Population dynamics of Tree Geebung (*Persoonia arborea*), a species of conservation interest in the Central Highlands of Victoria, Australia

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Abstract

The Central Highlands of Victoria are subject to disturbances from wildfire and harvesting. Within the footprint of these disturbances lies Tree Geebung (*Persoonia arborea*), a small understorey tree with a relatively unknown and complex ecology. Despite limited evidence, Tree Geebung is thought to be a very long-lived species, capable of regenerating *en masse* following mechanical disturbance from harvesting, and capable of surviving wildfire despite being regarded as a fire sensitive obligate seeder. Its recent listing as an endangered species has incited considerable interest from management to elucidate the ecology of Tree Geebung. Using a spatial analysis combined with field surveys, this study aims to uncover key life history traits relevant to management (e.g., age of reproductive maturity) and shed more light on how Tree Geebung responds to disturbances related to wildfire and forest harvesting using size-age relationships derived from radiocarbon dating,

I found that Tree Geebung can become at least 74 years old with individuals ranging from 28-40 years old having a 50% probability of producing fruit. Individuals protected by forest management prescriptions (≥10 cm DBH) have a probability of 0.4-0.7 to bear fruit. Tree Geebung can survive low intensity wildfire and recruits in response to disturbance from both harvesting and wildfire, with a stronger response to harvest (ρ = 46,480 ha^{-1}) than to wildfire (ρ = 33,420 ha^{-1}). Our findings imply that Tree Geebung might not become as old as thought, but its response to disturbance may still have implications for its conservation taking into account projected climate change scenarios.

1. Introduction

The wet forests of the Victorian Central Highlands are characterised by tall, open forests dominated by Mountain Ash (*Eucalyptus regnans*), with cool temperate rainforests commonly found near gullies and riparian zones (Simkin & Baker, 2008). These Mountain Ash forests are highly productive (Attiwill et al., 2001; R. B. Smith & Woodgate, 1985) and prized for timber production (Lindenmayer & Ough, 2006), water supply, and recreation (Burns et al., 2015). Mountain Ash forests are also highly susceptible to fire, due to the substantial production of leaf and bark litter combined with the dry seasonal conditions within the region (Ashton & Attiwill, 1994; McCarthy et al., 1999). The two major forms of disturbance in these forests are wildfire, and clearfell logging for timber production (Lindenmayer & Ough, 2006).

1.1 Fire history of the Central Highlands

The Central Highlands are subjected to frequent wildfires, with the earliest records dating back to 1851 (Forest Fire Management Victoria, 2023). Mountain Ash is an obligate seeder, meaning it is generally killed by wildfire and then regenerates from seed (A. L. Smith et al., 2014), creating even-aged stands of Mountain Ash (Ashton, 1981). In the Central Highlands, the majority of Mountain Ash were established immediately after the 1939 Black Friday wildfire (Simkin & Baker, 2008).

Historic fire maps indicate that the 1939 Black Friday fires burned an area of over one million ha (Vickers et al., 2021). Since this event, two other large wildfires occurred in this region: the 1983 Ash Wednesday fires (72,000 ha) and the 2009 Black Saturday fires (275,000 ha) (Vickers et al., 2021). These fires overlapped in some location, producing double burned areas (1939 and 1983, 45,000 ha; 1939 and 2009, 212,000 ha; 1983 and 2009, 24,000 ha) (Vickers et al., 2021).

1.2 Forest Management

The Central Highlands of Victoria have been subject to forest harvesting since Europeans first settled in the region in 1834 (Lutze et al., 1999). Since the 1960s, “clear-fell, burn and sow” (CBS) harvesting has been the dominant logging practice for timber production (Murphy & Ough, 1997; Ough, 2001) with a more recent move to variable retention harvesting (VicForests, 2022). In CBS, the overstorey is removed in one operation (clear-felling). The logging debris (‘slash’), which includes the understorey, is subsequently burnt (burn) to remove the slash and optimise the soil for regeneration. Finally, the burnt area is artificially sown (sow) with eucalypt seeds to promote the regeneration of the new cohort of overstorey trees (Ough, 2001). This process is aimed to imitate the natural disturbances in this ecosystem (Baker et al., 2004).

In terms of forest management, understorey species were typically only considered when they could potentially jeopardize regeneration of commercial species, rather than focussing on the impact of CBS on understorey species (Murphy & Ough, 1997). Studies on understorey flora in the Central Highlands have shown that CBS leads to floristic differences in the understorey compared to wildfire, characterised by a decrease in understorey species richness and abundance after disturbance (Blair et al., 2016; Murphy & Ough, 1997; Ough, 2001; White & Vesk, 2019). This has led to state and federal obligations on forest management, which include special protections for rare and threatened understorey species (Baker et al., 2017; State of Victoria, 2014b; State of Victoria & Commonwealth of Australia, 2020) with surveys for these species prior to logging operations (State of Victoria, 2018). One such threatened species is Tree Geebung (*Persoonia arborea*), a small tree in the family *Proteaceae.*

1.3 Tree Geebung

Tree Geebung produces small, yellow flowers which develop into a green, ovoid drupe (Figure 1) (VicFlora, 2022). It is endemic to the Central Highlands (Gullan, 2021), where it falls within the bioregions "Highlands Northern Fall", "Highlands Southern Fall", and "Victorian Alps" (VicFlora, 2022) (Figure 2). Within its geographical distribution, Tree Geebung is often found in wet forests and cool temperate mixed-forests (VicFlora, 2022), though its distribution according to NatureKit is mainly consistent with damp forest (42%) and wet forest (40%) (State of Victoria, 2023b). About 40% of its habitat lies in Yarra Ranges National Park, with the rest occurring in State Forests (Gullan, 2021) with 22% of this State Forest available for timber harvesting (State of Victoria, 2021).

Figure 1. A Tree Geebung with flowers and fruit. Matured flowers (slightly left and down from centre) are yellow white. Tepals are 16-20 mm and reflexed half-way. Fruits (bottom-right) are yellow-green, ovoid drupe to c. 14 mm long, c. 12 mm wide (VicFlora, 2022).

Tree Geebung was listed as vulnerable under the *Advisory List of Rare and Threatened plants in Victoria* in 2014, but more recently classified as endangered under the *Flora and Fauna Guarantee Act 1988* in 2022 (State of Victoria, 2014a, 2022b). Additionally, it is listed as critically endangered under the IUCN Red List of Threatened Species (Weston & Cameron, 2020).

The life history of Tree Geebung is not fully understood. This may be explained by the lack of studies that include this species, possibly due to its rarity. Studies on more common *Persoonia* species such as the Lance-leaf Geebung (*P. lanceolata*) and the Broad-leaf Geebung (*P. levis*) appear to be more numerous. Nevertheless, we may infer important information of Tree Geebung life history from field observations of Tree Geebung, and studies of other *Persoonia* species.

