Tolerable Fire Intervals for TASVEG communities

Conservation Science Section

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Summary

Fire is both a threat and an important management tool for nature conservation. Knowledge of ecologically beneficial or benign fire regimes is required to inform planned burning and assess bushfire impacts. The fire interval (i.e. time between fires) is an important aspect of the fire regime, and influences the ecological impacts of fire. This report details work undertaken by Environment, Heritage and Land Division, Natural Resources and Environment Tasmania to define 'Tolerable Fire Intervals' (TFIs) for Tasmanian vegetation communities. TFI is defined here as the fire interval range under which a particular community is likely to be resilient i.e. persist and retain its characteristic composition and function. TASVEG 4.0 mapping units are used to define vegetation communities as TASVEG has state-wide coverage and is the standard vegetation classification used by Tasmanian land and fire management agencies.

TFIs are intended to comprise one aspect of guidance for considering appropriate fire regimes for a given area. While community-level guidelines such as TFIs should cater for the needs of most species within communities, site-level fire planning should consider threatened or otherwise significant species/values that may have fire interval requirements distinct to those of the community as a whole, as well as other drivers such as herbivory and drought and weed invasion. Burning outside TFIs may be required to reduce bushfire hazard, to achieve particular conservation outcomes or for Aboriginal cultural purposes. Minimum TFI should not be interpreted as the point at which vegetation communities require burning. Ideally the interval between a series of planned burns applied to an area should vary within the minimum-maximum TFI range for the communities present.

Ideally TFIs would be developed via analysis of empirical data on responses of species and other ecosystem characteristics to variation in fire intervals. However, such data are lacking for most species and ecosystem attributes. Therefore, a structured expert elicitation process was used to derive TFI values. Nineteen experts provided estimates of minimum TFI (under low and high severity fire) and maximum TFI for 'Ecological Fire Groups', groups of TASVEG communities expected to have similar fire interval responses. Expert estimates for each Ecological Fire Group were then aggregated to derive the TFI values detailed in this report.

The resultant TFI values were broadly consistent with results of previous research and fire interval recommendations for Tasmanian vegetation, although there were some differences reflecting a focus of previous recommendations on fire intervals in a hazard reduction context, versus the more ecological focus of the current study. The elicitation process also highlighted areas of uncertainty regarding vegetation responses to fire intervals, that would benefit from further research.

The TFI values presented here can provide reliable guidance as to appropriate fire intervals for maintaining TASVEG communities. However, these values are based on very generalised characterisation of vegetation community fire response. Therefore, it is suggested that these values be subject to ongoing refinement via more focused expert elicitation and/or collection of empirical data.

To facilitate operational use of TFI estimates, it is recommended that TFI values be included in the TASVEG Fire Attributes data set. In addition, a more concise, operationally focussed, document summarising the key content of the current report has been produced (see supplementary material). This includes TFI estimates, as well as outlining a process for updating TFI values as better information becomes available. It is envisaged that this document will become the primary source of TFI values and related processes for fire managers and as such will be updated as TFI values are refined.

Introduction

Fire is well recognised as a key driver in terrestrial ecosystems (Bowman et al. 2019). Fire is an integral part of the ecology of Tasmania, with natural and anthropogenic fire shaping the distribution of species and ecosystems for millennia (Jackson 1968; Fletcher and Thomas 2010; Wood et al. 2011; Fletcher et al. 2020). In the contemporary landscape, bushfires are a regular occurrence and are predicted to become more frequent, larger and more intense as climate change intensifies (Fox-Hughes et al. 2015; Bowman et al. 2020; DPIPWE 2021). In addition, planned burning is carried out for a variety of purposes including bushfire hazard reduction, Aboriginal cultural purposes, natural values conservation, weed control and improving livestock fodder quality (Marsden-Smedley 2009).

In the context of natural values conservation, fire may represent both a threat and an important management tool. A central concept in understanding the ecological impacts of fire is the fire regime i.e. the pattern of fire over time and space (Gill 1975; Gill and Allan 2008). Species vary in their ability to persist under different regimes and hence the fire regime acts as a 'filter' on species composition, in turn shaping ecosystem composition and function (Keith et al. 2002a). Understanding the relationships of natural values to fire regimes therefore contributes to assessing likely impacts of bushfire. Similarly, knowledge of ecologically beneficial or benign fire regimes is required for land managers to be able to use planned burning to promote natural values or minimise the detrimental effects of planned burning applied for other purposes. Determining appropriate fire regimes for ecological communities may also provide the basis for performance metrics for fire management e.g. the area or proportion of each community that has experienced fire(s) within an acceptable range of key fire regime parameters (York and Friend 2016; Leonard et al. 2020).

Fire interval is one parameter of the fire regime and is defined as the time elapsed between successive fires at a point in the landscape (Gill 1975). Organisms, most obviously many plants, are adapted to persisting under fire intervals within a particular range (Keith et al. 2002a). For example, short fire intervals may result in local elimination of obligate seeder species that are unable to attain reproductive maturity between successive fires. Conversely, species that rely on disturbance by fire for regeneration may be eliminated if fire intervals are longer than the lifespan of individuals and persistence of propagules. Similar principles may apply to keystone faunal habitat features e.g. tree hollows or vegetation structural attributes (Clarke et al. 2021).

This report details work undertaken by Environment, Heritage and Land Division, Natural Resources and Environment Tasmania to define 'Tolerable Fire Intervals' (TFIs) for TASVEG communities. TFI is defined here as the fire interval range under which TASVEG communities are likely to persist and retain their characteristic composition and function. The aim of the study is to develop an 'authoritative' set of TFI definitions for TASVEG (version 4.0) communities to be used across the Tasmanian fire management sector for assessment of the ecological appropriateness of actual or potential fire regimes arising from bushfire and/or planned burns. This information can be applied in planning and assessing the effectiveness of planned burning strategies in maintaining ecological values, as well as for assessing the impacts of bushfire. Similar schema are used to inform fire management in other jurisdictions (e.g. Cheal 2010 for Victoria). For Tasmania, TASVEG communities are the appropriate entities upon which to focus development of TFIs, as TASVEG is the standard vegetation classification used by Tasmanian land and fire management agencies and is integrated into fire management planning via the TASVEG Fire Attributes data set. Furthermore, the state-wide mapping of TASVEG communities allows landscape-region-state scale, cross-tenure assessment of fire regimes. TASVEG communities are defined in Kitchener and Harris (2013).

Policy and management context

Fire in native vegetation in Tasmania is primarily managed by the Tasmania Parks and Wildlife Service (PWS), Tasmania Fire Service (TFS) and Sustainable Timber Tasmania (STT), guided by the *State Vegetation Fire Management Policy 2017* (amongst other legislation and policy documents). Principle 7 of this policy recognises that fire is a key tool in maintaining ecological values. Defining TFIs contributes to realising this principle through providing guidance for fire regimes likely to maintain ecological values. In addition, the TFI guidelines produced by this study allow better evaluation of potential ecological impacts of planned burning and bushfires, thereby informing the risk-based approach to fire management identified in Principle 3 of the policy.

Fire management by PWS is guided by regional strategic plans, which recognise the importance of appropriate fire regimes for maintaining natural values within the reserve estate (PWS 2009, 2010, 2012) Similarly, the draft *TWWHA Fire Management Plan* (PWS 2021) includes the objective "Maintain natural values through appropriate fire regimes". A method for assessing this objective is set out in the draft *Fire impacts on biodiversity values in the Tasmanian Wilderness World Heritage Area: monitoring strategy* (Leonard et al. 2020). This method consists of an annual assessment of the proportion of vegetation within the TWWHA that is within/outside TFI, with greater than 20% of the area of the TWWHA outside TFI identified as a threshold for concern. The TFI definitions reported here will allow this assessment to be implemented.

Burn planning formally considers appropriate fire intervals for Threatened Native Vegetation Communities (TVNC) as defined in EcoTAS (2018). Fire intervals for other communities are informally considered, though the basis for determining appropriate fire intervals is not clear. The approach detailed in this report addresses this issue by providing TFIs for all TASVEG communities, therefore allowing refinement of recommended fire intervals for TNVC, as well as formalising fire interval recommendations for TASVEG communities generally.

Tolerable fire intervals: principles and assumptions

TFI definition is based on the concept of ecological resilience i.e. that systems can absorb a particular type of disturbance within certain bounds of frequency, intensity etc. and retain their fundamental identity (defined by composition, structure, function; Figure 1).

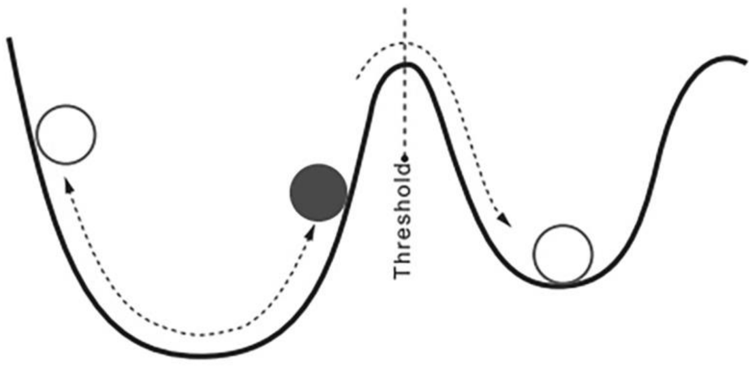

Figure 1. 'Ball and basin' analogy for ecosystem resilience (figure rom Keane et al. 2018). Basins represent ecosystem identity defined by composition, structure, function, ball represents ecosystem state at any given time. Ecosystems change, but retain their identity when disturbance is within certain bounds of type, frequency and intensity. However, when these bounds are exceeded, ecosystems may shift to a different identity basin, from which return to the original state may be difficult or impossible.

TFI represents a fire interval range within which systems are expected to be resilient. Within this paradigm it is accepted that fire may induce change in vegetation at a site provided that this change does not represent a shift in community identity or permanent reduction in condition (i.e. loss of function). TFI is largely determined by the regeneration traits of plants but also by regeneration of keystone features such as soils and important faunal habitat features (Clarke et al. 2021).

Minimum TFI represents the minimum time between successive fires under which populations of species and processes (e.g. species interactions, nutrient cycling) characteristic of a vegetation community are likely to persist, thereby maintaining community identity and function. This value may differ between high and low severity fire. A key consideration for determining minimum TFI is the time required for plants to recover from fire such that they will persist when subject to a subsequent fire e.g. time required for seeders to mature and set seed and for resprouters to replenish carbohydrate stores. Fire severity may influence the minimum TFI for a community, with ecosystems often taking longer to recover from higher severity fire.

Maximum TFI represents the maximum time between successive fires under which populations of species and processes characteristic of a vegetation community are likely to persist, thereby maintaining community identity and function (note that this may include 'old growth' expressions of a community). A key consideration for determining maximum TFI is the period for which species that require disturbance for regeneration can persist (as living individuals and/or as propagules) in the absence of fire, which in turn is often linked to inter-species competition and vegetation successional processes.

Key assumptions of using vegetation community TFIs to guide ecological fire management are that 1) vegetation communities can act as surrogates for other elements of the biota and 2) fire intervals that maintain vegetation communities are also likely to maintain constituent biota (across taxonomic groups) and ecosystem processes (Clarke 2008). There is empirical support for these assumptions (Pharo and Beattie 2001; MacMullan-Fisher et al. 2010; Egidi et al. 2016; Kelly et al. 2017) although floristic communities do not necessarily correspond closely to communities of all taxonomic groups (Mac Nally et al. 2002), and the 'optimal' fire interval range may differ amongst different elements of the system (Clarke et al. 2021; Rainsford et al. 2021). Despite these caveats, the broad congruence between the fire interval requirements of biota within vegetation communities, combined with the fact that vegetation communities are often well defined and readily mapped, make community level fire interval guidelines a useful tool for landscape scale fire management planning.

Tolerable Fire intervals and Fire Management

TFIs are formulated with regard to the general or typical occurrence of a community and are intended to comprise one aspect of guidance for considering appropriate fire regimes within a given area. In particular, while community-level guidelines such as TFIs should cater for the needs of most species within communities, site-level fire planning should consider threatened or otherwise significant species/values that may have fire interval requirements distinct to those of the community as a whole. Assessment of the appropriateness of fire regimes should also consider other drivers such as herbivory and drought and weed invasion. Sites or communities of high conservation significance may require tailored fire regimes, which should be informed by consideration of local conditions and dynamics (e.g. via on-ground inspection, monitoring and/or adaptive management and/or extrapolation from similar sites/systems elsewhere). In addition, there is often much structural and compositional variation within vegetation, even at the TASVEG community level, which should be considered in fire management planning.

