consequence values, the resulting Wildfire Consequences map showed a complex distribution of consequences with the highest consequence areas hosting multiple Wildfire Consequences. These are generally residential areas with problematic evacuation. Following these locations are residential areas and then known locations of endangered species.

2.4.4 Wildfire Risk

The distribution of Wildfire Risk across the study area is illustrated in Figure 5. Areas with high Wildfire Risk are limited to locations with both high fire consequences and moderate to high relative wildfire probabilities. Areas with a risk value of 0 had low Wildfire Probability or low Wildfire Consequences or both. Risk was highest on North and South Pender Island and lowest on the less populated islands such as Saturna Island.

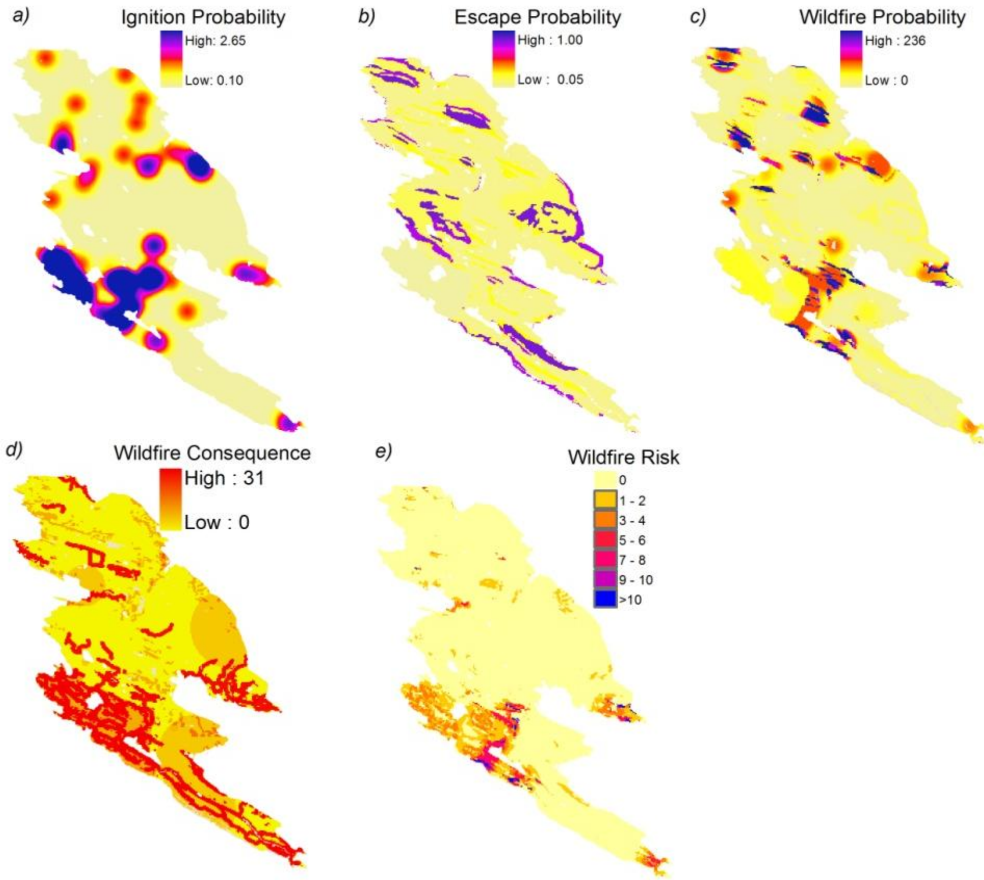

Figure 5. Maps showing *a)*Ignition Probability, *b)*Escape Probability, *c)*Wildfire Probability, d)Wildfire Consequence, and e)Wildfire Risk values for North Pender Island. Wildifre Probability is the product of Ignition Probability and Escape Probability. Wildfire Risk is the product of Wildfire Probability and Wildfire Consequence. All probabilities are relative probabilities.

2.4.5 Wildfire Risk Mitigation Scenarios

We evaluated the effectiveness of 4 risk mitigation scenarios (FireSmarting, fuel treatments, reducing ignitions by 50%, and improving evacuation at Magic Lakes Estates) at reducing Wildfire Risk. The Total Wildfire Risk resulting from each risk mitigation scenario is illustrated in Figure 6. Reducing ignitions by 50% proved to be the most effective management strategy, reducing total risk by 50% across North Pender Island. Providing an effective evacuation strategy for the Magic Lakes Estates was also very effective at reducing total risk on North Pender, but Wildfire Risk outside of Magic Lakes Estates remained unmitigated. FireSmarting residential areas in evacuation problem zones was the third most effective strategy for reducing total risk on North Pender, reducing Wildfire Consequence in the highest risk areas. The Fuel Treatment management scenario had no impact on total risk on North Pender as treated stands were still predicted to have fire intensities well over 10,000 KW/min. These very high fire intensities are a product of the outflow weather conditions chosen for the simulation. The Wildfire Risk map produced by each management scenario is shown in Figure 7.

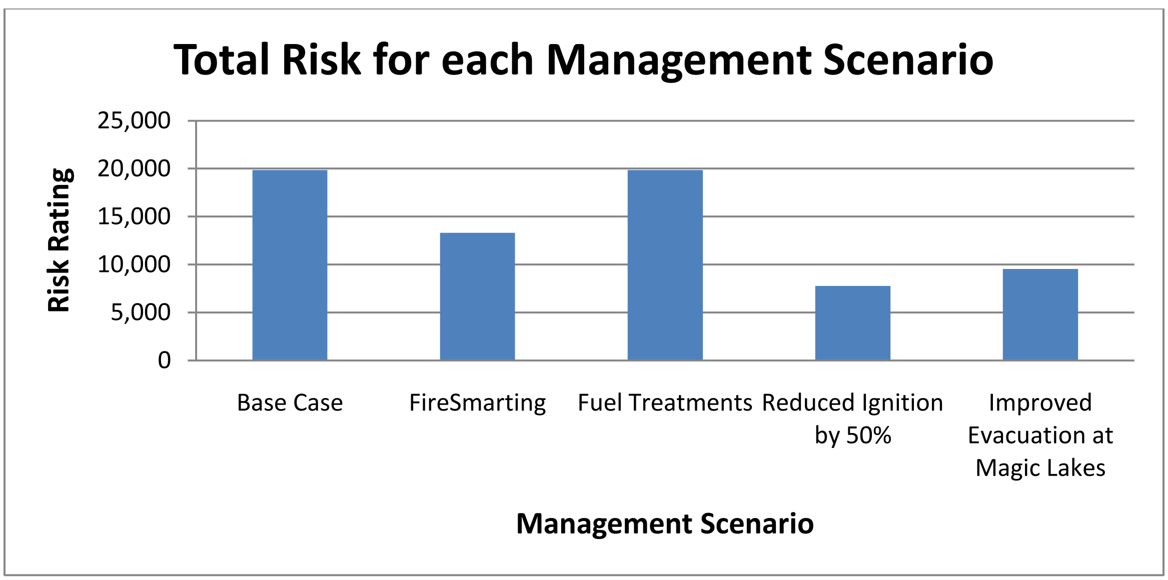

Figure 6 Total Wildfire Risk on North Pender Island resulting from the base case scenario (ie. no management) and each of the four proposed mitigation scenarios. Total Wildfire Risk associated with each mitigation scenario was derived by adding up the Wildfire Risk for each 25 meter by 25 meter raster cell in the study area.