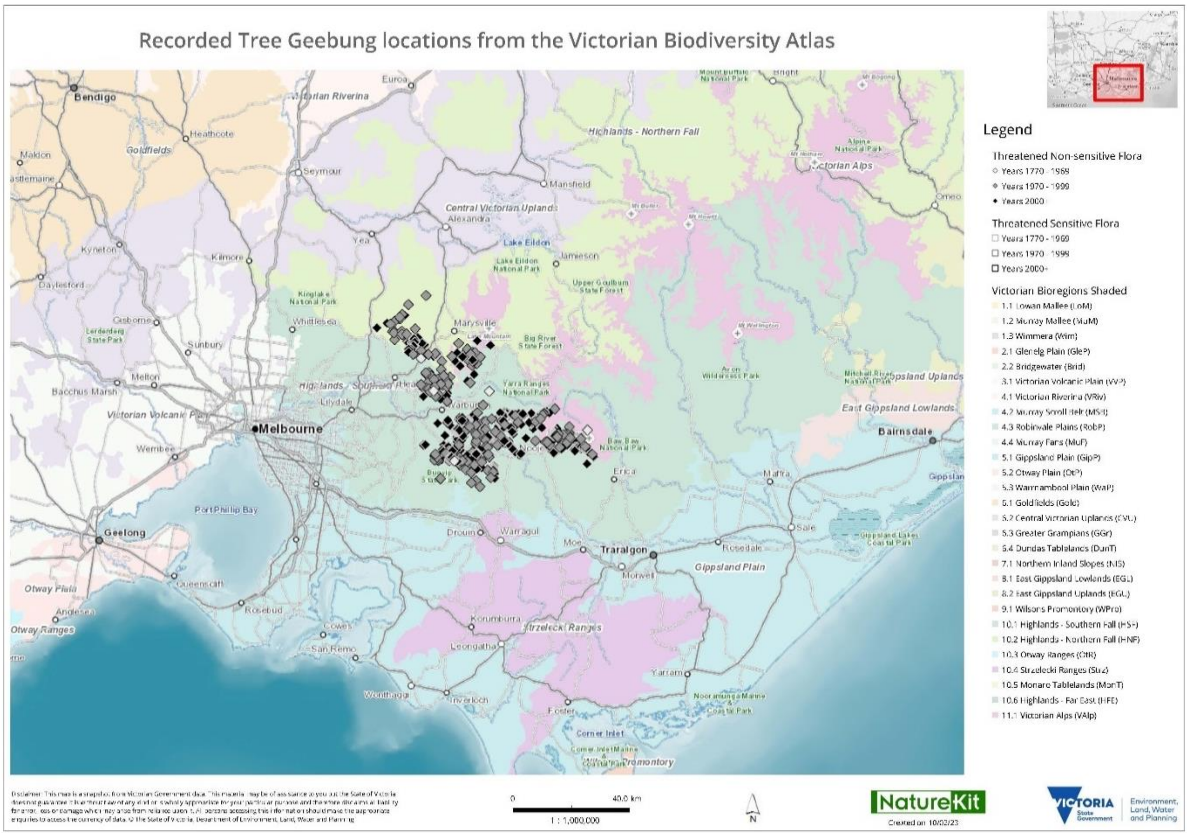

Figure 2. Tree Geebung distribution in the Central Highlands based on records from the Victorian Biodiversity Atlas, overlayed on Victorian bioregions (map drafted from NatureKit 2.0) (State of Victoria, 2023b).

1.2 Ecological Complexities of Tree Geebung

Complexities in life history traits of *Persoonia*

Longevity

Tree Geebung is thought to be a very long-lived species, capable of living at least three to four centuries (Mueck et al., 1996). The pre-bomb radiocarbon dating of two individuals that was used to inform longevity provided three age ranges for Tree Geebung (Figure 3). Mueck et al., 1996 subsequently selected the age range with the highest confidence interval, being the range between 320-510 years old. Despite limited evidence, this age magnitude is widely reported for Tree Geebung.

Specimen	Sample no.	Height (m)	Location (ZONE 55 AMG)	Radiocarbon age* ($\pm\sigma$)	Age (95% CI)†	Year of Origin (95% CI)	Mean height increment (cm/year)‡
Persoonia 1	(ANU 9242)	12	5837500, 395800	280 ± 50 BP	320–510 (0.91)	1486–1675	0.19–0.30
					190–220 (0.06)	1776–1798	0.43–0.50
					40–50 (0.03)	1943–1955	1.90–2.38
Persoonia 2	(ANU 9243)	8	5842200, 392800	240 ± 60 BP	170–500 (0.86)	1488–1820	0.21–0.62
					120–150 (0.03)	1839–1870	0.70–0.89
					40–80 (0.12)	1915–1955	1.31–2.63

Figure 3. Predicted age ranges for two Tree Geebung individuals in Mueck et al., 1996. Note the higher confidence interval for the upper age ranges in both individuals.

Germination

Persoonia species are notorious for being difficult to germinate (Emery & Offord, 2018). Like many other *Persoonia* species, Tree Geebung produce fleshy fruit characterized by a woody endocarp directly encapsulating the seed (Figure 4) (French, 1992). In Snottygobbles (*P.*

longifolia) and North Rothbury persoonias (*P. pauciflora*), germination followed only after the endocarp was considerably weakened, which was estimated to take up to two years (Chia et al., 2016; Emery & Offord, 2019b).

The seeds that are produced from these fruits are typically of small number and high viability, rather than an abundance of low viability seeds (Emery, 2016). This reproductive strategy is then very dependent on viability, as seed survival carries considerably more weight when numbers are low. In Spreading Snottygobbles (*P. elliptica*), seed viability was recorded as low, which may further impede recruitment if this applies to Tree Geebung (Nield et al., 2015).

The dormancy mechanisms of Tree Geebung seeds are not fully understood, but many findings have been made for other *Persoonia* species e.g., Hairy Geebung (*P. hirsuta*) (Emery & Offord, 2019a, 2021; The Royal Botanic Garden Sydney, 2023; Whitely, 2022). It is inferred from many studies on *Persoonia* that some form of disturbance is required to break its seed dormancy, but specific requirements are largely unknown (Atchison, 2009; Chia et al., 2015; McKenna, 2007; Mueck, 2020; Nield et al., 2015). A soil seedbank study has succeeded in germinating a single seedling of Tree Geebung following a heat, smoke, and gibberellic acid (GA3) treatment (Kasel, pers. comm.). Other *in situ* studies on *Persoonia* have also identified gibberellic acid (GA3) as a catalyst for germination (Mullins et al., 2002; Norman & Koch, 2008).

Figure 4. Tree Geebung seed with dissected woody endocarp (Photo by Robert Hare, CC BY-NC-SA 4.0)

These dormancy requirements may be the result of bet-hedging strategies, to reduce the risk of negative impacts of climate change, such as frequent fires and increased temperatures (Ayre et al., 2009; Catelotti et al., 2020; Emery & Offord, 2018). Although these complex dormancy mechanisms have contributed to failures in restoration efforts of *Persoonia* species (Abbott & Van Heurck, 1988; Emery et al., 2018; Nield et al., 2015), some recent successes were made for

Hairy Geebung for which hundreds of plants were successfully propagated in their native habitats in Sydney (Whitely, 2022).

Maturation

Complexities in the life history traits of *Persoonia* are also not limited to the recruitment stage. Some species of *Persoonia* are known to have long primary juvenile periods. Lance-leaf Geebung, for example, has a primary juvenile period of 6-8 years (Auld et al., 2007; Emery & Offord, 2018), while the Soft Geebung (*P. mollis* subsp. *maxima*) can have a juvenile period of up to ten years (Benson & McDougall, 2000). According to Catelotti et al. 2020, other *Persoonia* species reach sexual maturation in 7-12 years. Altered fire regimes where fires occur within the primary juvenile period of a plant species can have a decimating effect on the persistence of local populations, as plants cannot reach an age of maturity that allows them to contribute seed to the seed bank (Enright et al., 2015).