By definition, the TFIs presented here are those thought to maintain vegetation within a given state (i.e. TASVEG communities). There are instances where conservation outcomes will be enhanced by management to change vegetation state e.g. using burning to restore native grassland in areas currently dominated by shrubs. In such instances, the TFI of the desired vegetation type will inform fire management. Similarly, burning outside TFI may be required to achieve particular management objectives e.g. hazard reduction (see below), catering for requirements of threatened species, weed control or for Aboriginal cultural purposes.

Minimum TFI should not be interpreted as the point at which vegetation communities require burning. Ideally the interval between a series of planned burns applied to a site should vary within the minimum-maximum TFI range for the communities present. Repeated burning at a particular interval, even if this is within the TFI range, is likely to favour a subset of species at the expense of others, thereby potentially reducing diversity. However, such burning may be required in some instances to achieve conservation aims, such as promoting threatened species.

Tolerable fire intervals and fire management zoning

Tasmanian fire management agencies use a zoning system to assist in planning (Marsden-Smedley 2009). There are three main zone categories (in some instances further sub-zones are recognised), each with particular fire management objectives (Table 1). In the Asset Protection Zone (APZ), the priority is reducing bushfire risk, usually through intensive fuel management, while in the Land Management Zone (LMZ) the focus is on applying fire regimes to maintain ecological values (Figure 2). The Strategic Fire Management Zone (SMZ) combines both bushfire risk reduction and ecological objectives.

It is expected that burning below minimum TFI will often (though not necessarily) be required within APZs to maintain fuels at levels that reduce bushfire risk (Table 1). Guidelines for fire frequency required to reduce bushfire risk in broad vegetation types are outlined in Marsden-Smedley (2009). Within SFMZ, burning will usually be within TFI, though often at the lower end of the TFI range. Burning below minimum TFI will sometimes be required to meet bushfire risk reduction objectives and/or ecological objectives. In LMZ there is scope for burning to occur across the full TFI range, as required to produce desirable fire mosaics within the landscape. Burning limited areas of LMZ outside TFI may occasionally be required to achieve particular ecological aims.

Table 1. Fire management zone objectives and indicative likelihood burning outside TFI required to achieve objectives.

Fire management zone	**Objective(s)**	**Likelihood burning outside TFI required to achieve objectives**
Asset Protection Zone	Provide a reduced fuel level in order to protect assets from potential bushfire.	Moderate-high
Strategic Fire Management Zone	Minimise the risk of large bushfires by providing areas of low fuel loads across the landscape that prevent the forward spread, or assist in the containment, of bushfires. Provide the necessary fire regimes for ongoing healthy ecological functioning.	Low-moderate. Burning may often be at lower end of TFI range.
Land Management Zone	Provide the necessary fire regimes for ongoing healthy ecological functioning.	Low. Burning outside TFI occasionally required to meet ecological objectives.

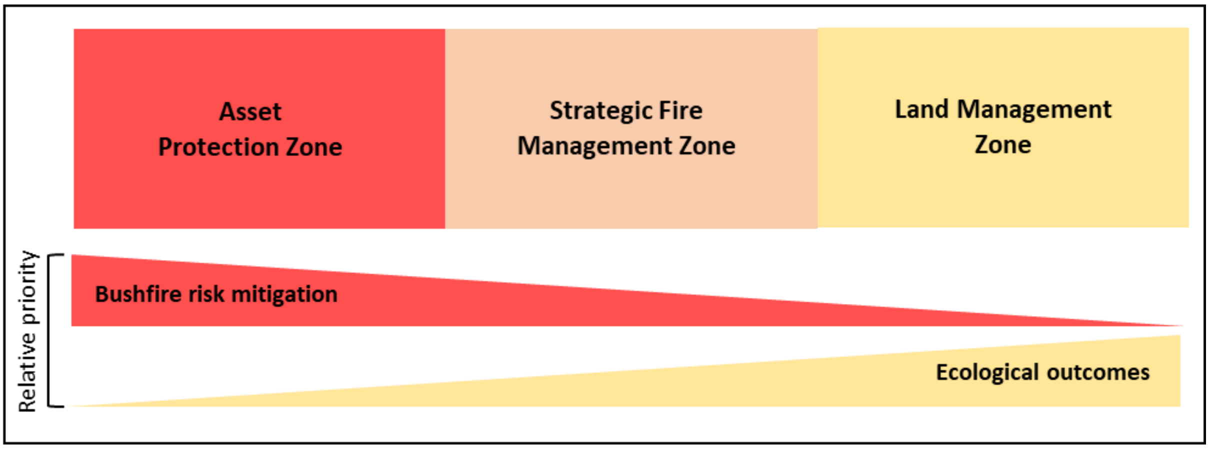

Figure 2. Fire management zones and relative priority of bushfire risk mitigation/ecological outcomes.

Existing fire interval recommendations for Tasmanian vegetation communities

Tasmanian fire managers currently draw on three main sources of recommended fire intervals: Pyrke and Marsden-Smedley (2005), ECOtas (2018) and DPIPWE (2015), hereafter referred to as PM-S, ECOtas, and FRNC respectively. As a preliminary step to the current study, these documents were examined to determine whether they provided, individually or in combination, a robust basis for determining TASVEG community TFIs. Results of this analysis are provided in Appendix 1 and briefly summarised below.

The aim of PM-S was to reduce the complexity of the TASVEG schema for fire management applications by assigning TASVEG communities to 'Fire-attributes' categories, and ascribing fire sensitivity, and flammability ratings to these larger groupings. The fire sensitivity classification includes recommended fire intervals. PM-S is the basis of the TASVEG Fire Attributes data currently used in fire management in Tasmania.

ECOtas was produced from work commissioned by the Tasmania Fire Service in order to provide guidance on tolerable fire intervals for threatened vegetation communities in the context of burning for hazard reduction purposes. Recommendations were formulated via review of existing literature and consultation with relevant experts.

The aim of FRNC was to provide guidelines for appropriate fire (planned burning) regimes to maintain natural values in the TWWHA.

While these sources provide useful guidance, they present several issues that make it difficult to adopt one, or a synthesis, as an authoritative set of tolerable fire intervals including:

- inconsistency in recommended intervals;
- incomplete coverage of TASVEG communities (ECOTas, FRNC);
- recommended fire intervals often very broad (this may be appropriate for some communities, or represent 'bet hedging' in the face of uncertainty);
- lack of transparency as to how intervals were derived.

In light of these issues, the current study was initiated to develop a single, comprehensive and authoritative set of TFIs for all TASVEG communities.

Methods

Ideally TFIs would be developed by analysing empirical data on responses of species and other ecosystem characteristics to variation in fire intervals. However, such data are lacking in most cases and would require substantial effort to collect for even a small number of species (Cornelissen et al. 2003). Furthermore, fire responses can vary within species due to genetic variation and/or environmental context (Vivian et al. 2010). In the absence of sufficient appropriate data, it was decided to develop TFIs for TASVEG communities based on expert judgement.

Expert judgement is often useful in conservation management when data are lacking or incomplete (Sutherland 2006). However, experts can make mistakes due to contextual biases or heuristics (mental 'shortcuts' people tend to use to simplify decision making; Burgman 2004). Structured elicitation processes can help reduce these biases and hence improve the accuracy of expert judgements (O'Hagan et al. 2006). Such processes also have the advantage of being transparent and hence the information derived from them is more defensible.

In determining TFIs for TASVEG communities the IDEA protocol was employed (Hemming et al. 2018). The 'IDEA' acronym encapsulates the main steps of the process, these being Investigate, Discuss, Estimate, Aggregate (Figure 3). This method has been found to yield reliable judgements and is relatively simple to implement. The process can be summarised as five basic steps:

1. A group of experts is recruited to participate in the process.
2. Experts individually provide numerical estimates in response to questions regarding the issues of interest.
3. Individual estimates are compiled and reviewed and discussed by the expert group.
4. Experts revise their estimates as required in light of discussion.
5. Estimates are aggregated to provide final set of values.

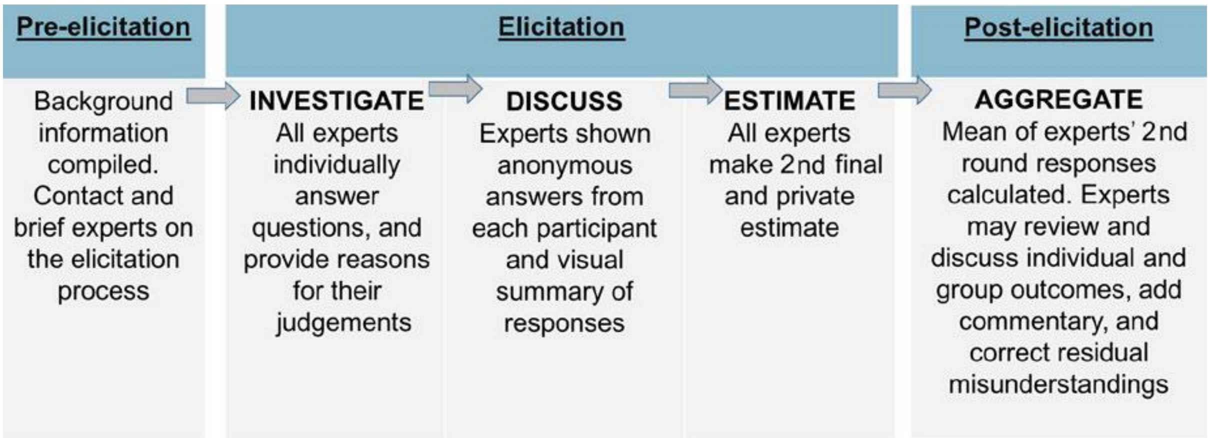

Figure 3. Steps in the 'IDEA' structured expert elicitation process (from Hemming et al. 2018).

An advantage of the IDEA protocol is that it is amenable to experts doing much of the work 'in their own time' i.e. outside a workshop setting. This is particularly advantageous in the current study as, even with TASVEG communities grouped into Ecological Fire Groups (see below), it would not have been possible for experts to make the full set of required estimates in a single session. This also allows experts to consult relevant data, literature and other experts (not involved in the process), which should result in them making better estimates. The method is also well suited to being carried out remotely via online meetings or even email, potentially expanding the possibilities for participation and allowing greater flexibility in the format of the process.

An important feature of the IDEA approach is that it does not aim to arrive at a consensus amongst experts. Each expert's estimates are treated as independent 'data points' based on each individual's (incomplete) knowledge of the system in question. To maintain this independence, experts are instructed to not discuss their estimates with other participants prior to the 'discuss' step of the process. Similarly, data presented to the expert group is de-identified to reduce 'peer pressure' effects on estimates. The final set of values is derived by aggregating expert estimates by calculating e.g. mean or median value.

For the current study, the IDEA protocol was implemented as shown in Table 2.

Table 2. Implementation of IDEA protocol to derive Tolerable Fire Intervals for TASVEG communities.

Stage of IDEA protocol	**Activity**	**Date**
Pre-elicitation	Experts recruited and provided with instructions.	December 2020 - February 2021
	Introductory meeting.	11 February 2021
Investigate	Experts provide 'Round 1' TFI estimates.	11 February – 1April 2021
Discuss	Workshop to discuss Round 1 estimates.	1 April 2021
Estimate	Experts revise estimates as required and provide final version.	April – May 2021
Aggregate	Estimates compiled to form final set of TFI values (this report)	June 2021

Selection of experts

Experts engaged in this process obviously needed to have knowledge of Tasmanian ecosystems and fire ecology. Beyond this, research indicates that the quality of information gained from expert elicitation is increased by ensuring diversity amongst the experts involved (e.g. in age, gender, cultural background, life experience, education and specialisation; Page 2008). Hemming et al. (2018) recommend involving 10-20 experts in the elicitation process to ensure robust estimates are obtained.

For the current study, 42 experts were invited to participate, of which 19 accepted. Participating experts consisted of land and fire management agency staff, researchers and ecological consultants (Table 3). The gender composition of the expert group was 9 female, 10 male.