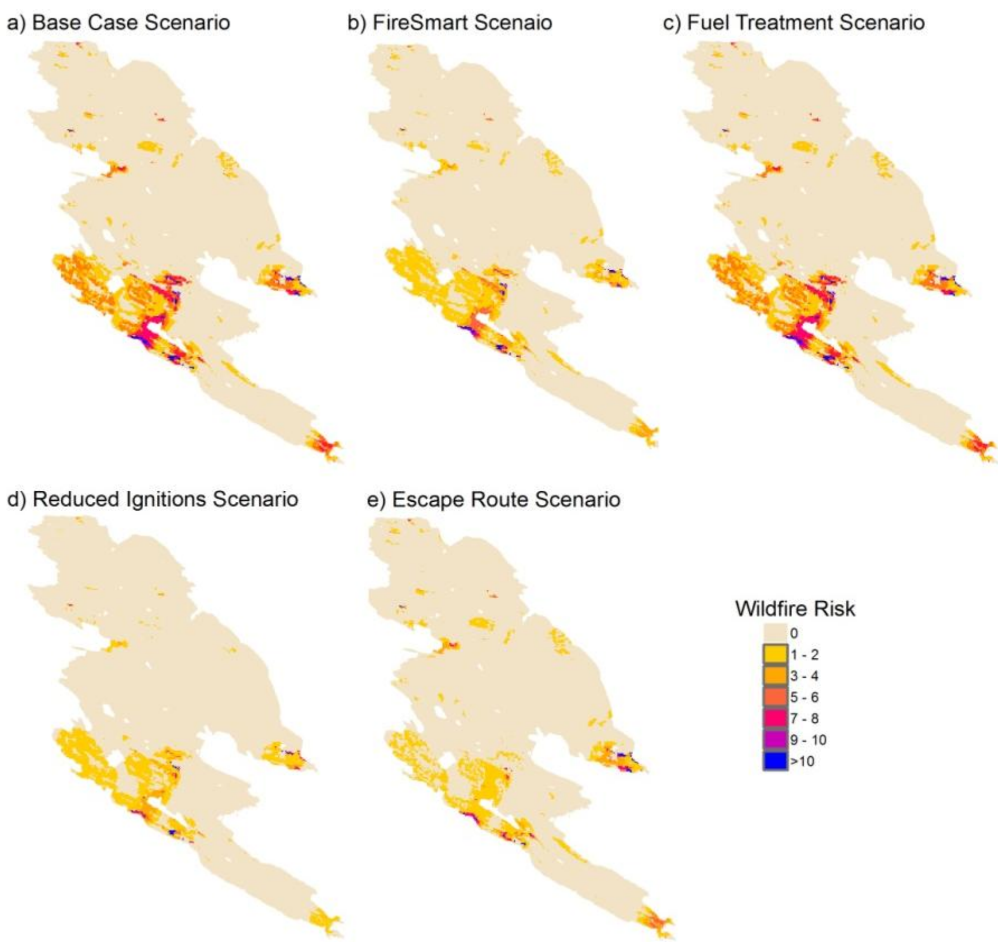

Figure 7. Maps of North Pender Island showing the Wildfire Risk map resulting from a) no mitigation, b) FireSmarting Scenario, c) Fuel Treatment Scenario, d) Reduced Ignitions Scenario, e) Escape Route Scenario.

2.5 Discussion

Our results show that it is people who are both the problem and the solution to risk and risk mitigation in the southern Gulf Islands. It is people and their influence on wildfire ignition and wildfire consequences that drive the distribution of wildfire risk. Both wildfire ignition and wildfire consequences are highest around residential developments. This theme is played out again in the results of our evaluation of risk mitigation strategies where reducing human ignitions and protecting values at risk are the two most effective mitigation strategies. Because people drive wildfire risk in this intermix area, people also become an essential part of risk mitigation solutions with changes in human behaviour surrounding fire ignition, building materials, and evacuation planning being the most effective way to mitigate risk. The most effective way of producing these changes in behaviour is challenging communities to develop, evaluate, and initiate risk mitigation initiatives themselves (Steelman and Kunkel 2004).

2.5.1 People Drive Wildfire Risk

Our results show that it is people, not biophysical factors such as fuel type or topography, that have the most influence on wildfire risk in this forest-urban intermix; this is due to people's influence on Ignition Probability and Wildfire Consequence. In the southern Gulf Islands, moderate and high risk areas are always centred on areas with concentrations of values-at-risk and high relative Ignition Probability. Other studies of intermix areas in Spain (Romero-Calcerrada et al. 2008) and California (Syphard et al. 2007) also found that human variables such as proximity to urban areas and roads was most strongly associated with Ignition Probability.

The consequences of fire are often negative because fire disrupts human use of the landscape, negatively affects residents, damages development, and, in some cases, damages natural environments (Daniel et al. 2007). Changing perspectives among stakeholders on the relative importance of specific wildfire consequences may have a dramatic effect on wildfire risk (see Chapter 2). Fire, even in intermix areas, is not a problem in and of itself. Wildfire is a natural part of the disturbance regime of the Gulf Islands (McCoy 1997; Meidinger and Pojar 1991), playing an important role in the restoration of natural systems and reducing fuel loads (Reinhardt et al. 2008). In the Gulf Islands, the human dimension of wildfire consequence is illustrated by concentrations of wildfire risk around residential development and evacuation problem areas. The FireSmart and Magic Lake Estates risk mitigation scenarios illustrate how values at risk can be protected such that a wildfire produces very few negative consequences.

2.5.2 Effectiveness of Ignition Reduction

Reducing ignitions proved to be the most effective strategy for reducing risk in this intermix area. This was because a reduction in ignitions produced lower Wildfire Risk values across the entire study area, whereas, the other mitigation strategies only reduced Wildfire Risk values in higher risk areas. 72% of the Total Wildfire Risk in the study area was associated with lower risk sites, thus, the broadly focused risk mitigation strategy produced a greater reduction in Total Wildfire Risk. This is a strong argument for engaging all landowners in risk any mitigation efforts.