Tree Geebung flowers in late summer and autumn, and develops fruit from winter into summer (Figure 5) (French, 1992). The duration and timing of fruit development is consistent with other species of *Persoonia*, which typically take several months to mature over autumn, winter, and spring (Emery, 2016; French, 1992). This creates an additional timeframe in which disturbance could lead to local extinction (Bauer et al., 2001). During this maturation period, fruits are also vulnerable to theft by predators. This is the case for Tree Geebung, where 80% of fruits were observed to be parasitised by a wasp which destroys the seed (Mueck, 2020).

Figure 5. Season of flowering and fruiting for Tree Geebung (French, 1992).

Complex responses to disturbance of *Persoonia*

Response to fire

Tree Geebung is an obligate seeder, meaning it is generally killed by fire, and only regenerates from seed (Auld et al., 2007). Its persistence is therefore dependent on adequate presence of seeds stored in a soil seed bank (Cunningham & Cremer, 1965; Mueck, 2020). Despite being regarded as fire sensitive, Tree Geebung is thought to be capable of surviving low intensity fire. This is inferred from field observations where live individuals were found with substantial fire scars up to 1 m stem height, in areas that were burnt by fire (J. Voet, pers. obs., Figure 6).

Germination of Tree Geebung is thought to be cued to wildfires (Mueck, 2020), consistent with findings of The Royal Botanic Garden Sydney which identified temperature as a germination requirement (The Royal Botanic Garden Sydney, 2023). This trait is shared among other species in the genus such as the Lance-leaf Geebung, Soft Geebung (McKenna, 2007), Snottygobble (Chia et al., 2015), Spreading Snottygobble (Nield et al., 2015), and Wild Pear (*P. falcata*) (Atchison, 2009).

Figure 6. Tree Geebung bearing damage from deer rubbing with charcoal evident from the 2009 wildfire, found during a reconnaissance survey of the Mozambique coupe in September 2022 (Photo by Sabine Kasel).

Response to mechanical disturbance

Tree Geebung often germinate *en masse* along logging roads that were subjected to mechanical disturbance from harvesting activities (Gullan, 2021). This was prevalent in many field observations, where numerous mature individuals were associated with historical logging roads (Figure 7 and 8) (Kasel, 2020). Further vigorous regeneration of seedlings have also been observed on recently built snig tracks (Figure 9, J. Voet, pers. obs.). This is in line with results of other *Persoonia* species, with the largest populations of the rare Hairy Geebung occurring along the edges of tracks and road easements (Emery & Offord, 2018).

Figure 7. Mature Tree Geebung with pink tape growing along the edge of a historical logging track in Christian Road, North (462-507-0012) coupe in Loch Valley (Photo by J. Voet, 5 Dec 2022)

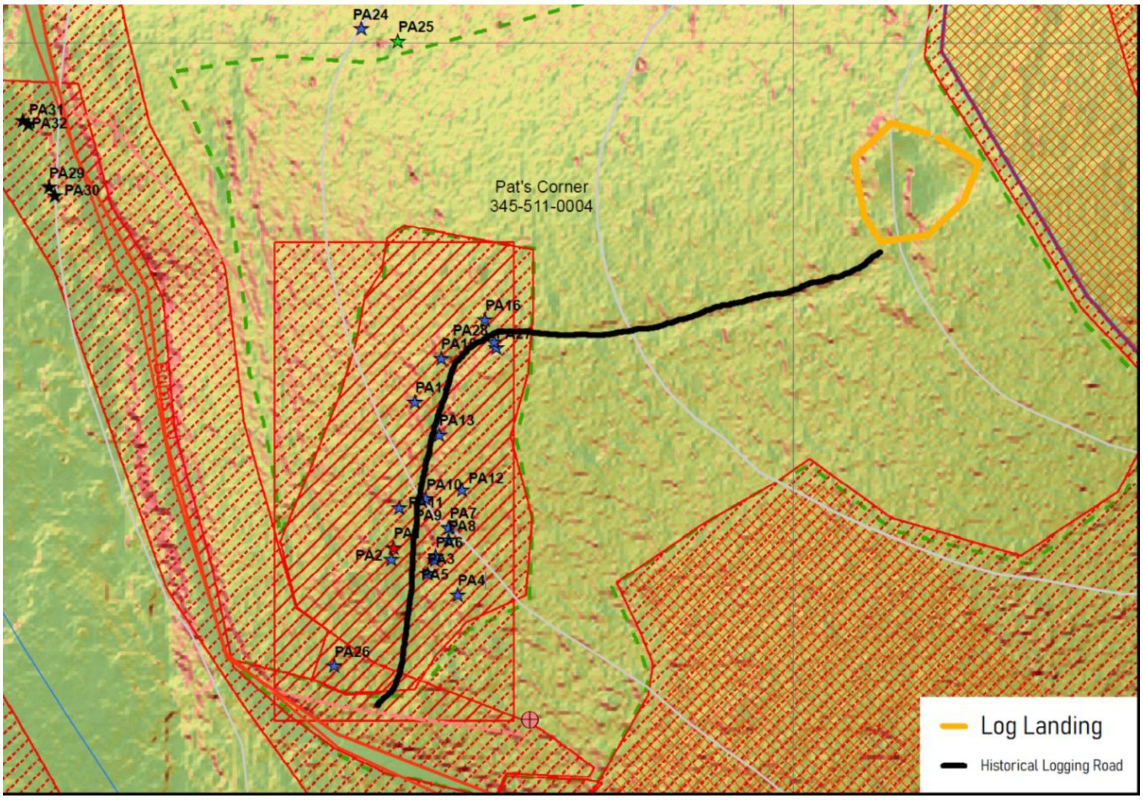

Figure 8. Map of Tree Geebung locations from a site inspection of Pat's Corner (345-511-0004). Note how the Tree Geebung recruitment coincides with a historical logging road (outlined in black) (Kasel, 2020).

Figure 9. Thicket of Tree Geebung seedlings growing along a snig track that was laid out in 2018 in the Dragon Ball Z (345-513-0001) coupe (Photo by J. Voet, 1 Dec 2022).

1.3 VicForests: management of Tree Geebung

The Mountain Ash forests in the Central Highlands are both a key timber resource for Victoria and the predominant habitat for Tree Geebung. For this reason, Tree Geebung is subject to disturbances by parties that carry out silvicultural practices in their habitat. The main actor in this is VicForests, a state-owned enterprise which oversees and executes the harvest, sale, and regrowth of timber from state forests in Victoria (VicForests, 2022).

According to the 2019 Order under the *Sustainable Forests (Timber) Act 2014*, VicForests is permitted to allocate areas of State Forest for timber harvesting, individually known as "coupes" (Appendix 1). However, in doing so, VicForests must comply with all relevant laws, including the *Code of Practice for Timber Production 2014 (as amended 2022)* ('The Code') and the *Management Standards and Procedures for Timber Harvesting Operations in Victoria's State Forests* ('Standards') (State of Victoria, 2014b, 2022a).

The Code

The Code is the primary instrument for regulating timber harvesting operations in Victoria's State forests, private native forests and plantations (State of Victoria, 2022a). It was implemented in 2014 by the then Department of Environment, Land, Water and Planning (DELWP). Its aim is to steer harvesting practices and management of forests in a responsible way, and ultimately to maintain the benefits to society provided by forest ecosystems. These are also referred to as 'forest values'. The Code was amended in 2021 and 2022.

One forest value that applies to Tree Geebung is the conservation of threatened species. When such species are encountered, specific management procedures must be applied. These are included in Schedule 1 of The Code, referred to as the Management Standards and Procedures ('Standards').