Table 3. Affiliation of experts participating in process to derive Tolerable Fire Intervals (TFI) for TASVEG communities.

Expert affiliation	Number of experts
Consultant	4
Environment, Heritage and Land Division, Natural Resources and Environment Tasmania	4
Sustainable Timber Tasmania	1
Tasmania Fire Service	3
Tasmania Parks and Wildlife Service	2
Tasmanian Land Conservancy	1
University of Tasmania	4

TFI estimation process

To make the task of estimating TFIs for the 164 TASVEG 4.0 communities more tractable, communities were assigned to 28 'Ecological Fire Groups' based on broad similarity of structure, composition and environmental relationships and hence expected similar TFIs. TASVEG communities/mapping units within the 'Modified land', 'Other natural environments' and 'Macquarie Island vegetation' groups were excluded from assessment.

For each of the Ecological Fire Groups, experts were asked to consider the questions below with regard to:

- Minimum TFI under low severity fire.
- Minimum TFI under high severity fire (note: high/low severity minimum TFI will not necessarily differ).
- Maximum TFI.

Questions:

1. Realistically, what do you think is the lowest plausible value (years)?
2. Realistically, what do you think is the highest plausible value (years)?
3. What is your best guess as to the true value (years)?
4. How confident are you that your lowest-highest plausible value range captures the true value? (estimate between 50 and 100%.)

The estimation process was framed in this way to encourage experts to consider the plausible bounds of TFI values before making an estimate of the true value. Considering counterfactual events and reasoning before estimating the true values improves the accuracy of estimates (Hemming et al. 2018). Similarly, asking experts to consider their level of confidence has been shown to improve the quality of estimates. Also, in the present context, quantifying uncertainty around TFI estimates will help identify communities that may warrant further investigation to develop more robust TFI estimates in the future.

Experts were asked to formulate their estimates for the general or typical occurrence of each Ecological Fire Group. Experts were also given the option of making estimates for individual TASVEG communities where they deemed this necessary e.g. when they believed that the Ecological Fire Group TFI values were not appropriate for a constituent TASVEG community. To inform their estimates, experts were encouraged to draw on existing literature and data sets, discussion with experts not involved in the process as well as their personal observations of vegetation fire responses. In some cases, experts omitted estimates for particular Ecological Fire Groups where they felt they did not have sufficient experience/information upon which to form a judgement. The minimum number of estimates provided for any Ecological Fire Group was 13.

For this exercise, high/low severity fire were defined as:

High severity	Forest	Majority of tree canopy scorched or burnt, understorey more or less completely consumed.
	Non-forest	Few unburnt patches within fire boundary. Most standing vegetation burnt. In buttongrass moorland, little thatch remaining.
Low severity	Forest	Most of canopy not scorched or burnt. Unburnt patches present in understorey.
	Non-forest	Fire coverage patchy. Shrubs tend to be scorched rather than burnt. Grass/sedge foliage may be consumed but thatch remains

With regard to minimum TFI varying between high and low severity fires, experts were instructed to consider the severity of the 'preceding' fire e.g. in the case of high severity, consider "what is the minimum interval required between a high severity fire and a subsequent fire to maintain ecosystem resilience?" This approach accounts for the potential difference in recovery time of plants after fires of high/low severity, which influences the ability to then recover from a subsequent fire. The severity of the 'subsequent fire' was not defined. While the ecological effects of repeated high severity fires are likely to be different to repeated low severity fires, trying to account for responses to different permutations of severity in sequences of fires was deemed to be introducing unnecessary complexity to the estimation process.

Clearly fire interval is not the only influence on vegetation and the effects of fire interval may be mediated by other factors such as rainfall and herbivory (Clarke et al. 2021). Experts were encouraged to consider other drivers that typically apply to Ecological Fire Groups and that may interact with fire interval to determine vegetation state and factor these into TFI estimates.

It was recognised prior to initiating this process that some TASVEG communities have extremely low resilience to fire i.e. a single fire event may cause local elimination, such that there is potentially no tolerable fire interval. Similarly, there are communities that potentially achieve an effectively permanent steady state in the absence of fire ('climax communities') and hence have no maximum TFI. For these instances, experts were initially instructed to nominate values of 'exclude' or 'infinite' respectively. At the discussion workshop, it was agreed to substitute these values with a nominal value of 1000 years so that 'estimates' of the exclusion or absence of fire were reflected in the calculation of the final group aggregate TFI values.

Experts agreed that for TASVEG communities within the Wetland Ecological Fire Group, fire was likely to be rare, or at least sporadic, and not a major driver of community processes. Hence this group was excluded from further analysis.

Final aggregate TFI values, as well as aggregate highest/lowest plausible values and confidence values were derived by calculating the median of each set of values provided by experts. Median values were used, rather than means, to reduce the influence of outlying values on final estimates.

Results and discussion

Expert elicitation process

From a facilitator's perspective, the IDEA process for eliciting expert opinion worked well. The clear structure and focus on quantitative outputs made managing the process relatively straightforward. Approximately five days was required in preparing and running the elicitation process, plus another 10 days managing, analysing and reporting on the resultant data.

Feedback from expert participants on the process was not sought formally, but experts engaged in the task enthusiastically and expressed appreciation for the structured process and greater time available to consider their responses compared to the more typical single-session workshop format. The time spent by experts on Round 1 TFI estimates ranged from several hours to several days (typically 1-2 days). Three experts provided estimates but were unable to attend the discussion workshop. Only seven of the 19 participants returned revised estimates following the discussion workshop and of these most made few and minor revisions. Most experts that did not submit revisions stated that they were satisfied with their initial estimates, however it is likely that competing time demands also contributed to the low level of revision. It is estimated that on average experts each contributed 3-4 days to the process (including time spent considering estimates, introductory meeting, workshop).

Expert elicitation results

TFI values (median of expert estimates), plausible value range (median of low/high values) and median confidence values for Ecological Fire Groups are given in Table 4 (TASVEG communities within Groups are listed in Appendix 2). Few estimates were provided for individual TASVEG communities, making it difficult to robustly derive individual community-level aggregate estimates. Where possible community-level TFI values were calculated (see below, Appendix 2), otherwise community-level estimates provided were drawn upon to inform the discussion below.

Conifer-dominated, rainforest and Sphagnum communities

TFI estimates were most clear cut for the Alpine with conifers and Rainforest with *Athrotaxis/Lagarostrobos* groups, for which the median value of all TFI estimates was 1000 years. Experts had high confidence in these estimates (90-100%), reflecting the good understanding of fire responses of these communities i.e. extremely low resilience to fire, with community-level stability over very long periods without fire (Kirkpatrick et al. 2010; Jordan et al. 2016; Bowman et al. 2019; Holz et al. 2020).

There was also a high degree of consistency and confidence (>80%) in estimates amongst experts for the Rainforest without *Athrotaxis/Lagarostrobos* group, with minimum TFI estimates reflecting the capacity for these communities to (slowly) recover from fire events (Read 1999). As with the conifer groups, experts near-unanimously estimated maximum TFI as 1000 years, again reflecting the 'climax' nature of most rainforest communities. One expert suggested lower TFI values for the Coastal rainforest and *Nothofagus - Leptospermum* short rainforest TASVEG communities, on the basis of their greater sclerophyll component compared to other rainforest communities.

Experts were similarly confident in estimates for 'Sphagnum peatland', with TFI estimates indicating this vegetation is resilient to occasional low severity fires, but not to high severity fires in which the peat substrate is destroyed and is also likely to persist in the long-term absence of fire (MacDougall 2007; Whinam et al. 2010).

Alpine communities

Cushion moorland was ascribed a median maximum TFI of 1000 years, with a median confidence of 90%. Expert confidence was also high for minimum TFI values for this group, although the plausible range was relatively wide. This reflects the likely difference in fire response between 'eastern' and 'western' cushion moorland. The former, dominated by *Abrotanella forsteroides*, is relatively resilient to fire, whereas the latter, featuring a diversity of species but commonly dominated by *Donatia novae-zelandiae* and/or *Dracophyllum minimum*, is thought to be more fire sensitive (Kirkpatrick et al. 2010). Experts highlighted a need to delineate these groups, which currently fall within a single TASVEG community, and assign TFI values accordingly.

Estimates were also somewhat varied and with low confidence (50-70%) for Alpine heath and Alpine sedgeland groups. This reflects the variation in environmental conditions (e.g. altitudinal/exposure, soil nutrient and drainage gradients) and composition observed within the constituent communities (Crowden 1999), and hence likely variation in fire response. Longer TFIs were assigned to western alpine heath due to generally slower recovery from fire compared to eastern heaths. Western alpine sedegland was also ascribed longer TFIs than its eastern counterpart, with experts pointing to occurrences in long fire-free areas such as the Tyndall Range as indicative of potential fire sensitivity and stability in the absence of fire. Conversely, western alpine sedgeland dominated by *Isophysis tasmanica* commonly occurs on more fire-prone mountains (e.g. Denison Range) and appears quite resilient to periodic burning. Some experts suggested there was no tolerable interval for these alpine communities, though it is unclear whether they believed they have very low resilience or whether they had in mind the potential for gradual succession to coniferous heath and/or perceived undesirability of planned burning (on the latter point note that alpine communities are considered 'non-treatable' by planned burning; EFDTC 2020). Experts expressed uncertainty as to the dynamics of alpine sedgeland vegetation in relation to fire, suggesting that further research in this area would be beneficial.

Buttongrass moorland

TFI estimates for Buttongrass moorland groups were largely consistent across experts, although confidence was perhaps surprisingly low (63-75%) given that moorland fire responses have been quite well studied (e.g. Brown and Podger 1982, 2002; Balmer 2010; French et al. 2016) and most experts had some experience working in this vegetation type. Experts highlighted uncertainty about fire-related dynamics of the Alkaline pans TASVEG community, in particular the role of fire in the persistence of this community within a moorland matrix. TFI estimates also diverged somewhat for Buttongrass moorland (sparse), reflecting uncertainty over whether this community is a long-standing expression of fire-vegetation interactions or is a recently induced degraded state of some other community, which may recover or at least stabilise in the long-term absence of fire.

Dry eucalypt communities

TFI estimates for dry eucalypt groups (excluding sub-alpine) were within a fairly narrow range, both within and across groups. This was somewhat surprising given the number of TASVEG communities within these groups and the intra-community variation exhibited by many. A few experts did nominate TFI values at the TASVEG community level. However, these mostly only diverged slightly (<5 years) from the group median estimate and were almost always within the range of estimates provided at Ecological Fire Group level. Hence, incorporating these estimates into the aggregate estimates would result in minor, if any, adjustment to overall TFI values.

Some experts also noted that a number of TASVEG dry eucalypt communities can exhibit variation in understorey type (e.g. can be either grassy or shrubby) and suggested that for site-level fire planning TFIs appropriate to the understorey type present should be applied. Median TFI values were very similar amongst the understorey type-based dry eucalypt Ecological Fire Groups, so such adjustment of TFI would only be a consideration for burning at the extremes of the TFI envelope. Also, in many cases the understorey type exhibited by dry eucalypt communities is mediated by fire interval (Duncan 1999), so applying a fire regime that promotes a transition to a different understorey structure is not necessarily of concern and indeed could be desirable.

TFI estimates for sub-alpine dry eucalypt communities were substantially higher than for their lowland counterparts, reflecting the longer time required for fire recovery in harsh alpine environments. Some experts nominated very high maximum TFI values for this group (300-1000 years), although it seems these experts were also envisaging a (desirable) gradual transition to rainforest within this timeframe. Confidence in TFI estimates for this group was generally low (median 60-62.5%), suggesting more research on fire responses in warranted.

Wet sclerophyll and Mixed Forest

Experts were broadly consistent and confident (75-77.5%) in TFI estimates for the Wet sclerophyll and Mixed forest groups. Fire responses of these vegetation types are reasonably well understood (e.g. Gilbert 1959; Jackson 1968; Mount 1979; Turner et al. 2009). Given this, it is somewhat surprising that a few experts suggested fire exclusion/infinite maximum TFI for these groups, as this would almost certainly lead to a transition to rainforest. It may be that these experts were flagging exclusion from planned burning as desirable, given that bushfire is likely to occur in most occurrences of wet/mixed forest within the several centuries required for succession to rainforest to occur. As with alpine communities, wet/mixed forest communities are deemed non-treatable by planned burning (EFTDC 2020). In addition, some experts flagged that some wet sclerophyll TASVEG communities may include mixed forest (e.g. *E. regnans* forest, *E. brookeriana* wet forest and *E. subcrenulata* forest and woodland), to which the Mixed forest TFIs should be applied.