These results are consistent with a Wisconsin WUI study where a 25% reduction in ignitions achieved by banning local debris burning was the most effective wildfire probability mitigation strategy. Other mitigation strategies evaluated were the strategic redistribution of risky forest types away from the high ignition rates of the WUI, fire breaks, and reducing roadside ignitions (Sturtevant et al. 2009). Weather and Ignition have been found to be the most important variable influencing burnt area when compared to fuel management scenarios (Cary et al. 2009). Conveniently, ignition reduction was found to be more popular with the Wisconsin public than building codes, infrastructure investment, landscape modification, prescribed burning, education, safety ordinances, and zoning (Winter and Fried 2000).

2.5.3 Effectiveness of Escape Routes and FireSmarting

Providing an effective escape plan for Magic Lakes Estates, the study area's largest evacuation problem area proved to be the second most effective risk mitigation strategy. This comes as no surprise as an effective escape route would significantly reduce the potential for loss of life, a consequence which was established to be 3 times more important than any other wildfire consequence. The advantage of this risk mitigation strategy is that it reduces the risk at the highest risk locations. If managers are particularly concerned with eliminating worst-case scenarios, they may prioritize a risk mitigation strategy such as this one over broadly focused strategies such as general ignition reduction. The FireSmarting mitigation scenario was less effective than the escape route scenario because stakeholders found damage to houses less important than the potential for loss of life.

2.5.4 Effectiveness of Fuel Treatments

The fuel treatment mitigation scenario resulted in no reduction of Wildfire Risk values. Fuel treatments have little benefit to wildfire suppression during extreme fire weather conditions (Reinhardt et al. 2008) such as those used in this risk assessment. In extreme fire weather conditions, all fuel types in the Gulf

Islands will burn with high intensity, making suppression difficult. During these fire weather conditions, the only effective risk mitigation strategies were found to be those that either reduced fire ignition, or reduced the consequences of wildfire such as FireSmarting homes or providing effective escape routes. The benefit of fuel treatments in extreme fire weather is increased ecosystem resilience (Reinhardt et al. 2008). Organic soil layers are generally very thin in the southern Gulf Islands (Green 2007) and there is the potential for an intense fire to burn much of them off.

2.5.5 People are the Solution

If human behaviour creates risk in this intermix area and the most effective mitigation strategies are those that change behaviour by reducing ignition or protecting values at risk, then the key to mitigating risk here must be raising local capacity to change human behaviour. Encouraging communities to develop their own mitigation strategies has been identified as the most effective way to raise this capacity to undertake ongoing mitigation initiatives (Steelman and Kunkel 2004). By involving stakeholders in this risk assessment process, we increased local knowledge around wildfire risk, promoted common understandings, and facilitated future engagement in risk mitigation projects. For example, at the outset of this risk assessment, there was a divergence of opinion among stakeholders on expected fire behaviour and a perceived divergence of opinion on the relative importance of specific wildfire consequences. The process of collecting stakeholder opinion through the fire behaviour workshops, consequences survey, and escape probability survey eliminated these divergences of opinion and producing informed and engaged stakeholders.

2.6 Conclusion

2.6.1 Implications for Fire Management

Wildfire managers in intermix areas should encourage communities to take part in the risk assessment process. Perhaps the most important product of a risk assessment is informed stakeholders that understand the impacts of their risk mitigation choices (Finney 2005). Fire managers undertaking risk assessments should consider using methods such as those described in this paper to involve stakeholders in the risk assessment process. Accordingly, funding must be provided by government that supports the time and staff resources it takes to meet and work with local stakeholders. Wildfire mangers in intermix areas should also consider allocating mitigation resources away from fuel treatments to strategies targeted at changing human behaviour such as public education campaigns, FireSmart residential development standards, building code amendments, and improved evacuation strategies.

2.6.2 Applicability of These Results

Fire managers should recognize that the southern Gulf Islands are a somewhat unique example of a wildland-urban intermix area and be careful when applying the results of this study to other intermix areas. The island setting of this study area creates a distinct example of an intermix area in that it cannot receive large wildland fires. Many intermix areas are part of a wildland urban interface and are therefore subject to large fires from surrounding wildland forests. To account for the probability of fire arriving from the wildland, WUI risk assessments benefit from the addition of fire growth modelling (Finney 2005). It is likely that reducing human ignitions will become less effective at mitigating risk as the probability of ignition from large wildland fires increases. Reducing human ignitions will also be less effective as the incidence of lightning ignition, which is very rare in the Gulf Islands, increases. As well, sites with lower relative humidities during 90th percentile fire weather conditions will likely benefit to a greater extent than the Gulf Islands from fuel treatments.

Fire managers in intermix areas should also note that a risk-based management approach (in this case, targeting reductions in human ignitions) is only appropriate when fire management resources are insufficient to protect values at risk. If fire management resources are sufficient, mitigation should be focused on reducing the vulnerability of values at risk to wildfire. Given that a wildfire will eventually happen (Reinhardt et al. 2008), protecting values at risk is the only mitigation strategy that will eliminate wildfire consequences in the long term.

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3: ESTIMATING THE CONSEQUENCES OF WILDFIRE FOR WILDFIRE RISK ASSESSMENT

3.1 Introduction

Forest fires are increasing in both their number and their size across North America (Westerling et al. 2006). Since 1986, the number of wildfires in the western United States has jumped by 400% while forest area burned has increased by more than 600% when compared to the fires from the period between 1970 and 1986. Similar increases have been documented in Canada from 1920 to 1999 (Gillett et al. 2004). In the next century, area burned by wildfires in Canada is projected to increase by 74 to 118% (Flannigan et al. 2005).

A variety of management challenges are associated with changing fire regimes: protection of forests and communities from damages associated with forest fires is one such challenge. In the western US, the fire suppression budget has steadily increased from an average annual cost of less than $500 million in the 1980's to well over 1 billion after the year 2000 (Dale 2006; National Academy of Public Administration 2002; National Interagency Fire Center 2005). These costs have been driven by record area-burned over the same period (Dombeck et al. 2004). Not only are more forests burning, but in many forests which experienced historically low severity fire regimes, fire suppression has resulted in fire severity (Agee 1998; Brown et al. 2004; Kauffman 2004; Noss et al. 2006). The combination of changing forests in response to forest management and changing fires in response to changing climate and forest structure has lead to significant uncertainty around the nature of fire risk.