Standards
The Standards is a secondary instrument for regulating timber production. Its aim is to provide detailed mandatory operational instructions, including regional instructions for timber harvesting operations in Victoria's State Forests (State of Victoria, 2022a). The Standards are in addition to the mandatory actions set out in the main body of The Code (State of Victoria, 2014b).

The Standards include specific instructions for threatened species that co-occur in areas allocated to timber harvesting. These areas are subject to forest management, and are referred to as Forest Management Areas ('FMAs').

Tree Geebung occurs in the Central Highlands FMA and are subjected to specific management actions. The Code was recently amended and the management actions specific to Tree Geebung have changed with each review (Table 1).

Table 1. Management Actions that apply to Tree Geebung according to the three available versions of the Standards until 2022. Note that "value" is missing in the 2014 version. This is because the format changed in 2021, where the "value" property was added. The table is formatted according to the 2022 version.

Standards Version	Value	Applicable FMAs	Management Actions
2014	-	Central Highlands FMAs	Protect mature individuals from disturbance where possible.
November 2021	Mature Individuals	Central Highlands FMAs	Protect mature individuals from disturbance where possible
June 2022	Individual Tree	Central Highlands FMAs	Protect individual trees with a DBHOB of at least 10 cm from disturbance where reasonably practicable

The proposal for the 2022 Standards Version comprised the change in management actions from "where possible" in previous versions of The Code, to "where reasonably practicable". Following consultation, the change from "mature individuals" to "individual trees with a DBHOB of at least 10 cm" was included, due to ambiguity as to what a "mature individual" pertains to.

Special Management Plan
In 2020, a Special Management Plan for Tree Geebung ('SMP') was developed by VicForests with the intent to provide more detailed management practices for Tree Geebung, in accordance with the Code and Standards. Below, the practical applications of the prescription to "protect individual trees with a DBHOB of at least 10 cm from disturbance where reasonably practicable" are summarised.

Pre-Harvest Surveys by DELWP (now DEECA)
The harvesting process starts with the initial coupe planning by VicForests, in which forest areas are designated as coupes. These coupes are subsequently surveyed by DELWP as part of the Forest Protection Survey Program (FPSP). Its aim is to survey areas of state forest scheduled to be harvested in order to detect conservation values, such as threatened animals and plants (State of Victoria, n.d.). 73 faunal and 312 floral species are included in the FPSP – including Tree Geebung (State of Victoria, 2018).

The type of survey conducted and the trigger for detection is dependent on the species. For Tree Geebung, the relevant surveys are Coupe Habitat and Sign Surveys (CHASS) and Opportunistic Observations (OppObs). In CHASS, the relevant target which applies to Tree Geebung is "Trees

>2.5 cm DBH". The trigger for detection of Tree Geebung is simply its presence. Thus, FPSP records all Tree Geebung individuals with a DBH > 2.5 cm (State of Victoria, 2018).

In total, there are 121 entries for Tree Geebung from FPSP (to 02 Sep 2022), of which 30 resulted from CHASS and 91 from opportunistic observations (State of Victoria, 2023c).

Pre-Harvest Surveys by VicForests
When mature Tree Geebungs (DBH > 10 cm) are detected in FPSP surveys, this prompts VicForests to perform Targeted Species Surveys (TSS) for Tree Geebung. These surveys are specifically targeted to Tree Geebung. However, a TSS may also occur when a coupe overlaps with high quality habitat as mapped in the Habitat Distribution Model for Tree Geebung (VicForests, 2020).

Sightings of mature individuals must be recorded during any field visit. This includes TSS, but also Opportunistic Observations (OppObs) from VicForests surveys not related to Tree Geebung (i.e., Coupe Reconnaissance Transects, Habitat and Hollow-Bearing Tree Surveys, and Coupe Marking). The minimum information that must be recorded when a mature individual is detected is the GPS location, maturity information such as size (height and DBH) and presence of flowers/fruit, and number of individuals at the GPS point (VicForests, 2020).

In TSS, surveyors must initially target and confirm existing FPSP detections in the field. Then, surveys are undertaken on transects at varied length no more than 100 m apart according to the SMP, but in practice they are usually 30 m apart (Ben Drouyn, pers. comm.). Along and between these transects, all Tree Geebung individuals are to be recorded. When a mature individual is recorded, an additional measure is required where surveyors must search for other mature individuals in a ±15 m radius around the initial individual. This is for the purpose of identifying clusters of Tree Geebung (VicForests, 2020).

To 02 Sep 2022, a total of 3626 records were collected from pre-harvest surveys, of which 3505 are from TSS and 121 from opportunistic observations. A record may contain one or several Tree Geebung individuals.

Protection planning and execution during harvest (VicForests)
Using the collected Tree Geebung records from pre-harvest surveys, the protection of Tree Geebung is planned for a relevant coupe. This is done with a desktop assessment. In GIS, a 10 m radius circle is drawn around all field-verified records. Where three or more circles overlap or touch, this denotes a cluster (signifying a cluster to be a minimum of three mature trees). If a single record comprises at least three mature individuals in close proximity of each other, this must also be considered a cluster.

VicForests will consider clusters as the minimum unit for creating harvesting exclusion areas – individual trees without two or more overlaps in a 10 m radius are disregarded. After exclusion areas are designated, the area is assessed for its harvesting potential. Where exclusion areas account for more than 10% of harvestable area, advice from the Environmental Performance team must be sought before proceeding. Where exclusion areas account for less than 10% of harvestable area, the coupe is assigned for harvest (VicForests, 2020).

Harvest is to be performed under the conditions that trees should not be felled into or within exclusion areas, that machines are not to enter the exclusion area, and that slash and harvesting debris must not be allowed to accumulate within 3 m of an exclusion area. Modifications to exclusion areas are allowed when there are no other practical options to avoid clearing Tree Geebung individuals, e.g. for the purpose of constructing a new road (VicForests, 2020).

Post-harvest surveys (VicForests)

All harvested coupes where Tree Geebung has been protected are to be surveyed according to the VicForests' standard regeneration survey program. This entails that recruitment of Tree Geebung and isolated mature Tree Geebung that have persisted post-harvest must be recorded to the same level of detail as pre-harvest surveys. Observations of Tree Geebung recruitment and survival outside the regeneration survey plots should also be recorded when encountered (VicForests, 2020).

A total of 1373 records of Tree Geebung were collected from post-harvest regeneration surveys.

VF database
All recorded Tree Geebung from previous surveys (Pre-harvest surveys by DELWP and VicForests, and Post-harvest surveys by VicForests) are added to the VicForests Species Observation database ("VF"). A full list of parameters for VF is shown in Appendix 2. In addition, VF also contains Tree Geebung records from other surveys of DELWP and third-party detections. The final build-up of VF is shown in Table 2. Prior to commencing harvest, all verified records of Tree Geebung in the relevant coupe(s) are to be provided to DELWP (VicForests, 2020).

Table 2. Components of VF with associated number of records, where a single record may include more than one individual of Tree Geebung, and individuals can pertain to trees and seedlings.