Grassland and Dry scrub/heath groups

TFI estimates for the Highland and Lowland grassland and Dry scrub/heath groups were mostly within a relatively narrow range. Experts were moderately confident in most estimates (>70%), reflecting that the role of fire in maintaining grassland and heath communities is well known (Keith et al. 2002b; Bowman et al. 2013; Leonard and Kingdom 2017). For highland grassland, the minimum TFI estimate is consistent with evidence regarding fire intervals that will maintain floristic richness and prevent shrub invasion (Wood et al. 2017; Kirkpatrick et al. 2020). However, the fire-related dynamics of grassland can be difficult to predict, particularly in interaction with grazing (Leonard et al. 2010; Kirkpatrick et al. 2016) and in high conservation value grasslands tailored fire management planning informed by appropriate monitoring is warranted.

Experts agreed that fire regimes for the TASVEG communities Rookery halophytic herbland and Spray zone coastal complex were distinct from the remainder of the Dry heath/scrub group in that, due to usually being dominated by succulent species, fire is likely rare or a least sporadic and therefore these communities do not have a characteristic fire regime. Some experts also suggested that the Heathland on calcareous substrates TASVEG community may require longer inter-fire intervals than other dry heathland communities due to occurring on wind-exposed and drought prone sites.

Non-eucalypt forest, Sub-alpine scrub/heath and Wet scrub groups

The Non-eucalypt forest, Sub-alpine scrub/heath and Wet scrub groups were the most challenging for experts to ascribe TFI values to, with confidence in estimates generally low (<60%). This is because fire regimes vary within these groups both between and within constituent TASVEG communities. Also, many of the communities within these groups have seldom been foci for research regarding effects of fire and similarly are rarely primary targets for planned burning, hence their fire responses are not well understood. Nonetheless, estimates for minimum TFIs for these groups were mostly within a fairly narrow range, with maximum TFI estimates being more variable. Experts also suggested that the *Acacia*-dominated communities within the 'Non-eucalypt wet' group should have lower TFI values than the rest of the group (medians for estimates provided: minimum TFI low/high severity = 20/40 years, maximum TFI = 80 years).

Table 4. Median Tolerable Fire Interval (TFI) estimates (years), low/high plausible values (years) and confidence values for Ecological Fire Groups.

Ecological Fire Group	Minimum TFI (low severity)			Minimum TFI (high severity)			Maximum TFI		
	Estimate	Plausible range	Confidence (%)	Estimate	Plausible range	Confidence (%)	Estimate	Plausible range	Confidence (%)
Alpine heath (east)	40	(20-67.5)	60	60	(40-100)	65	165	(137.5-600)	50
Alpine heath (west)	50	(30-100)	70	100	(50-200)	70	600	(150-1000)	62.5
Alpine sedge east	30	(20-40)	70	40	(25-80)	70	135	(100-200)	50
Alpine sedge west	40	(25-50)	65	100	(50-200)	62.5	595	(165-1000)	80
Alpine with conifers	1000	(1000-1000)	90	1000	(1000-1000)	99	1000	(1000-1000)	95
Buttongrass moorland low productivity	10	(7-15)	70	15	(10-25)	70	70	(50-72.5)	66
Buttongrass moorland moderate productivity	10	(5-15)	75	15	(10-20)	70	30	(22.5-50)	68
Buttongrass moorland sparse	15	(8-20)	65	20	(10-30)	65	100	(60-100)	63
Callitris	30	(20-50)	75	40	(25-60)	75	500	(150-1000)	80
Cushion moorland	55	(40-100)	80	130	(80-225)	90	1000	(1000-1000)	90
Dry eucalypt grassy	9.5	(5-15)	75	20	(10-30)	72.5	40	(30-50)	70
Dry eucalypt heathy	12	(8-20)	70	20	(15-30)	65	35	(25-50)	60
Dry eucalypt shrubby	12	(8-20)	70	25	(15-30)	70	35	(30-50)	60
Dry eucalypt sub-alpine	30	(20-50)	60	55	(30-75)	60	120	(80-300)	62.5
Dry scrub/heath	12	(10-15)	70	15	(11-25)	70	40	(30-60)	70
Grassland highland	7	(4-10)	75	10	(5.5-16)	65	27.5	(20-40)	75
Grassland lowland	5	(3-8)	75	7	(5-10)	72.5	20	(10-25)	75
Mixed forest	80	(50-105)	77.5	100	(90-150)	75	362.5	(300-500)	77.5
Non-eucalypt grassy	15	(10-20)	60	20	(11-30)	60	80	(50-150)	60
Non-eucalypt heathy	15	(10-22.5)	60	20	(12.5-27.5)	60	45	(35-55)	60
Non-eucalypt wet	40	(25-50)	67.5	60	(40-80)	67.5	190	(150-250)	62.5
Rainforest with *Athrotaxis/Lagarostrobos*	1000	(1000-1000)	95	1000	(1000-1000)	100	1000	(1000-1000)	100
Rainforest without Athrotaxis/*Lagarostrobos*	200	(150-250)	80	750	(400-750)	80	1000	(1000-1000)	82.5
Sphagnum peatland	100	(35-160)	92.5	1000	(200-1000)	95	1000	(1000-1000)	97.5
Sub-alpine scrub/heath	37.5	(20-55)	52.5	62.5	(40-100)	52.5	122.5	(90-175)	52.5
Wet sclerophyll	35	(20-45)	75	65	(45-80)	75	250	(200-350)	75
Wet scrub	18	(15-25)	60	20	(20-30)	60	60	(50-100)	70
Wetland	NA			NA			NA		

Comparison with previous fire interval recommendations

As described above and in Appendix 1, there have been several previous attempts to define desirable fire intervals for Tasmanian vegetation communities. As with the current study, these have also been derived from expert opinion, though apparently without employing a structured elicitation process and in the case of EcoTas and PM-S one and two experts respectively. Therefore, the results of the current study are likely to be more reliable, given they are derived from the input of 19 experts using a structured process designed to avoid the main problems often encountered in expert elicitation. Nonetheless it is worth comparing the results presented here with those of previous work, as major differences may highlight areas needing further examination. In addition, the earlier recommendations are currently embedded in fire management planning, notably the recommendations for threatened communities provided by EcoTas. Therefore, if the current results are adopted for fire management planning, as is the intention, policy and procedure will need updating to account for any differences with previous guidelines.

In fact, there were few major inconsistencies between results of the current and previous studies, with TFI ranges for communities mostly broadly overlapping (Table 5, Appendix 2). In particular, FRNC recommended intervals are closely congruent with the results of the current study. PM-S recommendations diverge most markedly from the current estimates with regard to alpine communities. PM-S recommend a fire interval of greater than 100 years for alpine heath communities, compared to the 40/60 and 50/100 years for low/high severity minimum TFI for eastern and western alpine heath respectively derived from expert estimates. Conversely, the PM-S recommendation of a minimum fire interval of 15 years for alpine sedgeland is shorter than the minimum TFI estimates of 30/40 and 40/100 for eastern/western alpine sedgeland in the current study. PM-S also recommend substantially shorter minimum intervals for buttongrass moorland, dry eucalypt and Sphagnum communities and a higher minimum interval for highland grassland communities.

For the threatened communities covered by EcoTas, fire interval recommendations for dry eucalypt were substantially shorter (4-10 years) than in the results of the current study (Table 4; PM-S also gives a substantially shorter minimum fire interval of 3 years). EcoTas also recommends exclusion from planned burning for a number of communities, including conifer rainforest communities, which is in accord with results of the current study (and the non-treatable by planned burning status of these communities). For other communities, the fire exclusion recommendation has the caveat of being subject to expert advice. The TFI estimates presented here may inform such advice, though consideration of site-specific conditions will still be required in many cases.

The likely explanation for EcoTas and PM-S recommending much shorter minimum fire intervals than the estimates in the current study for vegetation types such as dry eucalypt forest and buttongrass moorland is that the earlier studies focus on fire regimes in a hazard reduction context (EcoTas explicitly, PM-S implicitly), with ecological values a secondary consideration. Therefore, their minimum fire intervals are those that are effective in reducing fuels to the level required to facilitate bushfire suppression and hence at (or perhaps exceeding) the extreme limits of fire regimes that allow ecological resilience to be maintained. In contrast, in the current study experts were primarily focussed on fire intervals that are likely to maintain resilience, resulting in more 'conservative' minimum TFI estimates.

An explanation for PM-S providing a higher minimum interval for alpine heath than the minimum TFI estimates in the current study is less clear. This difference is possibly due to PM-S's "broad-brush" approach to assigning desirable fire intervals, where alpine heath is grouped with several other vegetation types requiring long inter-fire intervals (rainforest, mixed forest). Alternatively, the difference could arise from a shift in thinking amongst experts as to the fire resilience of at least some elements of the alpine vegetation since PM-S was published, perhaps reflecting recent evidence concerning past fire regimes in this context (e.g. Holz et al. 2014).

Table 5. EcoTas fire interval recommendations and TFI estimates for Threatened Native Vegetation Communities. TFI estimates for current study given as Minimum TFI low severity (minimum TFI high severity) – maximum TFI. EcoTas fire interval codes: NS = no specific recommendation, E = exclude fire, S = seek specialist advice

Listed no.	TNVC community	TASVEG code	EcoTas fire interval	TFI estimate (current study)
14	*Eucalyptus amygdalina* forest and woodland on sandstone	DAS	4-10	12 (20)-35
15	*Eucalyptus amygdalina* forest and woodland on Cainozoic deposits	DAZ	4-10	12 (20)-35
17	*Eucalyptus globulus* dry forest and woodland	DGL	4-10	9.5 (20)-35
18	*Eucalyptus globulus* King Island forest	DKW WGK	4-10 NS	12 (25)-35 80 (100)-363
19	*Eucalyptus morrisbyi* forest and woodland	DMO	E	9.5 (20)-35
20	*Eucalyptus ovata* forest and woodland	DOV, DOW, DMW	4-10	DOV: 12 (25)-35 DOW: 12 (20)-35 DMW: 10 (20)-35
21	*Eucalyptus risdonii* forest and woodland	DRI	4-10	12 (25)-35
22	*Eucalyptus tenuiramis* forest and woodland on sediments	DTO, DPE	4-10	12 (25)-35
23	*Eucalyptus viminalis-Eucalyptus globulus* coastal forest and woodland	DVC	4-10	9.5 (20)-35
24	*Eucalyptus viminalis* Furneaux forest and woodland	DVF	4-10	12 (25)-35
16	*Eucalyptus brookeriana* wet forest	WBR	NS	35 (65)-250
25	*Eucalyptus viminalis* wet forest	WVI	NS	35 (65)-250
2	*Allocasuarina littoralis* forest	NAL	30 (S)	15 (20)-45
10	*Banksia serrata* woodland	NBS	S	15 (20)-45
11	*Callitris rhomboidea* forest	NCR	15 (S)	30 (40)-500
30	*Melaleuca ericifolia* swamp forest	NME	10-15 (S)	40 (60)-190
38	Subalpine *Leptospermum nitidum* woodland	NLN	E	37.5 (62.5)-122.5
3	*Athrotaxis cupressoides-Nothofagus gunnii* short rainforest	RPF	E	E/∞
4	*Athrotaxis cupressoides* open woodland	RPW	E	E/∞
5	*Athrotaxis cupressoides* rainforest	RPP	E	E/∞
6	*Athrotaxis selaginoides-Nothofagus gunnii* short rainforest	RKF	E	E/∞
7	*Athrotaxis selaginoides* rainforest	RKP	E	E/∞
8	*Athrotaxis selaginoides* subalpine scrub	RKS	E	E/∞
33	Rainforest fernland	RFE	E	200 (750)-∞
32	*Notelaea-Pomaderris-Beyeria* forest	SBR	E	35 (65)-250
9	*Banksia marginata* wet scrub	SBM	I	18 (20)-60
26	Heathland on calcareous substrates	SCL	E	12 (15)-40
27	Heathland scrub complex at Wingaroo	SCL	S	12 (15)-40
31	*Melaleuca pustulata* scrub	SMP	I	12 (15)-40
34	Riparian scrub	SRE	E (S)	18 (20)-60
35	Seabird rookery complex	SRH	E	NA
36A	Spray zone coastal complex	SSZ	E	NA
1	Alkaline pans	AAP	I	10 (15)-70
36	*Sphagnum* peatland	ASP	E	100 (E)-∞
39	Wetlands	AHF, ASF, AHL, AWU, AHS	E	NA
13	Cushion moorland	HCM	E	55 (130)-∞
28	Highland grassy sedgeland	MGH	5-15	7 (10)-27.5
37	Subalpine *Diplarrena latifolia* rushland	MDS	5-15	7 (10)-27.5
29	Highland *Poa* grassland	GPH	5-15	7 (10)-27.5

Conclusions

This study used the IDEA protocol, a structured expert elicitation process, to derive TFI estimates for TASVEG communities. These estimates were broadly consistent with previously published fire interval recommendations for Tasmanian vegetation and the results of previous studies. Furthermore, while the IDEA method does not seek to establish a consensus amongst experts, in this case experts agreed that the aggregate (median) TFI estimates derived were appropriate. Therefore, it seems likely that the TFI estimates presented here can provide reliable guidance as to appropriate fire intervals for maintaining TASVEG communities.