Land managers are now using forest fire risk assessment as a wildfire management approach that looks beyond simple fire suppression and prevention (Filmon 2004; United States Government 2002). Where it may not be possible to prevent or suppress all forest fires, forest fire risk assessments are a tool for establishing priorities and achieving the most efficient allocation of fire management resources such as fire suppression crews, forest fuel treatments, evacuation planning, or public education efforts (Filmon 2004; Haight et al. 2004; Johnson et al. 2005; Union of British Columbia Municipalities 2005; United States Government 2002). Risk assessments can also evaluate the relative effectiveness of wildfire risk mitigation projects by simulating proposed management actions in the model and then comparing the resulting changes in risk levels (eg. B.A. Blackwell and Associates Ltd. 2004; Ohlson et al. 2003).

3.2 Defining Forest Fire Risk

The term *fire risk* is often used to mean the probability of a fire (Fiorucci et al. 2008; Haight et al. 2004; National Wildfire Coordinating Group 2008), however, within the broader field of risk assessment, *risk* is defined as the probability of an event multiplied by the consequences associated with the event (ie. *fire probability x fire consequences*) (Allison et al. 2004; Bachmann and Allgower 2001; Cohan et al. 1984; Finney 2005; Kerns and Ager 2007). The probability x consequences definition of risk is used in quantitative risk assessment (QRA) and has been applied successfully in such fields as health sciences (Lee et al. 2006), environmental engineering (Bernatik et al. 2008), conflict resolution (Maguire and Boiney 1994), and wildlife conservation (Drechsler 2000). QRA has been found useful because it promotes (Apostolakis 2004):

- A better understanding of accident scenarios
- A better understanding of the complex interactions between events and systems
- Communication among stakeholders and a common understanding of the problem
- An integrated approach which allows for contributions from diverse disciplines such as engineering and social sciences

In contrast to a definition of risk focused entirely on the probability of occurrence of fire, defining risk as equal to [probability x consequences] means that fire consequences can play an important role in determining risk ratings. Risk levels become just as sensitive to fire consequences as fire probability. In this context it thus becomes critically important that we obtain accurate estimates of fire consequences.

3.3 Estimating Expected Fire Consequences

Wildfire risk assessment research has made considerable progress towards measuring the probability of fire occurrence (eg. Fiorucci et al. 2008; Haight et al. 2004; Misoula Fire Sciences Laboratory ; Preisler et al. 2004; Sanborn Total Geospatial Solutions 2006) but comparatively little progress towards estimating the consequences associated with a potential fire. For example, many current risk assessments still apply the risk-equals-fire-probability definition and do not include fire consequences when identifying high risk areas (eg. Brown 2003; Fiorucci et al. 2008; Haight et al. 2004; Sturtevant et al. 2009). This approach has the potential to overlook high risk areas that have only moderate fire probabilities but very high fire consequences.

Finding a common metric that can be applied to all consequences has been a primary challenge to estimating wildfire consequence (Finney 2005). Wildfire consequences can range from damage to non-market goods such as endangered species and human life to the loss of market good such as timber and residential homes. In recent years, the most advanced methods for estimating fire consequences use local experts or community members to identify values at risk and weight them according to their relative importance (eg. Alberta Ministry of Sustainable Resource Development 2004; B.A. Blackwell and Associates Ltd. 2006; Sanborn Total Geospatial Solutions 2006; Santa Barbara County 2006; Wallowa County 2006; Wildland Fire Associates 2008). This method becomes problematic, however, when there are more than two values at risk, as it is extremely difficult to accurately estimate the importance of each fire consequence relative to all other consequences. This is important because how we set the relative importance of specific wildfire consequences will directly influence wildfire risk findings (B.A. Blackwell and Associates Ltd. 2004).

In this paper I describe a novel approach for assessing fire consequences that reflects the values of fire management stakeholders. The approach incorporates stakeholder consultation as a tool for establishing values at risk from fire and uses a stakeholder survey to establish the relative importance of specific fire consequences. A fire consequence map is produced by combining predicted fire intensity with established values at risk for each location. I demonstrate this approach by application to a case study in the southern Gulf Islands, British Columbia, Canada. My application of this method is part of a larger wildfire risk assessment for the southern Gulf Islands, British Columbia, Canada that integrates other risk elements, such as ignition potential and escape probability, with fire consequences to evaluate wildfire risk (see Chapter 2).

I use the maximum -difference conjoint analysis (MDC) technique to measure the relative importance of various components of fire consequences. This is an approach commonly used in the health sciences (eg. Flynn 2007; Marley 2005). The method provides an understanding of how stakeholders undertake crucial tradeoffs such as: how much more important is the loss of a life than the loss of 10 houses? How much more important is the loss of an endangered species than the loss of 10 houses? Is the loss of an endangered species more important than the loss of a cultural heritage site? These are challenging questions, the answers to which are subjective by nature. Furthermore, each stakeholder involved may have a different answer to these questions.

3.4 Study Area

This wildfire consequences assessment was applied to the southern Gulf Islands, which includes the Gulf Islands National Park Reserve (GINPR). The

Gulf Islands are located in southwestern British Columbia in the Straight of Georgia between the city of Vancouver and Vancouver Island (see Figure 8). The southern Gulf Islands include Mayne Island, Saturna Island, North and South Pender, as well as many smaller surrounding islands. The GINPR was established in 2003 and holds parcels of land on each of the larger southern Gulf Islands as well as managing the entirety of several of the smaller surrounding islands.

Mayne Island, Saturna Island, North and South Pender all host rural residential development and are characterized by discrete residential areas in a matrix second-growth mixed-species forests, including Douglas-fir, Arbutus (*Arbutus menziesii*), Grand fir (*Abies grandis*), western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), Rocky Mountain Juniper (*Juniperus scopulorum*), bigleaf maple (*Acer macrophyllum*), and red alder (*Alnus rubra*). Many residential areas can only be accessed by one road, creating evacuation challenges. In addition to human values at risk, the Gulf Islands host some of Canada’s most endangered plant communities (British Columbia Conservation Data Center 1999; Garry Oak Ecosystem Recovery Team 2002) and associated species at risk.