Survey Type	Responsible Organ	Survey Name	Time period covered	n records
Pre-Harvest	DELWP	CHASS (FPSP)	10-07-2018 to 02-05-2022	30
Pre-Harvest	DELWP	OppObs (FPSP)	12-10-2018 to 23-05-2022	91
Pre-Harvest	VicForests	TSS	23-04-2019 to 19-08-2022	3505
Pre-Harvest	VicForests	OppObs (from Coupe Reconnaissance Transects, Hollow-Bearing Tree Surveys, Coupe Marking)	21-04-2020 to 27-06-2022	121
Post-Harvest	VicForests	Standard Regeneration Survey Program	14-07-2021 to 19-05-2022	1373
Others (other surveys from DELWP and third-party detections)			18-08-2017 to 02-05-2022	2196
Total (VF)				**7316**

1.4 Purpose statement

The genus *Persoonia* is synonymous with a complex life history and limited distribution. As a result, *Persoonia* species are facing serious conservation issues in an ever-changing climate. According to Andres et al., 2021, climate change is expected to cause habitat loss of several *Persoonia* species, whether listed as threatened or not. Increased fire frequency, severity and drought impacts were found to be significant risk factors for obligate seeding-species and tall growing plants as these typically take longer to reach reproductive maturity (Andres et al., 2021). Tree Geebung, being an obligate seeding-species of limited distribution, may be particularly susceptible to increases in severity and frequency of wildfire associated with climate change.

Translocation might be a valid conservation strategy to mitigate its susceptibility to local extinction due to its high endemism, but difficulties might arise from its complex dormancy mechanisms. Despite this, the dormancy mechanisms of other *Persoonia* species have been explained in great detail (Emery & Offord, 2019a; The Royal Botanic Garden Sydney, 2023). While germination of Tree Geebung in response mechanical disturbance appears strong (Gullan, 2021; Kasel, 2020), this may result in seedbank exhaustion leaving the species highly susceptible to localised reduction or population loss where subsequent disturbances occur prior to the cohort becoming reproductively mature and replenishing the seed bank, as demonstrated for a suite of obligate seeders, including Mountain Ash (Fairman et al., 2016).

Addressing the knowledge gaps in the ecology of Tree Geebung will be essential to maximise conservation efforts. This study will aim to resolve the knowledge gaps in relation to its life history – in particular its longevity and maturity - and response to disturbance. The results of this study may be used to highlight risk factors relevant to its conservation, as well as inform future management of this species.

1.5 Research Questions

The following research questions will be addressed in this thesis:

- How old is Tree Geebung?
- What is the age of Tree Geebung at 10 cm DBH?
- What is the age of flowering/fruiting in Tree Geebung?
- Does Tree Geebung respond to disturbance from wildfire, harvest, and planned burning?
  - Is there an effect of disturbance type on recruitment intensity?
  - Does recruitment align with disturbance events related to wildfire, harvest and planned burning?
  - Can Tree Geebung survive wildfire?

2. Methods

2.1 Datasets of Tree Geebung records

To perform targeted fieldwork surveys based on targeted disturbance histories, the database of Tree Geebung from VicForests (VF) and from previous research by the University of Melbourne (UM) were consulted.

The 'UM' database consists of Tree Geebung records from previous research by the University of Melbourne, which was focused on coring Tree Geebungs across a wide elevation range for the purpose of radiocarbon dating and development of a size-age model (CORE). This work produced records for 151 individuals from which 229 cores were collected. Some additional work focused on DBH and height records across limited intact and recently harvested coupes that produced 1065 records for seedlings and 17 mature trees (PLOT).

A list of Tree Geebung records in UM by coupe ID and nature of research (whether CORE or PLOT) is shown in Appendix 3, with the available parameters in Appendix 4 and 5 (depending on the nature of research).

2.2 Study Area and Coupe Selection

Study Area

The study area for the fieldwork surveys encompasses the entire distribution of Tree Geebung in the Central Highlands of Victoria in south-east Australia (Figure 10).

Coupe selection

Selection of coupes for data collection is based on wildfire and logging history. The objective is to target replicate coupes overlying the range of underlying wildfire histories, with each replicate containing and classified by a decadal harvest event. This is achieved by overlaying Tree Geebung records from VF with two datasets from the data portal of the Victorian Government (State of Victoria, 2023a): "Fire History Records of Fires across Victoria" ('FIRE_HISTORY') and "Logging history overlay of most recent harvesting activities" ('LASTLOG25').

Disturbance category is primarily categorised by the three major wildfires of the Central Highlands: 1939 (Black Friday), 1983 (Ash Wednesday), and 2009 (Black Saturday). This data is extracted from FIRE_HISTORY. Each selected coupe contains a footprint of one of these wildfires (Figure 10).

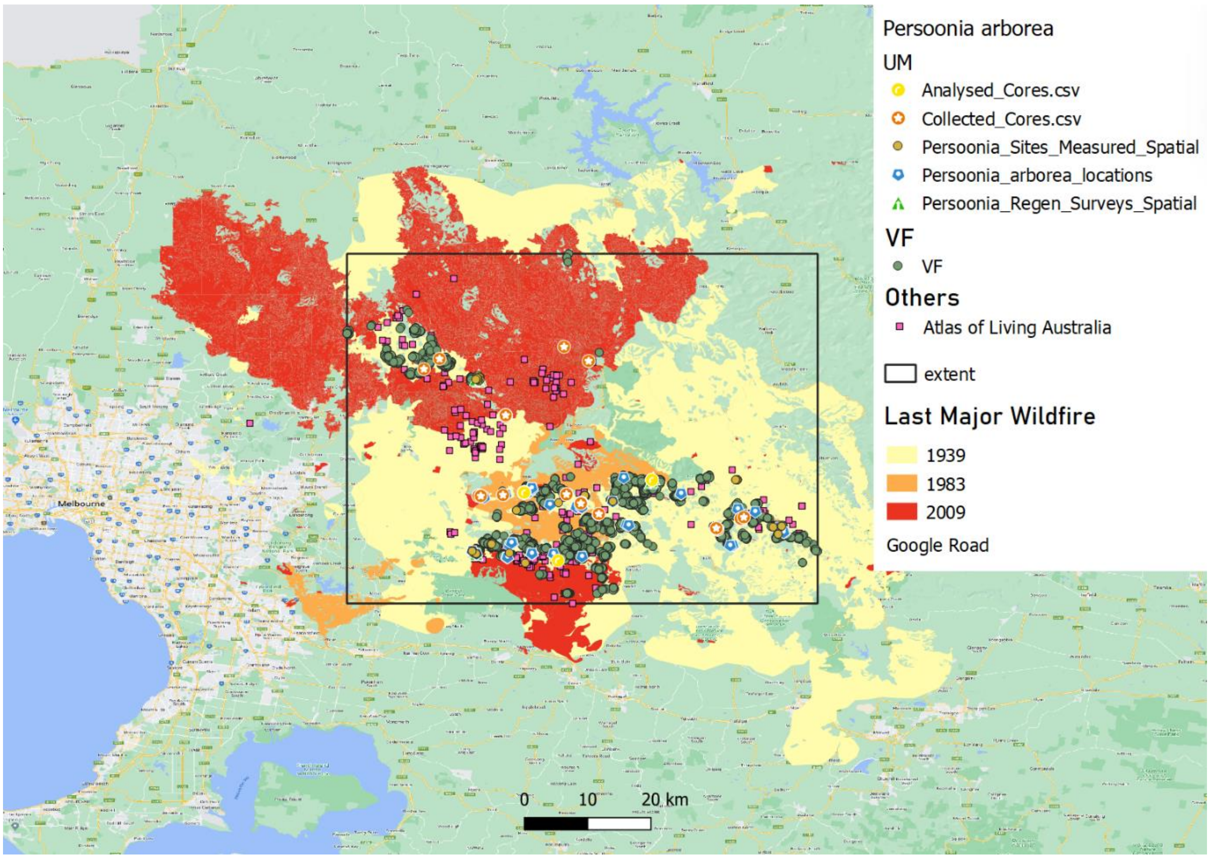

Figure 10. Overview of Tree Geebung locations from all available data sources (VF, UM, and the Atlas of Living Australia/Victorian Biodiversity Atlas) overlayed on the last major wildfire in the study site. Outer boundaries of Tree Geebung distribution is visualized by a grid ('extent'). Longitudinal boundaries are Xmin: 145.4424° and Xmax: 146.2951°, and latitudinal boundaries are Ymin: -37.9752° and Ymax: -37.3596°. The grid does not exemplify the actual distribution range of Tree Geebung.