The process of determining these TFI estimates has highlighted several areas that warrant further investigation. These include improving knowledge of the fire responses of alpine heath, alpine sedgeland and cushion moorland and potentially splitting some current TASVEG communities based on this e.g. creating eastern and western cushion moorland communities. Better definition of the fire sensitivity of alpine communities would assist in bushfire response planning by allowing resources to be targeted to the vegetation most likely to suffer long term bushfire impact. In addition, as the threat of bushfire increases, there will be increasing need to consider planned burning in alpine environments to protect the most fire sensitive components such as confer-dominated vegetation. Better understanding of alpine vegetation fire responses will help ensure such burning does not have inadvertent negative consequences.

These results also highlight the need for better mapping of eucalypt forest understorey types, and perhaps further delineation of TASVEG communities to reflect this. Such mapping would be beneficial in informing ecological fire planning, as well as enhancing information on fuels and potential fire behaviour. Understorey type mapping could be produced via the current main TASVEG mapping method of aerial imagery interpretation and/or by modelling understorey type from mapped environmental correlates (e.g. climate, soils). Whatever method is used, mapping would need to account for the dynamism in understorey structure related to fire history.

The TFI estimates presented here are based on very generalised characterisation of vegetation community fire response. It is suggested that these estimates be treated as a ‘first cut’, to be refined over time. One approach to this refinement process would be to repeat the expert elicitation method described here but with focus on a subset of TASVEG communities (e.g. those within one of the Ecological Fire Groups used here), making it possible for experts to more fully engage with the nuances of vegetation communities and estimate community-level TFIs directly. Refinement of TFIs could also be achieved via analysis of spatial and field data. Priority for more detailed revision should be given to communities that are treatable by planned burning and those of high conservation value, including threatened communities.

To facilitate operational use of TFI estimates, it would be beneficial to include median minimum (low/high severity) and maximum TFI values as additional fields in the TASVEG Fire Attributes data set. In addition, a more concise, operationally focussed, document has been produced (see Supplementary material). This summarises the key content of the current report including TFI estimates (in some cases rounded off to the nearest whole year/five year/decade value to reflect a more practical level of precision for a management context), as well as outlining a process for updating TFI values as better information becomes available. It is envisaged that this document will become the primary source of TFI values and related processes for fire managers and as such will be updated as TFI values are refined.

Empirical data based on site-specific observations remains the ‘gold standard’ for determining TFIs and other fire regime parameters that are likely to maintain natural values. Collection of data to improve knowledge of vegetation fire responses should continue to be a priority. As climate change intensifies, the challenge of managing fire to maintain and support natural values will only increase. The ongoing improvement of knowledge concerning the role of fire in ecosystems and translation of this knowledge into tools for fire management is key to addressing this challenge.

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Appendix 1: Analysis of existing fire interval recommendations for Tasmanian vegetation communities

Background and aim

Fire is well recognised as both a key threat and a key management tool for natural values. Knowledge of ecologically beneficial or benign fire regimes is required for land managers to be able to use planned burning to promote natural values, or minimise the detrimental effects of planned burning for reducing risk to other values. Determining appropriate fire regimes for ecological communities may also provide the basis for performance metrics for fire management e.g. the area or proportion of each community that has experienced fire(s) within an acceptable range of key fire regime parameter(s) (York and Friend 2016).

There are currently several sources of ecologically desirable/tolerable fire regimes for Tasmanian vegetation communities that (potentially) inform fire management. The aim of this document is to collate these sources, check for consistency, highlight uncertainties and suggest approaches to identifying consistent and transparent guidelines for ecological fire regimes that can be used in the future.

Method

Three sources of recommended fire regimes were considered: Pyrke and Marsden-Smedley (2005), ECOtas (2018) and DPIPWE (2015), hereafter referred to as PM-S, ECOtas, and FRNC respectively.

The aim of PM-S was to reduce the complexity of the TASVEG schema for fire management applications by assigning TASVEG communities to 'Fire-attributes' categories, and ascribing fire sensitivity, and flammability ratings to these larger groupings. The fire sensitivity classification includes recommended fire intervals. PM-S is the basis of the TASVEG Fire Attributes data commonly used for fire management.

ECOtas was produced from work commissioned by the Tasmania Fire Service to provide guidance on tolerable fire intervals for threatened vegetation communities. Recommendations were formulated via a review of existing literature and consultation with relevant experts.

The aim of FRNC was to provide guidelines for appropriate fire (planned burning) regimes to maintain natural values in the TWWHA.

Recommendations in these documents were cross referenced with TASVEG 3 communities and associated Fire Attributes data (Pyrke and Marsden-Smedley 2005; see accompanying spreadsheet). This information were examined for (in-) consistencies amongst sources and other relevant issues.

Results and discussion

Only FRNC systematically addresses components of the fire regime other than interval (e.g. seasonality, intensity). FRNC also provides guidance on fire mosaics (desirable size and arrangement of burns), although this is very general.

The sources vary in their coverage of TASVEG communities. Only PM-S provides complete coverage, though this is only through extrapolation of values for Fire Attributes categories to corresponding TASVEG communities. ECOtas only covers threatened communities (as per its scope), while FRNC focusses on communities that occur within the TWWHA that are treatable with planned burning, with additional recommendations to exclude fire from several fire sensitive communities. The FRNC recommendations can also be extrapolated to some additional non-TWWHA communities with similar characteristics to those within the TWWHA e.g. several dry eucalypt communities. It's possible that the ECOtas recommendations could be similarly extrapolated.

With regard to fire interval, the three sources are mostly, in very general terms, consistent in that where more than one source identifies a desirable/tolerable interval range for a community, the ranges overlap. However in many cases this is due to the very broad recommended interval ranges in PM-S, e.g. 3-50 years for most dry eucalypt communities, 15-100 years for many other communities.

In general FRNC recommends longer minimum intervals than the other sources e.g. minimum interval of 7 or 10 years for dry eucalypt communities (depending on understorey type), compared to 4 or 3 years for ECOtas and PM-S respectively. This may be due to FRNC being explicitly aimed at identifying fire regimes that maintain natural values and therefore 'optimal' ecologically, whereas the other sources lean more towards regimes that are 'tolerable' in a hazard reduction burning context. One key instance in which FRNC recommends a minimum fire interval shorter than other sources is in the case of highland *Poa* grassland. In fact this community is perhaps where recommendations of the three sources diverge most dramatically, with recommended interval ranges being: FRNC: 3-10 years, ECOtas: 5-15 years, PM-S: 15-100 years. While optimal fire regimes for highland grassland are not known precisely and are likely to be context dependent (Leonard and Kingdom 2017), they are more likely to be in the range suggested by the FRNC and ECOtas recommendations than that of PM-S. Similarly, FRNC recommends substantially longer fire intervals (40-60 years) for sparse buttongrass moorlands on slopes than PM-S (3-50 years), with the latter recommendation being uniform across all moorland types.

Conclusions

While the three sources considered here provide useful guidance for fire management, there is much scope for further development. An obvious initial step would be to review the fire interval recommendations described above with a view to resolving inconsistencies across sources and narrowing the broad ranges in interval values currently ascribed to many communities where necessary and possible. Beyond this, it would be beneficial to review and refine recommendations for other aspects of the fire regime and fire mosaics.

A major issue for such a process is the lack of empirical data on which to base recommendations for fire regimes. Expert opinion is likely to provide useful information, in particular if it is elicited using a systematic and transparent method (e.g. Hemming et al. 2018). However there is also a risk of perpetuating 'received wisdom' of unknown veracity. Hence reliance on expert opinion should be viewed as an interim measure, to be gradually replaced by empirical data as it is acquired. This in turn will require a sustained program of targeted research. To maximise utility to land managers, this research should be integrated with fire management within an adaptive management framework.

References included in main reference list.

Table A1. Median values for TFI estimates and low/high plausible values (years) and confidence values for Ecological Fire Groups, TASVEG communities within Ecological fire groups and fire interval recommendations from Pyrke and Marsden-Smedley (2005; PM-S), ECOtas (2018; EcoTas) and DPIPWE (2015; FRNC).

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity)			Minimum TFI (high severity)			Maximum TFI			EcoTas	PM-S	FRNC
		Estimate	Plausible range	Confidence (%)	Estimate	Plausible range	Confidence (%)	Estimate	Plausible range	Confidence (%)			
Alpine heath (east)		40	(20 - 67.5)	60	60	(40 - 100)	65	165	(137.5 - 600)	50			
Eastern alpine heathland	*HHE*											>100	
Eastern alpine vegetation (undifferentiated)	*HUE*											>100	
Alpine heath (west)		50	(30 - 100)	70	100	(50 - 200)	70	600	(150 - 1000)	62.5			
Western alpine heathland	*HHW*											>100	
Alpine sedge east		30	(20 - 40)	70	40	(25 - 80)	70	135	(100 - 200)	50			
Eastern alpine sedgeland	*HSE*											15-100	
Alpine sedge west		40	(25 - 50)	65	100	(50 - 200)	62.5	595	(165 - 1000)	80			
Western alpine sedgeland/herbland	*HSW*											15-100	
Alpine with conifers		1000	(1000 - 1000)	90	1000	(1000 - 1000)	99	1000	(1000 - 1000)	95			
Alpine coniferous heathland	*HCH*											E	
Athrotaxis cupressoides open woodland	*RPW*										E	E	
Athrotaxis cupressoides rainforest	*RPP*										E	E	
Athrotaxis cupressoides/Nothofagus gunnii short rainforest	*RPF*										E	E	
Buttongrass moorland low productivity		10	(7 - 15)	70	15	(10 - 25)	70	70	(50 - 72.5)	66			
Alkaline pans	*AAP*										I	3-50	
Buttongrass moorland with emergent shrubs	*MBS*											3-50	(10) 15-70
Restionaceae rushland	*MRR*											3-50	(10) 15-70
Western buttongrass moorland	*MBW*											3-50	(10) 15-70
Western lowland sedgeland	*MSW*											3-50	(10) 15-70