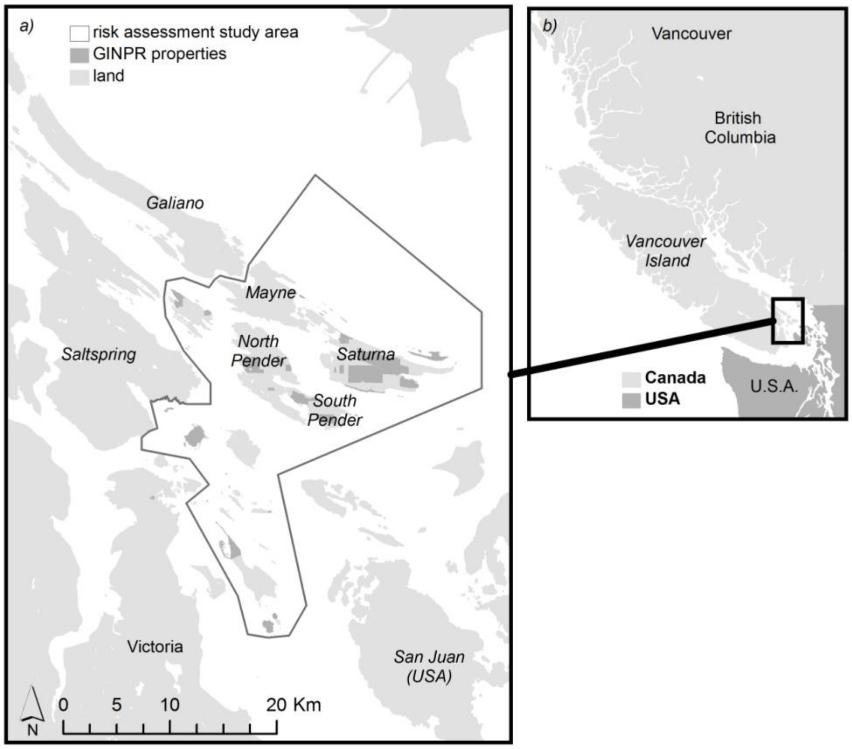

Figure 8 The southern Gulf Islands a) are located between the mainland and Vancouver Island b). The wildfire risk assessment study area encompassed Mayne Island, Saturna Island, North and South Pender Island as well as many smaller islands. The risk assessment was completed for all of the islands within the study area boundary with the exception of the evaluation of the mitigation scenarios which were limited to North Pender Island. For layout reasons only results for North Pender are shown in future figures in this paper.

3.5 Methods

3.5.1 Mapping Values at Risk

To identify features in the study area that could be damaged by wildfire we started by selecting specific values at risk to map. We define values at risk as elements that can be damaged by a forest fire and selected priority values at risk to map through consultation with local government, Fire Chiefs, and local experts in forest ecology and cultural heritage. The selected values at risk were then mapped in a Geographic Information System (GIS). Table 3 lists the values at risk that were selected and the data sources used to map them.

Table 3. A description of the values at risk in the study area and the information sources used to map them.

Value At Risk	Information Source
Residential Areas - residential development in the southern Gulf Islands is almost entirely rural residential with forested lots.	Terrestrial Ecosystem Mapping (2007)
Residents and Park Visitors - problem evacuation areas were identified within the GINPR and in residential neighborhoods. Evacuation problem areas were defined as residential areas with only one road access. Residential areas with well established marine docs or helicopter evacuation points were not included.	Terrain Resource Information Mapping (1:20,000), Personal communication with GINPR planners and Fire Chiefs
Cultural Heritage Sites - historical buildings and lighthouses within the GINPR	GINPR staff
Park Assets - park camp sites, research houses, heritage houses, radio towers, and cabins	GINPR staff
Rare Species - Rare species or plant communities designated by the British Columbia government as Red or Blue Listed.	BC Conservation Data Center Rare Elements mapping
Ecosystem Values - areas that will be ecologically benefited by a low or moderate intensity fire, areas that will be ecologically damaged by a high intensity fire, and areas where the net ecological impact of a fire is unclear or is zero.	This value at risk was not mapped due to time constraints.

3.5.2 Measuring the Relative Importance of Fire Consequences

To determine the consequences of a fire, we first established the relative importance of specific consequences. For example, one could ask which consequence is worse -- the loss of an endangered species or the loss of 10 houses? We answered these questions by surveying the perceptions of local and provincial government land managers and researchers, as well as local fire hall staff and provincial fire protection staff.

We convened a workshop for stakeholders to discuss values at risk and complete a survey on the relative importance of specific fire consequences in the southern Gulf Islands. The workshop was attended by 14 individuals representing local governments, fire halls, the Capital Regional District, provincial Fire Protection Branch, and Parks Canada staff. These individuals were invited to the workshop because of their expertise and knowledge of local fire protection, wildfire risk assessment, forest ecology, and/or cultural heritage.

In order to construct a map of the consequence values, it was important to evaluate all the consequences on an interval scale. While several methods can be applied for that purpose, such as pairwise comparison, the MDC is ideally suited because it places all attribute (ie. consequence type) and level (ie. specific consequence) combinations on one single interval scale. As is the case with all conjoint methods, hypothetical scenarios (the hypothetical fire in Figure 9. Sample survey question showing the 3 questions and 1 consequence set. Each question in the survey contained the same questions A, B, and C but a different Consequence Set. are created by combining several attributes and levels (see Consequence Set 1 in Figure 9). Respondents are asked to evaluate a number of these scenarios, each question containing a unique scenario. Respondents do not need to evaluate all possible combinations; instead by using an orthogonal fractional factorial design plan (e.g. Raktoe et al., 1981) a much smaller number of scenarios (i.e. 18 in the case of this study) is sufficient to estimate the main effects of all attributes. In each wildfire scenario, respondents are asked to pick the one best (Figure 9, Question B) and the one worst (Figure 9, Question A) attribute level present in the set. This choice of attribute levels can then be analyzed with a multinomial logit regression (Hensher et al. 2005; Louviere et al. 2000), in which only intercepts are estimated for each attribute level, which scale out on an interval scale. One of the levels is picked as an arbitrary 0-point, which serves as reference point for all other estimates.

1. Imagine a 10 hectare fire which has the following set of consequences:

Question A Pick the consequence that is the **worst** outcome	**Consequence Set 1**	**Question B** Pick the consequence that is the **best** outcome
☐	*Private Homes:* Major damage to 10 houses (e.g. structural fires)	☐
☐	*Evacuation Problem:* No potential for loss of life	☐
☐	*Cultural Heritage Sites:* Major damage (e.g. heritage building burns down)	☐
☐	*Ecosystem Benefits/Losses:* Major net ecological losses (e.g. a stand replacing fire)	☐
☐	*Rare Ecological Elements:* Rare element is lost due to the fire (e.g. rare flower, old growth forest)	☐

Question C: Do you consider the above consequence set (ie. All six of the above consequences) to be an acceptable outcome for a 10 ha fire in the Gulf Islands?

Yes No

Figure 9. Sample survey question showing the 3 questions and 1 consequence set. Each question in the survey contained the same questions A, B, and C but a different Consequence Set.

The maximum difference congoint (MDC) approach has several advantages over traditional survey approaches. Cognitively, respondents find it easy to identify the most distinct pair (ie. The best and worst) from a list of items (Flynn 2007; Marley 2005). Evaluating each item within the context of the other items present, rather than rating each condition individually simulates the respondent's natural way of evaluating items. Also, scale bias is prevented (Haider 1997). Furthermore, a single pair of best-worst choice contains more information than a "pick one" question typical of traditional discrete choice experiments (Flynn 2007).