The second level of disturbance is the most recent forest harvesting, which includes regeneration burns. Harvesting may be classified as harvest and regen (Table 3). Harvest data is extracted from LASTLOG25 and Regen data from FIRE_HISTORY.

Table 3. Classification of disturbance classes selected for field surveys.

Most recent disturbance	Description
Wildfire	The last major wildfire (either 1939, 1983, or 2009)
Harvest	Harvesting activity since 1962
Regen	Regeneration burn that may follow after forest harvesting since 1962

Joining last logging and fire data with Tree Geebung records

In QGIS 3.16.3, all Tree Geebung spatial data records from VF were overlayed on the last logging and last fire layers. Subsequently, the 'Join attributes by location'-tool was used to join the selected logging and fire data with the Tree Geebung records. The selected parameters are shown in **Table 4**.

Table 4. Parameters of the fire and logging datasets joined which were joined with VF and UM

	Parameter	Description	Unit/Classes
Fire	FIRETYPE	Indicates whether the fire was a wildfire, a planned burn, or other	BUSHFIRE, BURN, OTHER
	TREATTYPE	Indicates what the treatment type for a planned burn (bushfire will always be 'FIRE', other will always be 'OTHER')	FIRE (wildfire only), OTHER (other only), ECOLOGICAL, FUEL REDUCTION, SLASH – ASH, SLASH - MIXED, WINDROW - MIXED
	START_DATE	Starting date of the fire	As date (YYYYMMDD)
Logging	SEASON	Logging season in decadal increments, from 1961 to 2022	1960-69, 1970-79, 1980-89, 1990-99, 2000-10, 2010-19, 2020-29
	STARTDATE	Starting date of logging activity	As date (DD/MM/YYYY)
	ENDDATE	End date of logging activity	As date (DD/MM/YYYY)
	YEAR	Year that the logging activity ended	YYYY

In doing so, all records in VF and UM are provided with data of the last wildfire, planned burn, and harvesting activity. From this data, the last expected disturbance is manually assessed by comparing the data and selecting the most recent disturbance. This will be recorded into three data columns: the date of the last expected disturbance, the year of the last expected disturbance, and the type of the last expected disturbance (see **Table 5**).

The assessment is done manually because the analysis is very precise, whereas the Tree Geebung records and last fire and logging layers are not fully accurate – the fire and logging polygons do not precisely reflect the affected area. This results in irregular disturbance histories per coupe, which need to be adjusted manually.

Additionally, survey dates may precede the last expected disturbance, and this particularly relates to pre-harvest surveys. For example, if a coupe was last harvested in 2020 without a regeneration burn and it contains Tree Geebung records, they will automatically receive the 2020 harvest as last disturbance. However, if these records resulted from a pre-harvest survey in 2019, the 2020 harvest was not the last disturbance that resulted in their recruitment. For this example, the last recorded wildfire would be the last disturbance.

Table 5. Examples of the notation for last recorded disturbance, for the three disturbance classes.

CoupeName	LAST_DIST_EXP_DATE	LAST_DIST_EXP_YEAR	LAST_DIST_EXP_TYPE
Sylvia Creek Rd	30/06/1991	1991	Harvest
Mozambique	07/02/2009	2009	Wildfire
Ginger Cat	25/03/2017	2017	Regen

For the 1939 and 1983 wildfires and the planned burning activities before 2009, no exact dates were available from the dataset. The highest degree of specificity was the year. In these instances, the following date rules were assigned:

- The 1939 wildfire occurred on 13 January 1939, which is the date used for "LAST_DIST_EXP _DATE" if the last expected disturbance is the 1939 wildfire (Forest Fire Management Victoria, 2021b). For the 1983 wildfire, the date 16 February 1983 was used (Forest Fire Management Victoria, 2021a). The 2009 wildfire contained the date as 7 February 2009 in the dataset.

- Planned burning activities from 2009 onwards were dated, and ranged from 7 March to 18 May in their relevant years. For planned burning activities before 2009, the median of this date range was used which is 12 April, which was combined with the relevant year of the regeneration burn (e.g., regeneration burn in 2003 was dated 12-04-2003).

Coupe selection based on last recorded disturbance
The selection of coupes is based on the year and the type of the last disturbance. Any selected coupe will contain a footprint of one of the three major wildfires: 1939, 1983, 2009. This is the primary level of categorisation. On top of that, coupes were selected based on logging season and activity in decadal increments. This includes unharvested coupes for which the last expected disturbance is the last major wildfire, harvested coupes from 1960-2020 which has no record of a regeneration burn, and coupes that were harvested and burnt post-2010.

The coupes selected based on the above criteria are shown in **Tables 6 and 7**.

Table 6. Coupes selected for fieldwork surveys with assessment of last disturbance by category (wildfire, regeneration burn, harvest), and subsequent last recorded disturbance.

CoupeNumber	CoupeName	Survey Types occurring in records	Last wildfire	Last planned burn	Last harvest	Targeted, last recorded disturbance
462-510-0026	Christian Rd, South	Pre-Harvest (VicForests)	**1939**	-	-	*1939 bushfire*
349-515-0001	Even Steven	Post-Harvest	1939	-	**2019/20**	2020 logging
347-520-0008	Jumping Jack Flash	Post-Harvest	1939	**2020 (regen), 2021 (fuel red.)**	2018/19, 2019/20	2020 regen
297-542-0001	Sylvia Crk Rd	Pre-Harvest (VicForests)	1939	1986 (fuel red.)	**1965/66** or 1990/91	60s logging
297-542-0002	Sylvia Crk Rd	Pre-Harvest (VicForests)	1939	-	**1965/66** or 1993/94	60s logging
462-507-0012	Christian Rd, North	Pre-Harvest (VicForests)	1939	-	**1974/75** or **1977/78**	70s logging
300-503-0008	Yellowdindi Rd	Pre-Harvest (VicForests)	1939	-	**1976**	70s logging
462-505-0039	Pyke	Pre-Harvest (FPSP)	1939	-	**1987/88** or **1989/90**	80s logging
462-505-0040	Harlaw	Pre-Harvest (FPSP)	1939	-	**1989/90** or 1991/92	80s logging
462-505-0042	Eastwatch	Pre-Harvest (FPSP)	1939	-	**1986/87**	80s logging
462-505-0038	Lone Ranger Thinning	Pre-Harvest (FPSP)	1939	-	**1990/91** or **1993/94**	90s logging
349-510-0005	Columbus RDC	Pre-Harvest (VicForests)	1939	-	**2003/04**	00s logging
345-511-0005	Bluey Creek Track	Pre-Harvest (VicForests)	**1983**	-	-	*1983 bushfire*
345-506-0004	Opposite Fitzys	Post-Harvest	1983	-	**2015/16**	2016 logging
345-513-0001	Dragon Ball Z	Post-Harvest	1983	**2020 (regen)**	2018/19, 2019/20	2019 or 2020 regen
345-522-0002	Smyth Creek RDI	Pre-Harvest (FPSP)	1983	-	Unknown, possibly **1982/83** or **1987/88**	Unknown, possibly 80s logging
345-507-0008	Qantas	Pre-Harvest (FPSP)	1983	-	**1977/78**	70s logging
345-507-0005	Liittle Block	Pre-Harvest (FPSP)	1983	-	**1977/78**	70s logging
465-503-0002	Bullock Crk	Post-Harvest	2009	**2020 (regen)**	2018/19	2020 regen
350-513-002	East Beenak Rd	Post-Harvest	2009	**2019 (regen)**	2012/13	2019 regen
309-502-0008	Dom Dom Rd	Pre-Harvest	2009	-	**-**	Unknown
462-506-0003	Tropical	Post-Harvest	1939	**2020 (regen)**	2018/19	2020 regen
462-507-0008	Estate	Post-Harvest	1939	-	**2016/17**	2017 logging