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity) Estimate	Plausible range	Confidence (%)	Minimum TFI (high severity) Estimate	Plausible range	Confidence (%)	Maximum TFI Estimate	Plausible range	Confidence (%)	EcoTas	PM-S	FRNC
Buttongrass moorland (undifferentiated) (western Tasmania)	*MBU*											3-50	(10) 15-71
Buttongrass moorland moderate productivity		10	(5 - 15)	75	15	(10 - 20)	70	30	(22.5 - 50)	68			
Eastern buttongrass moorland	*MBE*											3-50	(6) 10-40
Pure buttongrass moorland	*MBP*											3-50	(6) 10-40
Buttongrass moorland (undifferentiated) (eastern Tasmania)	*MBU*											3-50	(6) 10-40
Buttongrass moorland sparse		15	(8 - 20)	65	20	(10 - 30)	65	100	(60 - 100)	63			
Sparse buttongrass moorland on slopes	*MBR*											3-50	40-60
Callitris		30	(20 - 50)	75	40	(25 - 60)	75	500	(150 - 1000)	80			
Callitris rhomboidea forest	*NCR*										15 (S)	>100	
Cushion moorland		55	(40 - 100)	80	130	(80 - 225)	90	1000	(1000 - 1000)	90			
Cushion moorland	*HCM*										E	>100	
Dry eucalypt grassy		9.5	(5 - 15)	75	20	(10 - 30)	72.5	40	(30 - 50)	70			
Eucalyptus barberi forest and woodland	*DBA*											3-50	>7
Eucalyptus globulus dry forest and woodland	*DGL*										4-10	3-50	>7 (grassy/sedgy) >10 (other)
Eucalyptus morrisbyi forest and woodland	*DMO*										E	E	E/S
Eucalyptus pulchella forest and woodland	*DPU*											3-50	>7 (grassy/sedgy) >10 (other)
Eucalyptus viminalis - Eucalyptus globulus coastal forest and woodland	*DVC*										4-10	3-50	>7 (grassy/sedgy) >10 (other)
Eucalyptus viminalis grassy forest and woodland	*DVG*											3-50	>7 (grassy/sedgy) >10 (other)
Midlands woodland complex	*DMW*										4-10	3-50	>7
Dry eucalypt heathy		12	(8 - 20)	70	20	(15 - 30)	65	35	(25 - 50)	60			

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity) Estimate	Minimum TFI (low severity) Plausible range	Minimum TFI (low severity) Confidence (%)	Minimum TFI (high severity) Estimate	Minimum TFI (high severity) Plausible range	Minimum TFI (high severity) Confidence (%)	Maximum TFI Estimate	Maximum TFI Plausible range	Maximum TFI Confidence (%)	EcoTas	PM-S	FRNC
Eucalyptus amygdalina coastal forest and woodland	*DAC*											3-50	>10
Eucalyptus amygdalina forest and woodland on sandstone	*DAS*										4-10	3-50	>10
Eucalyptus amygdalina inland forest and woodland on Cainozoic deposits	*DAZ*										4-10	3-50	>7
Eucalyptus dalrympleana - Eucalyptus pauciflora forest and woodland	*DDP*											3-300	
Eucalyptus nitida dry forest and woodland	*DNF*											3-50	>10
Eucalyptus nitida Furneaux forest	*DNI*											3-50	>10
Eucalyptus ovata heathy woodland	*DOW*										4-10	3-50	>7
Eucalyptus pauciflora forest and woodland not on dolerite	*DPO*											15-100	>7 (grassy/sedgy), >10 (other)
Dry eucalypt shrubby		12	(8 - 20)	70	25	(15 - 30)	70	35	(30 - 50)	60			
Eucalyptus amygdalina - Eucalyptus obliqua damp sclerophyll forest	*DSC*											15-100	>7 (grassy/sedgy), >10 (other)
Eucalyptus amygdalina forest and woodland on dolerite	*DAD*											3-50	>7 (grassy/sedgy), >10 (other)
Eucalyptus amygdalina forest and woodland on mudstone	*DAM*											3-50	>10
Eucalyptus cordata forest	*DCR*											30-300	
Eucalyptus delegatensis dry forest and woodland	*DDE*											3-50	>7 (grassy/sedgy), >10 (other)
Eucalyptus obliqua dry forest and woodland	*DOB*											3-50	>10
Eucalyptus ovata forest and woodland	*DOV*										4-10	3-50	>7 (grassy/sedgy), >10 (other)

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity)			Minimum TFI (high severity)			Maximum TFI					
		Estimate	Plausible range	Confidence (%)	Estimate	Plausible range	Confidence (%)	Estimate	Plausible range	Confidence (%)	EcoTas	PM-S	FRNC
Eucalyptus pauciflora forest and woodland on dolerite	*DPD*											15-100	>7 (grassy/sedgy), >10 (other)
Eucalyptus perriniana forest and woodland	*DPE*										4-10	E	E/S
Eucalyptus risdonii forest and woodland	*DRI*										4-10	3-50	>7 (grassy/sedgy), >10 (other)
Eucalyptus rodwayi forest and woodland	*DRO*											3-50	>7 (grassy/sedgy), >10 (other)
Eucalyptus sieberi forest and woodland not on granite	*DSO*											3-50	>10
Eucalyptus sieberi forest and woodland on granite	*DSG*											3-50	>10
Eucalyptus tenuiramis forest and woodland on dolerite	*DTD*											3-50	>10
Eucalyptus tenuiramis forest and woodland on granite	*DTG*											3-50	>10
Eucalyptus tenuiramis forest and woodland on sediments	*DTO*										4-10	3-50	>7 (grassy/sedgy), >10 (other)
Eucalyptus viminalis Furneaux forest and woodland	*DVF*										4-10	3-50	>10
King Island Eucalypt woodland	*DKW*										4-10	3-50	>10
Dry eucalypt sub-alpine		30	(20 - 50)	60	55	(30 - 75)	60	120	(80 - 300)	62.5			
Eucalyptus coccifera forest and woodland	*DCO*											30-300	
Eucalyptus gunnii woodland	*DGW*											30-300	
Dry scrub/heath		12	(10 - 15)	70	15	(11 - 25)	70	40	(30 - 60)	70			
Acacia longifolia coastal scrub	*SAL*											3-50	
Coastal heathland	*SCH*											3-50	
Coastal Scrub	*SSC*											3-50	

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity) Estimate	Plausible range	Confidence (%)	Minimum TFI (high severity) Estimate	Plausible range	Confidence (%)	Maximum TFI Estimate	Plausible range	Confidence (%)	EcoTas	PM-S	FRNC
Coastal scrub on alkaline sands	*SCA*											3-50	
Eastern scrub on dolerite	*SED*											3-50	
Heathland on calcareous substrates	*SCL*										E1	3-50	
Kunzea ambigua regrowth scrub	*SKA*											3-50	
Leptospermum glaucescens heathland and scrub	*SLG*											3-50	
Melaleuca pustulata scrub	*SMP*										I	3-50	
Rookery halophytic herbland	*SRH*	*NA*			*NA*			*NA*			E	>100	
Spray zone coastal complex	*SSZ*	*NA*			*NA*			*NA*			E	>100	
Grassland highland		7	(4 - 10)	75	10	(5.5 - 16)	65	27.5	(20 - 40)	75			
Highland grassy sedgeland	*GPH*										5-15	15-100	
Highland Poa grassland	*MDS*										5-15	15-100	3-10
Subalpine Diplarrena latifolia rushland	*MGH*										5-15	15-100	
Grassland lowland		5	(3 - 8)	75	7	(5 - 10)	72.5	20	(10 - 25)	75			
Coastal grass and herbfield	*GHC*											3-50	
Lowland grassland complex	*GCL*											3-50	
Lowland Poa labillardierei grassland	*GPL*											3-50	
Lowland sedgy grassland	*GSL*											3-50	
Lowland Themeda triandra grassland	*GTL*											3-50	
Rockplate grassland	*GRP*											3-50	
Mixed forest		80	(50 - 105)	77.5	100	(90 - 150)	75	362.5	(300 - 500)	77.5			
Eucalyptus delegatensis over rainforest	*WDR*											>100	
Eucalyptus nitida over rainforest	*WNR*											>100	
Eucalyptus obliqua forest over rainforest	*WOR*											>100	
Non-eucalypt grassy		15	(10 - 20)	60	20	(11 - 30)	60	80	(50 - 150)	60			

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity) Estimate	Plausible range	Confidence (%)	Minimum TFI (high severity) Estimate	Plausible range	Confidence (%)	Maximum TFI Estimate	Plausible range	Confidence (%)	EcoTas	PM-S	FRNC
Allocasuarina verticillata forest	*NAV*											3-50	>10
Bursaria - Acacia woodland and scrub	*NBA*											3-50	
Non-eucalypt heathy		15	(10 - 22.5)	60	20	(12.5 - 27.5)	60	45	(35 - 55)	60			
Banksia serrata woodland	*NBS*										S	3-50	>10
Allocasuarina littoralis forest	*NAL*										30 (S)	3-50	>7
Non-eucalypt wet		40	(25 - 50)	67.5	60	(40 - 80)	67.5	190	(150 - 250)	62.5			
Acacia dealbata forest	*NAD*	*20*			*40*			*80*				30-300	
Acacia melanoxylon forest on rises	*NAR*	*20*			*40*			*80*				30-300	
Acacia melanoxylon swamp forest	*NAF*	*20*			*40*			*80*				30-300	
Leptospermum lanigerum - Melaleuca squarrosa swamp forest	*NLM*											30-300	
Melaleuca ericifolia swamp forest	*NME*										10-15 (S)	>100	
Rainforest with *Athrotaxis/ Lagarostrobos*		1000	(1000 - 1000)	95	1000	(1000 - 1000)	100	1000	(1000 - 1000)	100			
Athrotaxis selaginoides - Nothofagus gunnii short rainforest	*RKF*										E	E	E
Athrotaxis selaginoides rainforest	*RKP*										E	E	E
Athrotaxis selaginoides subalpine scrub	*RKS*										E	E	E
Lagarostrobos franklinii rainforest and scrub	*RHP*											E	E
Nothofagus gunnii rainforest and scrub	*RFS*											E	E
Rainforest without *Athrotaxis/ Lagarostrobos*		200	(150 - 250)	80	750	(400 - 750)	80	1000	(1000 - 1000)	82.5			
Coastal rainforest	*RCO*											>100	
Highland low rainforest and scrub	*RSH*											>100	

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity) Estimate	Plausible range	Confidence (%)	Minimum TFI (high severity) Estimate	Plausible range	Confidence (%)	Maximum TFI Estimate	Plausible range	Confidence (%)	EcoTas	PM-S	FRNC
Highland rainforest scrub with dead Athrotaxis selaginoides	*RKX*											>100	
Nothofagus - Leptospermum short rainforest	*RML*											>100	
Nothofagus - Phyllocladus short rainforest	*RMS*											>100	
Nothofagus rainforest undifferentiated	*RMU*											>100	
Rainforest fernland	*RFE*										E	30-300	
Sphagnum		100	(35 - 160)	92.5	1000	(200 - 1000)	95	1000	(1000 - 1000)	97.5			
Sphagnum peatland	*ASP*										E	30-300	E
Sub-alpine scrub/heath		37.5	(20 - 55)	52.5	62.5	(40 - 100)	52.5	122.5	(90 - 175)	52.5			
Subalpine heathland	*SHS*											15-100	
Subalpine Leptospermum nitidum woodland	*NLN*										E	15-100	
Western subalpine scrub	*SSW*											15-100	
Wet sclerophyll		35	(20 - 45)	75	65	(45 - 80)	75	250	(200 - 350)	75			
Broadleaf scrub	*SBR*										E1	30-300	
Eucalyptus brookeriana wet forest	*WBR*										NS	30-300	
Eucalyptus dalrympleana forest	*WDA*											30-300	
Eucalyptus delegatensis forest over Leptospermum	*WDL*											30-300	
Eucalyptus delegatensis forest with broad-leaf shrubs	*WDB*											30-300	
Eucalyptus delegatensis wet forest (undifferentiated)	*WDU*											30-300	
Eucalyptus globulus King Island forest	*WGK*										NS	30-300	
Eucalyptus globulus wet forest	*WGL*											30-300	

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity) Estimate	Plausible range	Confidence (%)	Minimum TFI (high severity) Estimate	Plausible range	Confidence (%)	Maximum TFI Estimate	Plausible range	Confidence (%)	EcoTas	PM-S	FRNC
Eucalyptus nitida forest over Leptospermum	*WNL*											30-300	
Eucalyptus nitida wet forest (undifferentiated)	*WNU*											30-300	
Eucalyptus obliqua forest over Leptospermum	*WOL*											30-300	
Eucalyptus obliqua forest with broad-leaf shrubs	*WOB*											30-300	
Eucalyptus obliqua wet forest (undifferentiated)	*WOU*											30-300	
Eucalyptus regnans forest	*WRE*											30-300	
Eucalyptus subcrenulata forest and woodland	*WSU*											30-300	
Eucalyptus viminalis wet forest	*WVI*										NS	30-300	
Wet scrub		18	(15 - 25)	60	20	(20 - 30)	60	60	(50 - 100)	70			
Banksia marginata wet scrub	*SBM*										E	15-100	>10
Eastern riparian Scrub	*SRE*										E (S)	30-300	>10
Leptospermum forest	*NLE*											15-100	>10
Leptospermum lanigerum scrub	*SLL*											3-50	>10
Leptospermum scoparium - Acacia mucronata forest	*NLA*											15-100	>10
Leptospermum scoparium heathland and scrub	*SLS*											3-50	>10
Leptospermum scrub (deprecated)	*SLW*												>10
Leptospermum with rainforest scrub	*SRF*											>100	>10
Melaleuca squamea heathland	*SMM*											3-50	>10
Melaleuca squarrosa scrub	*SMR*											15-100	>10
Scrub complex on King Island	*SSK*											15-100	>10
Western regrowth complex	*SWR*											15-100	>10
Western wet scrub	*SWW*											15-100	>10