Assessing the importance of specific wildfire consequences is a trade-off question as the stakeholder must choose the one best or worst consequence from a list of consequences (eg. Figure 9, Consequence Set 1). Such trade-off decisions cannot be captured by traditional attitudinal measurements because traditional human dimensions research has measured preferences to specific conditions through opinion-type questions that are independent of other conditions (Haider and Rasid 2002; Oh et al. 2005).

Analysis of a Maximum Difference Conjoint survey assumes the distance between two attribute levels on a scale of preference is proportional to the relative choice probability of the two levels (Flynn et al. 1992). Thus, we can arrange all attribute levels on a scale of best to worst where the order and distance between the attribute levels reflects the probability of the attribute level being selected in the best –worst questions.

3.5.3 Mapping Consequences of a Fire

We mapped Wildfire Consequence by summing individual fire consequences at each location in the study area. For example, the Wildfire Consequence in a residential area could be the sum of both a “Major damage to 10 houses” consequence and a “Major potential for loss of life” consequence. Each of these individual consequences is assigned a weight (Table 6. The relative importance of each fire consequence is defined by its weight listed in the right-hand column. For example, major potential for loss of life is defined as 3 times worse than major damage to 10 houses.Table 6, Overall Score) that is a measure of its importance relative to other consequences. Individual consequences were mapped by overlaying values at risk maps and a predicted fire intensity map. Table 4 shows the consequence resulting from each value at risk and fire intensity combination.

Table 4. The fire consequence associated with each value at risk and fire intensity combination. For example, a Residential area hit by a low intensity fire is expected to sustain “minor damages to 10 houses”, whereas, a Residential hit by a Moderate or High intensity fire is expected to sustain “major damage to 10 houses”.

	FIRE INTENSITY		
VALUE AT RISK	**Low (<4,000 Kw/min)**	**Medium (4 – 10,000 Kw/min)**	**High (>10,000 Kw/min)**
Residential	minor damage to 10 houses	major damage to 10 houses	major damage to 10 houses
Residential - Firesmarted	no damage to houses	minor damage to 10 houses	minor damage to 10 houses
Evacuation Problem Area	minor potential for loss of life	major potential for loss of life	major potential for loss of life
Park Asset - High	damages < $40,000	damages < $40,000	damages > $40,000
Park Asset -	no damages to park	damages < $40,000	damages < $40,000

Medium	assets		
Rare Element	rare element is damaged	rare element is lost	rare element is lost
Cultural Heritage Site	minor damage to cultural heritage site	major damage to cultural heritage site	major damage to cultural heritage site
Area Benefited by Low Fire Intensity	major net ecological benefits	ecological benefits are unclear or net benefit is zero	major net ecological losses
Area Damaged by High Fire Intensity	major net ecological benefits	ecological benefits are unclear or net benefit is zero	major net ecological losses

3.5.4 Investigating the Effect of Alternate Consequence Scenarios on Risk Assessment Results

To investigate the sensitivity of risk assessment results to changes in wildfire consequences, we created two alternate scenarios (NoLossOfLife and Replaceability) to the consequence scenario described above (the BaseCase scenario) and performed the risk assessment for each. The NoLossOfLife scenario is identical to the BaseCase scenario but does not track evacuation problem areas (eg. Haight et al. 2004; Municipality of Anchorage 2004; Santa Barbara County 2006) and the associated potential for loss of life (Table 5). The Replaceability consequence scenario simulates a change in stakeholder opinion, focusing importance on irreversible wildfire consequences (loss of human life, endangered species, and cultural heritage sites) and assigning little importance on reparable wildfire consequences (damage to residential homes and park assets).

Table 5. Shows the relative importance weight as a percent of total consequence that is assigned to each wildfire consequence for each wildfire consequence scenario. The BaseCase scenario uses weights derived from the stakeholder survey. The NoLossOfLife scenario simulates a wildfire risk assessment that does not account for evacuation problem areas and the Replaceability scenario assumes that only irreversible wildfire consequences are important.

Wildfire Consequence	***Wildfire Consequence Scenario***		
	BaseCase	**NoLossOfLife**	**Replaceability**
major potential for loss of life	35%	0%	20%
minor potential for loss of life	22%	0%	10%
major damage to 10 houses	12%	27%	5%
rare element is lost	8%	18%	20%
rare element is damaged	7%	17%	10%
minor damage to 10 houses	6%	14%	0%
major damage to cultural heritage sites	6%	14%	20%
damages > $40,000	2%	4%	5%
minor damage to culturalheritage sites	1%	3%	10%
damages < $40,000	0%	1%	0%

3.6 Results

3.6.1 Survey Results

The survey produced interval scale measures of the relative importance of fire consequences. The potential for loss of life was found by all respondents to be a far worse consequence than all other fire consequences. Many respondents felt that even comparing the loss of life to other fire consequences was unwise. However, for the purposes of finding the most efficient allocation of fire management resources, it is important to establish how much more important the loss of life is relative to other fire consequences. The survey also produced a measure of the acceptability of each consequence set but failed to produce a measure of the acceptability of specific fire consequences.

Respondents felt that a fire which has a ‘minor potential for loss of life’ (-10.3) was twice as bad as ‘major damage to 10 houses’ (-5.5) (Table 6). A fire with a ‘major potential for loss of life’ (-16.6) was felt to be about three times worse than ‘major damage to 10 houses’ (-5.5) and 4.5 times worse than ‘rare element is lost due to the fire eg. rare flower, old growth forest ’ (-3.7). Of note is that ‘major net ecological losses eg. a stand replacing fire’ was of very little importance to respondents. This may be because respondents perceived ‘major net ecological losses’ to be commonly associated with forest fires. It may also be because respondents poorly understood the nature of ecological losses. In contrast, ‘rare element is lost due to the fire eg. rare flower, old growth forest’ was ranked as a very bad consequence (-3.7). Although the two outcomes are very similar in nature, we believe the loss of a rare species was rated worse because it is better understood and supported by provincial, federal, and agency representatives.

Table 6. The relative importance of each fire consequence is defined by its weight listed in the right-hand column. For example, major potential for loss of life is defined as 3 times worse than major damage to 10 houses.

	Consequence	Overall Score
WORST	major potential for loss of life	-16.604
	minor potential for loss of life	-10.2885
	major damage to 10 houses	-5.5008
	rare element is lost	-3.7067
	rare element is damaged	-3.3862
	minor damage to 10 houses	-2.9403
	no potential for loss of life	-2.9233
	major damage to cultural heritage sites	-2.8977
	damages > $40,000	-0.9093
	minor damage to cultural heritage sites	-0.7317
	damages < $40,000	-0.2482
	no rare elements are damaged	-0.0703
	no damage to houses	**0**
	no damage to cultural heritage sites	0.058
	no damages to park assets	0.3863
	major net ecological losses	1.0737
	ecological benefits are unclear or net benefit is zero	3.5146
BEST	major net ecological benefits	6.581

Table 7. Shows the relative importance (Weight) of each Consequence Type (Attribute).