Table 7. Overview of the selected coupes (from Table 6) for fieldwork surveys, displayed by last wildfire footprint and last harvesting activity (if any). Coupes from which data of UM was used are indicated by an asterisk.

Harvest Period	**Wildfire**		
	1939	1983	2009
No harvest	Christian Road south	Bluey Creek Track, Smythe Creek RDI, Pat's Corner*	Dom Dom Road, Mozambique*, Fishernak*,
1960-69 Harvest	Sylvia Creek Road	-	-
1970-79 Harvest	Christian Road north, Yellowdindi Road	Qantas/Liittle Block	-
1980-89 Harvest	Pyke/Harlaw/Eastwatch	(Smythe Creek RDI)	-
1990-99 Harvest	Lone Ranger Thinning	-	-
2000-10 Harvest	Columbus RDC	-	-
2010-20 Harvest	Even Steven, Estate	Opposite Fitzy's	Bullock Creek
2010-20 Regen	Jumping Jack Flash, Tropical, Ginger Cat*, Skerry's Reach	Dragon Ball Z	East Beenak Road

2.3 Field data collection

The fieldwork consists of visiting each of the identified coupes and selecting at least 25 live trees for measurements. One tree or a cluster of trees (maximum separation of 2 metres) represents the centre of a plot – in this case, a tree plot. The standard radius from the centre is 3 metres (Figure 11).

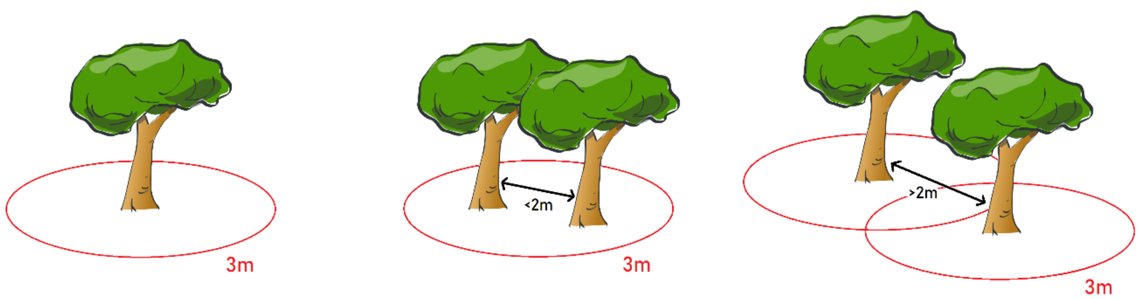

Figure 11. Approach to determining tree plots (3 m radius) under three different scenarios: (left) single tree, (centre) cluster of trees within 2 m of each other, (right) cluster of trees separated by more than 2 m.

Individual measurements are made of the tree(s) in the centre, including DBH in cm of all stems (multiple leaders only when bifurcation occurs below 1.3 m) using a diameter tape measure, tree height from base to top of the canopy in m using a Vertex 5 clinometer, and a flowering, fruiting, and damage assessment. Plot measurements include soil disturbance type according to the classification of VicForests shown in Appendix 6, elevation in m, slope in degrees, aspect in degrees, leaf area index (LAI) calculated from a hemispheric photo in the centre, and the number of other Tree Geebung individuals within the plot. These individuals are classified as either trees or seedlings. Seedlings are defined as Tree Geebung individuals with a height of 4 m from base to top of the canopy; all taller individuals are defined as trees.

Because the probability of finding 25 trees in post-harvest and post-regen coupes is low, a minimum of five seedling plots is done in addition to the number of mature individuals that can be found. Seedling plots (also 3 m radius) are conducted in the same fashion as plots around a tree, with a few differences. First, because there is no tree to represent the centre, a representative point is chosen instead. Second, in addition to counting the total number of seedlings, the seedlings are classified into three size classes: small (<0.25 m), medium (0.25 m<1 m), and large (1 m≤ 4 m) so that representative individuals across all size ranges are counted and measured. For each class, a maximum of five individuals are selected for measurement of height in m and DBH in cm (where possible). In seedling plots at Dom Dom Road, Estate, and Tropical, the basal diameters were also measured.

A summary of the measured parameters is shown in Appendix 7. The data collected from the fieldwork surveys yields the database 'FW'.

2.4 Transforming VF and UM databases to merge with FW database

Transformation of VF

The separate parameters in the VF database are shown in Appendix 2. Of these, only three parameters correspond with the fieldwork data parameters: "dateObserv" (VF) corresponds with "Date survey" (FW), "CoupeNumbe" (VF) with "Coupe Number" (FW), and "CountNumbe" (VF) with "Plot_Count" (FW). In most cases, "locationDe" (VF) corresponds with "Coupe Name" (FW), but not always. This is because a coupe with a unique coupe number can have multiple names in VF. In the FW database, only the most frequently occurring coupe name for a given coupe number was used.

For some of the remaining parameters in FW, the information is embedded as string data in the column "Observat_3" in VF. Subsequently, new columns were added in VF to extract the string data into separate parameters. Below, the most relevant ones are elaborated.

Diameter

Most trees are provided with a measure of the DBH in cm, for which the column "dbh_cm" was created. In most cases where trees had multiple leaders, only the largest leader was measured. If a second leader was measured, it is assigned to the column "dbh_2_cm".

Diameter measures in VF are sometimes subject to estimation, indicated by wording such as "DBH approx. 11 cm", "~20dbh", or "15 cm dbh (estimated)". To indicate the DBH was directly measured or estimated, two columns were created ("measured_DBH" and "approx_DBH") which function as Boolean operators. "1" will signify the parameter to be true, and "0" to be false. For example, a measured DBH will be scored 1 for measured_DBH and 0 for approx_DBH. Note that these scores are always mutually exclusive (i.e., both columns can not have the same score).

If a minimum DBH is given (ex. "DBH>2cm"), the value is assigned to "DBH_min_cm". If a maximum DBH is given (ex. "DBH<10cm"), the value is assigned to "DBH_max_cm". If a DBH range is given (ex. "DBH 15-18 cm"), the minimum value is assigned to "DBH_min_cm" and the maximum value is assigned to "DBH_max_cm". All records where DBH is recorded in DBH_min_cm or DBH_max_cm are considered estimations and are scored 0 for measured_DBH and 1 for approx_DBH accordingly. When the DBH is recorded in both DBH_min_cm and DBH_max_cm, the average of this range is used and scored 0 for measured_DBH and 1 for approx_DBH.