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG code	Minimum TFI (low severity) Estimate	Plausible range	Confidence (%)	Minimum TFI (high severity) Estimate	Plausible range	Confidence (%)	Maximum TFI Estimate	Plausible range	Confidence (%)	EcoTas	PM-S	FRNC
Wet heathland	*SHW*											3-50	>10
Wetland		NA			NA			NA					
Fresh water aquatic herbland	*AHF*										E	3-50	E
Fresh water aquatic sedgeland and rushland	*ASF*											3-50	E
Lacustrine herbland	*AHL*										E	3-50	E
Saline aquatic herbland	*AHS*										E	3-50	E
Saline sedgeland/rushland	*ARS*											3-50	E
Saltmarsh (undifferentiated)	*AUS*											3-50	E
Succulent saline herbland	*ASS*											3-50	E
wetland (undifferentiated)	*AWU*										E	3-50	E

Supplementary material

Tolerable Fire Intervals for TASVEG Communities: Application to Fire Management and Business Rules

Version 1 December 2021

Background

Fire is both a threat and an important management tool for nature conservation. A central concept in understanding the ecological impacts of fire is the fire regime, a key component of which is fire interval. Knowledge of ecologically beneficial or benign fire regimes is required to inform planned burning and assess bushfire impacts.

In 2020-21 Natural and Cultural Heritage Division of DPIPWE, in consultation with Tasmania Parks and Wildlife Service, Tasmania Fire Service, Sustainable Timber Tasmania and other stakeholders, undertook work to define 'Tolerable Fire Intervals' (TFIs) for Tasmanian vegetation communities, with the intention that the TFI estimates produced would be adopted as a guide for ecological fire management across the Tasmanian fire management sector. TFI is defined here as the fire interval range under which a particular community is likely to be resilient i.e. persist and retain its characteristic composition and function. TASVEG 4.0 mapping units are used to define vegetation communities as it has state-wide coverage, is the standard vegetation classification used by Tasmanian land and fire management agencies and is integrated into current fire management planning.

Ideally TFIs would be developed via analysis of empirical data on responses of species and other ecosystem characteristics to variation in fire intervals. However, such data are lacking in most cases. Therefore, a structured expert elicitation process was used to derive TFI values. Nineteen experts provided estimates of minimum TFI (under low and high severity fire) and maximum TFI for 'Ecological Fire Groups', groups of TASVEG communities expected to have similar fire interval responses. Expert estimates for each Ecological Fire Group were aggregated to derive TFI values.

Outcomes of the TFI estimation process are detailed in *Tolerable Fire Intervals for TASVEG communities* (Leonard 2021). To briefly summarise, TFI values were broadly consistent with results of previous research and fire interval recommendations for Tasmanian vegetation, although there were some differences reflecting a focus of previous recommendations on fire intervals in a hazard reduction context, versus the more ecological focus TFIs. The elicitation process also highlighted areas of uncertainty regarding vegetation responses to fire intervals, that would benefit from further research, as well as the need for a process to update TFI estimates as better information becomes available.

TFI estimates for each TASVEG community will be included in the TASVEG Fire Attributes database. The initial set of TFI estimates, based on those derived from the expert elicitation process outlined above are given in Appendix S1 of this document.

This document outlines:

1. Guidelines for applying TFIs in fire management.
2. Business Rules for review and update of TFI values.

Tolerable fire intervals: principles and assumptions

TFI definition is based on the concept of ecological resilience i.e. that systems can absorb a particular type of disturbance up to a certain level of frequency, intensity etc. and retain their fundamental identity (composition, structure, function; Figure 1).

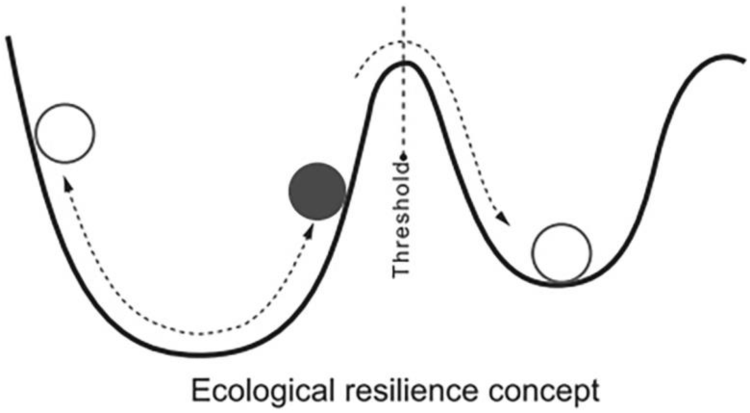

Figure 1. 'Ball and basin' analogy for ecosystem resilience (figure rom Keane et al. 2018). Basins represent ecosystem identity defined by composition, structure, function, ball represents ecosystem state at any given time. Ecosystems change, but retain their identity when disturbance is within certain bounds of type, frequency and intensity. However, when these bounds are exceeded, ecosystems may shift to a different identity basin, from which return to the original state may be difficult or impossible.

TFI represents a fire interval range within which systems are expected to be resilient. Within this paradigm it is accepted that fire may induce change in vegetation at a site so long as this change does not represent a shift in community identity or permanent reduction in condition (i.e. loss of function). TFI is largely determined by the regeneration traits of plants but also by regeneration of keystone features such as soils and important habitat features.

Minimum TFI represents the minimum time between successive fires under which populations of species and processes (e.g. species interactions, nutrient cycling) characteristic of a vegetation community are likely to persist, thereby maintaining community identity and function. This value may differ between high and low severity fire. A key consideration for determining minimum TFI is the time required for plants to recover from fire such that they will persist when subject to a subsequent fire e.g. time required for seeders to mature and set seed and/or for resprouters to replenish carbohydrate stores.

Maximum TFI represents the maximum time between successive fires under which populations of species and processes characteristic of a vegetation community are likely to persist, thereby maintaining community identity and function. A key consideration for determining maximum TFI is the period for which species that require disturbance for regeneration can persist (as living individuals and/or as propagules) in the absence of fire, which in turn is often linked to inter-species competition and vegetation successional processes.

Key assumptions of using vegetation community TFIs to guide ecological fire management are that 1) vegetation communities can act as surrogates for other elements of the biota and 2) fire intervals that maintain vegetation communities are also likely to maintain constituent biota (across taxonomic groups) and ecosystem processes (Clarke 2008). There is empirical support for these assumptions (Pharo and Beattie 2001; MacMullan-Fisher et al. 2010; Egidi et al. 2016; Kelly et al. 2017) although floristic communities do not necessarily correspond closely to communities of all taxonomic groups (Mac Nally et al. 2002), and the 'optimal' fire interval range may differ amongst different elements of the system (Clarke et al. 2021; Rainsford et al. 2021). Despite these caveats, the broad congruence between the fire interval requirements of biota within vegetation communities, combined with the fact that vegetation communities are often well defined and readily mapped, make community level fire interval guidelines a useful tool for landscape scale fire management planning.

Tolerable fire intervals and fire management

TFIs are formulated with regard to the general or typical occurrence of a community and are intended to comprise one aspect of guidance for considering appropriate fire regimes within a given area. In particular, while community-level guidelines such as TFIs should cater for the needs of most species within communities, site-level fire planning should consider threatened or otherwise significant species/values that may have fire interval requirements distinct to those of the community as a whole. Assessment of the appropriateness of fire regimes should also consider other drivers such as herbivory and drought and weed invasion. Sites or communities of high conservation significance may require tailored fire regimes, which should be informed by consideration of local conditions and dynamics (e.g. via on ground inspection, monitoring and/or adaptive management and/or extrapolation from similar sites/systems elsewhere) as well as general ecological fire management principles. In addition, there is often much variation within vegetation, even at the TASVEG community level, which should be considered in fire management planning.

By definition, the TFIs presented here are those thought to maintain vegetation within a given state (i.e. TASVEG communities). There are instances where conservation outcomes will be enhanced by management to change vegetation state e.g. to increase the extent of threatened vegetation types. In such instances, the TFI of the desired vegetation type will inform fire management. Similarly, burning outside TFI may be required to achieve particular management objectives e.g. hazard reduction (see below), catering for requirements of threatened species, weed control or for Aboriginal cultural purposes.

Minimum TFI should not be interpreted as the point at which areas 'need burning'. Ideally the interval between a series of burns applied to a burn unit should vary within the minimum-maximum TFI range for the communities present. Repeated burning at a particular interval is likely to favour a subset of species at the expense of others, thereby potentially reducing diversity. However, such burning may be required in some instances to achieve particular conservation aims, such as promoting threatened species.

Tolerable fire intervals and fire management zoning

Tasmanian fire management agencies use a zoning system to assist in planning (Marsden-Smedley 2009). There are three main zone categories (in some instances further sub-zones are recognised), each with particular fire management objectives (Table 1). In the Asset Protection Zone (APZ), the priority is reducing bushfire risk, usually through intensive fuel management, while in the Land Management Zone (LMZ) the focus is on applying fire regimes to maintain ecological values (Figure 2). The Strategic Fire Management Zone (SMZ) combines both bushfire risk reduction and ecological objectives.

With regard to TFIs, it is expected that burning below minimum TFI will most often (though not necessarily) be required within APZs in order to maintain fuels at levels that reduce bushfire risk (Table 1). Guidelines for fire frequency required to reduce bushfire risk in broad vegetation types are outlined in Marsden-Smedley (2009). Within SFMZ, burning will usually be within TFI, though often at the lower end of the TFI range. Burning below minimum TFI will sometimes be required to meet bushfire risk reduction objectives and/or ecological objectives. In the Land Management Zone there is scope for burning to occur across the full TFI range, as required to produce desirable fire mosaics within the landscape. Burning limited areas outside TFI may occasionally be required to achieve particular ecological aims.

Table 1. Fire management zone objectives and indicative likelihood burning outside TFI required to achieve objectives.

Fire management zone	**Objective(s)**	**Likelihood burning outside TFI required to achieve objectives**
Asset Protection Zone	Provide a reduced fuel level in order to protect assets from potential bushfire.	Moderate-high
Strategic Fire Management Zone	Minimise the risk of large bushfires by providing areas of low fuel loads across the landscape that prevent the forward spread, or assist in the containment, of bushfires. Provide the necessary fire regimes for ongoing healthy ecological functioning.	Low-moderate. Burning may often be at lower end of TFI range.
Land Management Zone	Provide the necessary fire regimes for ongoing healthy ecological functioning.	Low. Burning outside TFI occasionally required to meet ecological objectives.

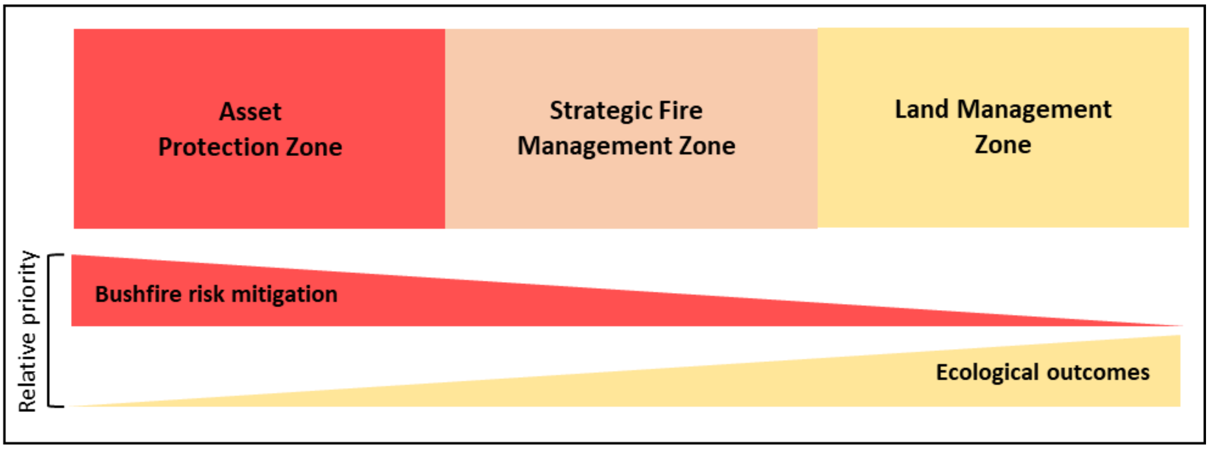

Figure 2. Fire management zones and relative priority of risk mitigation/ecological outcomes.