Attribute (Consequence Type)	Weight	Standard Error	Z-value
Damage to Homes	0	.	.
Loss of Life	-2.9233	1.2926	-2.2615
Damage to Park Asset	0.3863	0.2521	1.5321
Damage to Cultural Heritage	0.058	0.2408	0.2407
Damage/Benefit toEcosystem	1.0737	0.2272	4.7259
Damage to Rare Species	-0.0703	0.2333	-0.3012

The majority of respondents replied that all consequence sets were unacceptable. For example, even with the best consequence set (where no damages were incurred and ecosystem benefits occurred), 50% of respondents found the consequence set to be unacceptable. This may reflect a perspective that all fires are unacceptable and fire prevention is more important than mitigating damages from wildfire. These results do not tell us much about the acceptability of individual consequences. With proper dummy coding of the independent variables of the scenarios it is possible in a MDC analysis to separate the weight from the scale for each attribute, where the weight is the importance measure of the attribute (ie. the consequence types listed in Table 7). This analysis (Table 6) shows that despite an overall rejection of all scenarios, the respondents distinguished between the various attributes. Residential damages, park assets, cultural heritage sites, and rare ecological elements were regarded as concepts of approximately equal importance (z-values do not differ significantly from each other) while the loss of life was considered as significantly more important. Overall ecosystem benefits and losses were considered as significantly less important. [1]

3.6.2 Mapping Results

The complexity of the consequence map arising from this analysis illustrates the complex distribution of wildfire consequences across the study area (Figure 10). The locations with the highest consequence ratings are those where multiple values are at risk. These are generally residential areas with problematic evacuation that are predicted to sustain moderate or high intensity fires. The second highest rated locations are those with evacuation problems and moderate to high fire intensity. Following these locations are residential

[1] The stakeholder survey and MDC analysis and write-up benefitted from substantial collaboration with Dr. Wolfgang Haider.

areas with moderate to high fire intensity and then known locations of endangered species.

Most of the residential areas received lower fire consequence ratings than locations hosting endangered species. This is because residential areas are generally predicted to sustain low fire intensities and minor damages and stakeholders rated minor and major damage to endangered species as a worse consequence than minor damage to 10 houses. This is a significant departure from the results of many other risk assessments that do not include endangered species as fire consequences or generally rate residential areas or infrastructure locations with higher fire consequence ratings than locations with other values at risk areas (B.A. Blackwell and Associates Ltd. 2006; Five County Association of Governments 2007; Municipality of Anchorage 2004). Note that this map does not include the ecosystem benefits or losses associated with fire because the mapping of areas that would sustain ecological benefits or damages from wildfire was never completed.

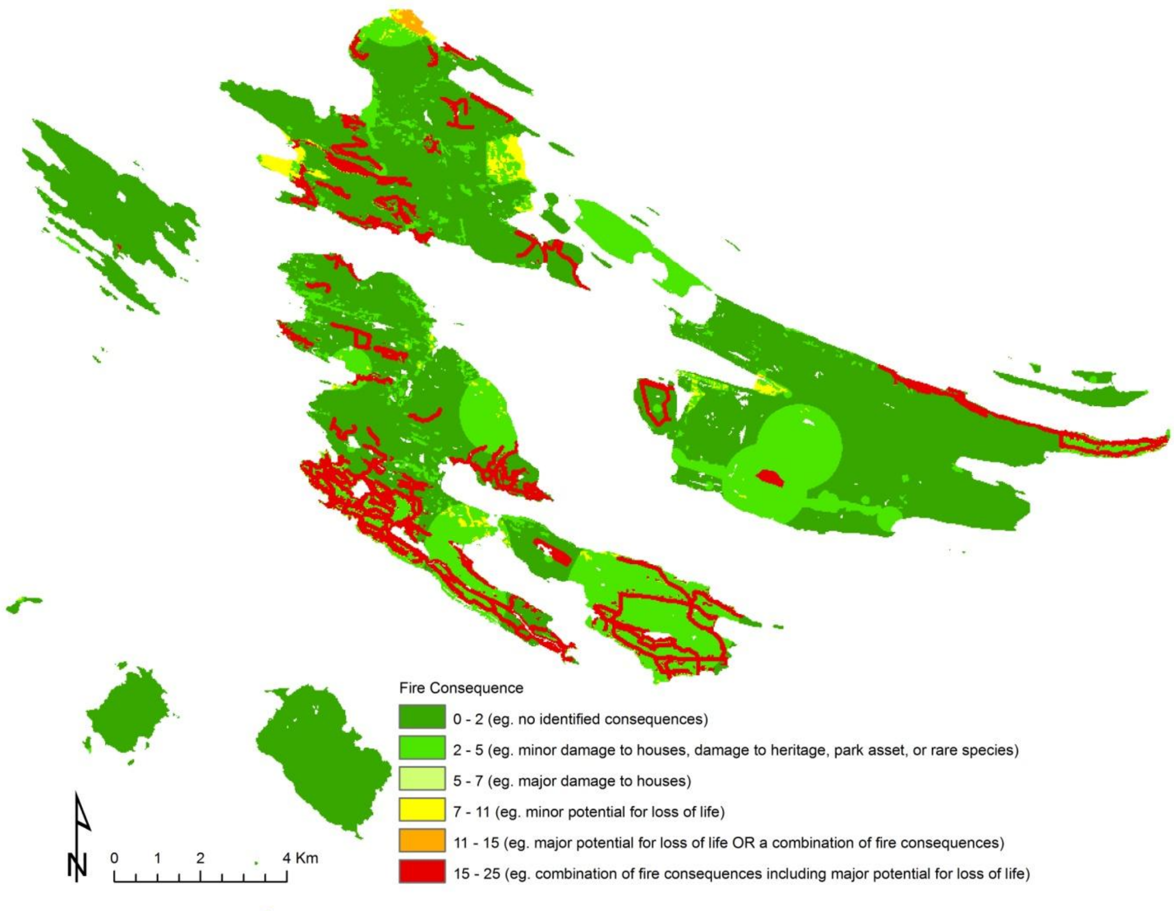

Figure 10. The fire consequence map produced shows a mosaic of fire consequence ratings. Areas coloured red and orange host the highest consequence ratings and are typically residential areas with poor evacuation potential and moderate to high predicted fire intensities.

3.6.3 Investigating the Effect of Alternate Consequence Scenarios on Risk Assessment Results

When compared to the BaseCase consequence scenario, the Replaceability and NoLossOfLife consequence scenarios produced dramatically different wildfire risk assessment results (Figure 11). 35% of the locations mapped as high risk (ie. Site where risk >= 3) in BaseCase scenario were no longer high risk when the NoLossOfLife consequence scenario was used in the risk assessment. 60% of the locations mapped as high risk in the BaseCase scenario were no longer mapped as high risk when the Replaceability scenario was used. When the NoLossOfLife consequence scenario was used, wildfire risk became focused on all residential homes as opposed to mainly homes in evacuation problem areas. Locations with endangered species also became higher risk sites. When the Replaceability method was used, wildfire risk was equally distributed on locations with endangered species, evacuation problem areas, and cultural heritage sites as opposed to risk being focused mainly on evacuation problem areas and residential home sites.

The degree to which the location of high risk sites changed depended in part on the amount of clustering of specific values at risk. Interestingly, many residential areas in the Gulf Islands are also evacuation problem areas, thus, shifting the relative importance of consequences away from loss of life towards residential areas, as was the case in the NoLossOfLife consequence scenario, did not result in as much change in the location of high risk areas (40%) as when the Replaceability scenario was used (60%). In the Replaceability scenario, the relative importance moved away from loss of life towards the loss of rare species. Rare species and evacuation problem areas are rarely in the same location, thus using the Replaceability scenario resulted in extensive movement of areas mapped as high risk.

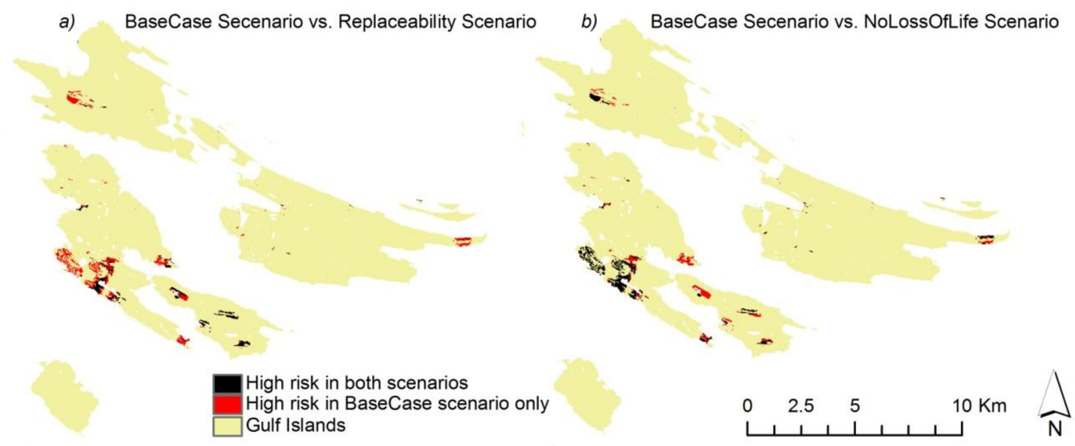

Figure 11. Shows the sensitivity of risk results to changing consequence scenarios. The red areas are high risk locations when the BaseCase consequence scenario is used that change to low or moderate risk locations when the Replaceability (a) or NoLossOfLife (b) consequence scenario is used for the risk assessment.

3.7 Discussion

3.7.1 Estimating Wildfire Consequences is Important

When *wildfire risk* is defined as *fire probability x fire consequence*, risk ratings are sensitive to changes in fire consequence ratings (Allison et al. 2004; Bachmann and Allgower 2001; Cohan et al. 1984; Finney 2005; Kerns and Ager 2007). In my case study, this phenomenon is illustrated by the dramatic movement of high risk locations observed when alternate consequence scenarios were used for the risk assessment (Figure 11). To address this sensitivity of risk assessment results to wildfire consequences, we developed an approach for measuring consequences that accurately represents stakeholder perceptions of the relative importance of wildfire consequences.

A common understanding of values at risk will be helpful as stakeholders collaborate on future fire management and risk mitigation projects (Ostrom 1992; Pinkerton 2003; Wollenberg et al. 2007). By measuring fire consequences in detail, we helped to catalyze, identify and characterize a common understanding among stakeholders of forest fire consequences in the southern Gulf Islands. The provincial government, local fire halls, and Gulf Islands National Park all share responsibility for forest fire management in the southern Gulf Islands and will be working together on this issue in the future. The survey revealed that all respondents generally had similar views as to the relative importance of values at risk.

The opportunity for stakeholders to have input into a forest fire risk assessment also makes them more likely to help implement the results of the assessment (Ludwig 2001). This effect was observed at the risk assessment workshop held for the survey where stakeholders agreed to collaboratively pursue further funding for the project. Some participants also volunteered to compile fire ignition information to aid in the risk assessment project.

3.7.2 Limitations of this Approach

This approach relies heavily on appropriate representation among stakeholders. It is unclear how risk assessment results would change with changing stakeholder representation. For example, how would risk assessment results change with First Nations representation in the stakeholder group versus without? Stakeholders may have varying perceptions as to what values at risk should be included in the risk analysis as well as the relative importance of these value at risk. We gained some insight into this question by looking at the degree to which survey responses diverged when respondents were grouped into local park and fire hall stakeholders. We found no significant divergence between respondent groups. Conveniently, surveying new stakeholders, re-running the analysis, and mapping the revised consequence and wildfire risk results would not take very long.

3.7.3 When Should this Method be Applied?

As the complexity of values at risk and number of stakeholders increase, the geographic complexity of wildfire risk increases and the most efficient allocation of wildfire prevention, protection, and suppression resources become increasingly hard to find. Thus, increasingly detailed and quantitative methods for measuring wildfire consequences are appropriate as stakeholder representation and values at risk become more complex. As the number and variety of stakeholders represented in the risk assessment process escalates, it becomes increasingly difficult to characterize stakeholder perceptions of the relative importance of specific wildfire consequences. Equally, as the number of different values at risk and their geographic complexity increases, the need for a thorough assessment of consequences will increase. If values at risk are clustered then high risk locations will undoubtedly be located at these clusters regardless of the relative importance of specific wildfire consequences.

Conversely, when the geographic layout of values at risk becomes more complex, establishing the relative importance of specific wildfire consequences becomes more relevant to risk assessment results. Wildland-urban interface and intermix areas are excellent examples of wildfire management areas with complex values at risk and stakeholder representation (eg. Santa Barbara County 2006)

Perhaps most importantly, a rigorous assessment of wildfire consequence is appropriate when fire managers want to improve stakeholder participation, knowledge, and support for community wildfire protection projects such as Community Wildfire Protection Plans (Union of British Columbia Municipalities 2005) and FireSmart initiatives (Province of British Columbia 2005). This approach allows for multiple stakeholders to come to a common understanding of the values at risk and their relative importance. Thus, the assessment process becomes a mechanism for building stakeholder knowledge and participation in future wildfire mitigation projects.

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