Tolerable fire intervals data management, review and update

The initial set of TFI estimates for TASVEG communities are given in Appendix 1. These values are derived from the expert elicitation process described above, with some values rounded off to the nearest whole year/five year/decade value for simplicity and to reflect the level of precision in the elicitation process.

As outlined in Leonard (2021) it is envisaged that TFI estimates will be subject to ongoing review and update to improve their accuracy, with a number of vegetation communities highlighted as priorities for such review. Review may also be prompted by observations suggesting that estimates are inaccurate, or when empirical data becomes available that supersedes expert opinion-based estimates.

Review of TFI estimates may be initiated by the Fire Science Coordinator, Natural Values Conservation Branch (NVCB), DPIPWE. Other parties may also propose review of TFI values to the NVCB Fires Science Coordinator, or present proposed changes to TFI values and supporting evidence to the Ecological Fire Data Technical Committee (EFDTC), which is made up of representatives of Tasmania Parks and Wildlife Service, Environment, Heritage and Land Division of Natural Resources and Environment Tasmania, Tasmania Fire Service and Sustainable Timber Tasmania, and manages the TASVEG Fire Attributes data set. In all cases, changes to TFI estimates will only occur with approval of the EFDTC.

TFI estimates may be revised on the basis of expert opinion. However, such opinion must be elicited using a robust protocol, such as the IDEA protocol (Hemming et al 2018) used in deriving the current set of TFI estimates.

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Appendix S1. Tolerable Fire Intervals for TASVEG Communities.

Tolerable Fire Interval (TFI) values for Ecological Fire Groups apply to constituent TASVEG communities, except for where TFI values have been stipulated for individual TASVEG communities.

Ecological Fire Group (bold, green highlight) Constituent TASVEG communities (italic)	TASVEG community code	Minimum TFI (low severity)	Minimum TFI (high severity)	Maximum TFI
Alpine heath (east)		40	60	165
Eastern alpine heathland	*HHE*			
Eastern alpine vegetation (undifferentiated)	*HUE*			
Alpine heath (west)		50	100	600
Western alpine heathland	*HHW*			
Alpine sedge east		30	40	135
Eastern alpine sedgeland	*HSE*			
Alpine sedge west		40	100	595
Western alpine sedgeland/herbland	*HSW*			
Alpine with conifers		1000	1000	1000
Alpine coniferous heathland	*HCH*			
Athrotaxis cupressoides open woodland	*RPW*			
Athrotaxis cupressoides rainforest	*RPP*			
Athrotaxis cupressoides/Nothofagus gunnii short rainforest	*RPF*			
Buttongrass moorland low productivity		10	15	70
Alkaline pans	*AAP*			
Buttongrass moorland with emergent shrubs	*MBS*			
Restionaceae rushland	*MRR*			
Western buttongrass moorland	*MBW*			
Western lowland sedgeland	*MSW*			
Buttongrass moorland (undifferentiated) (western Tasmania)	*MBU*			
Buttongrass moorland moderate productivity		10	15	30
Eastern buttongrass moorland	*MBE*			
Pure buttongrass moorland	*MBP*			
Buttongrass moorland (undifferentiated) (eastern Tasmania)	*MBU*			
Buttongrass moorland sparse		15	20	100
Sparse buttongrass moorland on slopes	*MBR*			
Callitris		30	40	500
Callitris rhomboidea forest	*NCR*			
Cushion moorland		55	130	1000
Cushion moorland	*HCM*			
Dry eucalypt grassy		10	20	40
Eucalyptus barberi forest and woodland	*DBA*			
Eucalyptus globulus dry forest and woodland	*DGL*			
Eucalyptus morrisbyi forest and woodland	*DMO*			
Eucalyptus pulchella forest and woodland	*DPU*			
Eucalyptus viminalis - Eucalyptus globulus coastal forest and woodland	*DVC*			
Eucalyptus viminalis grassy forest and woodland	*DVG*			

Midlands woodland complex	*DMW*			
Dry eucalypt heathy		12	20	35
Eucalyptus amygdalina coastal forest and woodland	*DAC*			
Eucalyptus amygdalina forest and woodland on sandstone	*DAS*			
Eucalyptus amygdalina inland forest and woodland on Cainozoic deposits	*DAZ*			
Eucalyptus dalrympleana - Eucalyptus pauciflora forest and woodland	*DDP*			
Eucalyptus nitida dry forest and woodland	*DNF*			
Eucalyptus nitida Furneaux forest	*DNI*			
Eucalyptus ovata heathy woodland	*DOW*			
Eucalyptus pauciflora forest and woodland not on dolerite	*DPO*			
Dry eucalypt shrubby		12	25	35
Eucalyptus amygdalina - Eucalyptus obliqua damp sclerophyll forest	*DSC*			
Eucalyptus amygdalina forest and woodland on dolerite	*DAD*			
Eucalyptus amygdalina forest and woodland on mudstone	*DAM*			
Eucalyptus cordata forest	*DCR*			
Eucalyptus delegatensis dry forest and woodland	*DDE*			
Eucalyptus obliqua dry forest and woodland	*DOB*			
Eucalyptus ovata forest and woodland	*DOV*			
Eucalyptus pauciflora forest and woodland on dolerite	*DPD*			
Eucalyptus perriniana forest and woodland	*DPE*			
Eucalyptus risdonii forest and woodland	*DRI*			
Eucalyptus rodwayi forest and woodland	*DRO*			
Eucalyptus sieberi forest and woodland not on granite	*DSO*			
Eucalyptus sieberi forest and woodland on granite	*DSG*			
Eucalyptus tenuiramis forest and woodland on dolerite	*DTD*			
Eucalyptus tenuiramis forest and woodland on granite	*DTG*			
Eucalyptus tenuiramis forest and woodland on sediments	*DTO*			
Eucalyptus viminalis Furneaux forest and woodland	*DVF*			
King Island Eucalypt woodland	*DKW*			
Dry eucalypt sub-alpine		30	55	120
Eucalyptus coccifera forest and woodland	*DCO*			
Eucalyptus gunnii woodland	*DGW*			
Dry scrub/heath		12	15	40
Acacia longifolia coastal scrub	*SAL*			
Coastal heathland	*SCH*			
Coastal Scrub	*SSC*			
Coastal scrub on alkaline sands	*SCA*			
Eastern scrub on dolerite	*SED*			
Heathland on calcareous substrates	*SCL*			
Kunzea ambigua regrowth scrub	*SKA*			
Leptospermum glaucescens heathland and scrub	*SLG*			
Melaleuca pustulata scrub	*SMP*			
Rookery halophytic herbland	*SRH*	NA	NA	NA
Spray zone coastal complex	*SSZ*	NA	NA	NA

Grassland highland		7	10	25
Highland grassy sedgeland	*GPH*			
Highland Poa grassland	*MDS*			
Subalpine Diplarrena latifolia rushland	*MGH*			
Grassland lowland		5	7	20
Coastal grass and herbfield	*GHC*			
Lowland grassland complex	*GCL*			
Lowland Poa labillardierei grassland	*GPL*			
Lowland sedgy grassland	*GSL*			
Lowland Themeda triandra grassland	*GTL*			
Rockplate grassland	*GRP*			
Mixed forest		80	100	360
Eucalyptus delegatensis over rainforest	*WDR*			
Eucalyptus nitida over rainforest	*WNR*			
Eucalyptus obliqua forest over rainforest	*WOR*			
Non-eucalypt grassy		15	20	80
Allocasuarina verticillata forest	*NAV*			
Bursaria - Acacia woodland and scrub	*NBA*			
Non-eucalypt heathy		15	20	45
Banksia serrata woodland	*NBS*			
Allocasuarina littoralis forest	*NAL*			
Non-eucalypt wet		40	60	190
Acacia dealbata forest	*NAD*	*20*	*40*	*80*
Acacia melanoxylon forest on rises	*NAR*	*20*	*40*	*80*
Acacia melanoxylon swamp forest	*NAF*	*20*	*40*	*80*
Leptospermum lanigerum - Melaleuca squarrosa swamp forest	*NLM*			
Melaleuca ericifolia swamp forest	*NME*			
Rainforest with Athrotaxis/Lagarostrobus		1000	1000	1000
Athrotaxis selaginoides - Nothofagus gunnii short rainforest	*RKF*			
Athrotaxis selaginoides rainforest	*RKP*			
Athrotaxis selaginoides subalpine scrub	*RKS*			
Lagarostrobos franklinii rainforest and scrub	*RHP*			
Nothofagus gunnii rainforest and scrub	*RFS*			
Rainforest without Athrotaxis/Lagarostrobus		200	750	1000
Coastal rainforest	*RCO*			
Highland low rainforest and scrub	*RSH*			
Highland rainforest scrub with dead Athrotaxis selaginoides	*RKX*			
Nothofagus - Leptospermum short rainforest	*RML*			
Nothofagus - Phyllocladus short rainforest	*RMS*			
Nothofagus rainforest undifferentiated	*RMU*			
Rainforest fernland	*RFE*			
Sphagnum		100	1000	1000
Sphagnum peatland	*ASP*			
Sub-alpine scrub/heath		35	60	120
Subalpine heathland	*SHS*			

Subalpine Leptospermum nitidum woodland	*NLN*			
Western subalpine scrub	*SSW*			
Wet sclerophyll		35	65	250
Broadleaf scrub	*SBR*			
Eucalyptus brookeriana wet forest	*WBR*			
Eucalyptus dalrympleana forest	*WDA*			
Eucalyptus delegatensis forest over Leptospermum	*WDL*			
Eucalyptus delegatensis forest with broad-leaf shrubs	*WDB*			
Eucalyptus delegatensis wet forest (undifferentiated)	*WDU*			
Eucalyptus globulus King Island forest	*WGK*			
Eucalyptus globulus wet forest	*WGL*			
Eucalyptus nitida forest over Leptospermum	*WNL*			
Eucalyptus nitida wet forest (undifferentiated)	*WNU*			
Eucalyptus obliqua forest over Leptospermum	*WOL*			
Eucalyptus obliqua forest with broad-leaf shrubs	*WOB*			
Eucalyptus obliqua wet forest (undifferentiated)	*WOU*			
Eucalyptus regnans forest	*WRE*			
Eucalyptus subcrenulata forest and woodland	*WSU*			
Eucalyptus viminalis wet forest	*WVI*			
Wet scrub		18	20	60
Banksia marginata wet scrub	*SBM*			
Eastern riparian Scrub	*SRE*			
Leptospermum forest	*NLE*			
Leptospermum lanigerum scrub	*SLL*			
Leptospermum scoparium - Acacia mucronata forest	*NLA*			
Leptospermum scoparium heathland and scrub	*SLS*			
Leptospermum scrub (deprecated)	*SLW*			
Leptospermum with rainforest scrub	*SRF*			
Melaleuca squamea heathland	*SMM*			
Melaleuca squarrosa scrub	*SMR*			
Scrub complex on King Island	*SSK*			
Western regrowth complex	*SWR*			
Western wet scrub	*SWW*			
Wet heathland	*SHW*			
Wetland		NA	NA	NA
Fresh water aquatic herbland	*AHF*			
Fresh water aquatic sedgeland and rushland	*ASF*			
Lacustrine herbland	*AHL*			
Saline aquatic herbland	*AHS*			
Saline sedgeland/rushland	*ARS*			
Saltmarsh (undifferentiated)	*AUS*			
Succulent saline herbland	*ASS*			
wetland (undifferentiated)	*AWU*			