In some cases, the circumference is given rather than DBH. Values for circumference were assigned to a column for circumference ("circ"), from which the associated DBH was calculated.

For the analyses, all DBH measurements of VF were used – including estimations. To signify that some measurements were directly measured and some were estimated, the data in the age histogram is classified by directly measured DBH (measured_DBH = 1) and not directly measured (approx_DBH = 1).

Height
Tree height inferences from "Observat_3" are handled similar to DBH. Tree heights in metres are assigned to "hgt_m". When exact height is given in cm, it is converted to metres before assigning the value to "hgt_m".

Height measures in VF may be subject to estimation, with the three most common indications of this being "approximate height", "average height" and "approximate average height". As a result, four extra columns are made to denote the accuracy of the height measurement: "measured_hgt" for exact measurements, "approx_hgt" for approximate measurements, "avg_height" for when the height of multiple individuals is averaged, and "approx._avg_hgt" for when the average height of multiple individuals is approximated. The indicator that is relevant to the measurement is scored with "1", while the others are scored "0".

If a minimum tree height is given (ex. ">5m tall"), the value is assigned to "hgt_min_m". If a maximum DBH is given (ex. "seedling <0.25m"), the value is assigned to "hgt_max_m". If a height range is given (ex. "3-5m tall"), the minimum value is assigned to "hgt_min_m" and the maximum value is assigned to "hgt_max_m". All records where height is recorded in hgt_min_cm or hgt_max_cm are considered estimations and are scored 0 for measured_hgt and 1 for approx_hgt accordingly. When height is recorded in both hgt_min_cm and hgt_max_cm, the average of this range is used and scored 0 for measured_hgt and 1 for approx_hgt.

For the analyses, all height measurements of VF were used – including estimations. To signify that some measurements were directly measured and some were estimated, the data in the age histogram is classified by directly measured heights (measured_hgt = 1) and not directly measured heights (approx_hgt = 1, avg_height = 1 or approx_avg_hgt = 1).

Plot count
The parameter "CountNumbe" indicates how many individuals are included in a record. This ranges from 1 (single individual) to 400 individuals for one record. First, this parameter is renamed to "Plot count" to match the fieldwork data.

Importantly, this number does not distinguish between trees and seedlings (**Table 8a**). Because trees and seedlings are separated in the fieldwork data, a record in VF is split into two records, one for trees and one for seedlings if both trees and seedlings are embedded in the same record. The "Plot count" is then divided into the number of trees for the tree record, and the number of seedlings for the seedling record. The distinction between trees and seedlings is subsequently made with the new column "Plot count class" (**Table 8b**).

Table 8a. Example of what a record with both trees and seedlings looks like in the VF database.

Plot	Observat_3	Plot count
71042	9m tall. One seedling at 10cm	2

Table 8b. Example of how the record in **Table 8a** is split to match the format of the fieldwork data.

Plot	Observat_3	hgt_m	hgt1s_m	Plot_count	Plot_count_class
71042	9m tall. One seedling at 10cm	9	NA	1	Tree
71042	9m tall. One seedling at 10cm	NA	0.01	1	Seedling

When multiple trees with different characteristics are embedded in the same record (**Table 9a**), the record is split so as to not lose individual data on the trees. In the example of Table 9a, the record is split into three separate records, and "Plot_count" is changed from 3 to 1 across the separate records (see **Table 9b**).

Table 9a. Example of what a record with multiple characterised individual trees looks like in VF.

Plot	Observat_3	Plot_count
138793	Tree Geebung 1, dbh: 19cm, height: 12m, flowers/fruit. Tree Geebung 2, dbh: 19.5cm, height: 11m, no flowers/fruit. Tree Geebung 3, dbh: 24.5cm, heigh	3

Table 9b. Example of how the record in **Table 9a** is split to match the format of the fieldwork data.

Plot	Observat_3	Dbh (cm)	Hgt (m)	Flowering	Fruiting	Plot count
138793	"Tree Geebung 1, dbh: 19cm, height: 12m, flower/fruit…"	19	12	1	1	1
138793	"Tree Geebung 1, dbh: 19cm, height: 12m, flower/fruit…"	19.5	11	0	1	1
138793	"Tree Geebung 1, dbh: 19cm, height: 12m, flower/fruit…"	24.5	NA	NA	NA	1

Flowers and fruit

Presence or absence of flowers and fruit is indicated for some trees. In such cases, the flowering and fruiting status is stated in the new columns "flower" and "fruit" respectively. These are Boolean expressions which are scored as either "1" (present) or "0" (absent) (Table 9b). No comment is made on the degree of flowering and/or fruiting. In certain cases, a tree is denoted as "Sexually mature" without any inference of flowering and/or fruiting. Flower and fruit are not scored in these cases, although it is suggested the tree is/was capable of producing reproductive stages.

Damage

Presence or absence of damage from various origins is given for some trees with a "1" for present and "0" for absent. These are classified for the most common types of damage which are fire (new column: "fire_damage"), deer rubbing (new column: "deer_damage"), and herbivory browsing (new column: "herbivory"). Presence or absence of a broken top is assigned to the new column "broken_top", while presence or absence of a snap in the main stem is assigned to the new column "snap". Presence or absence of any other damage not specified by one of the above is assigned to the new column "dmg_other".

Disturbance

Inferences of disturbance are occasionally made (e.g., "on disturbed logging track" or "potential growth factor: mechanical disturbance"). However, these are not according to the classification by VicForests in Appendix 6. Only UD, ST, and LL were complemented, as only inferences of undisturbed soil, snig tracks and log landings were distinctly described.

Topography

Quantitative data of elevation, slope, and aspect were absent. Elevational data was extracted from "VicMap Elevation DEM 10m" data layer from the data portal of the Victorian Government (State of Victoria, 2023a).

Lon/Lat

In VF, the spatial data of each record is recorded in the parameters "speciesEas" and "speciesNor", which respectively represents the X and Y-coordinate in the MGA55 Coordinate Reference System (CRS). To merge this spatial information with FW, the data was converted to

WGS84 CRS in QGIS 3.26.3 and extracted the X and Y-coordinates in this CRS using the tool "Add geometry attributes". The subsequent X and Y-coordinates represent longitude (Lon) and latitude (Lat).

Transformation of UM

Tree Geebung individuals coded by researchers at the University of Melbourne were either used for coring samples or plot studies (see Appendix 3). The nature of this research is relevant to the type of information that was extracted from the data. Individuals that were used for coring samples (UM CORE) were used as single tree plots. All available parameters from this research were directly transferable to FW (see Appendix 4).

Individuals that were used for plot studies (UM PLOT) were either used as standalone tree plots, or a tree plot in conjunction with a seedling plot. The methodology involved counting and measuring of seedlings at an incremental distance around a retained tree, with a maximum radius of 12 m. If there were no seedlings observed in the 12 m plot, the record is merged with FW as a standalone tree plot. If seedlings were recorded in the 12 m plot, the record is merged with FW as both a tree plot for the mature tree in the centre, and a seedling plot for the seedlings found within the plot.

The parameters for the UM PLOT tree plots were directly transferable to FW in a similar fashion as the coring research (see Appendix 5). To merge the seedling data with FW, the seedlings were divided into size classes according to the classes in FW (S, M, L). A maximum of five representative seedlings were chosen within each size class to merge with FW. Count numbers reflected the actual count of the seedlings per size class.

2.5 Disturbance assessment and merging all databases into the combined TG database

Disturbance history

The disturbance history, as opposed to the most recent disturbance, was extracted for each Tree Geebung using spatial records. The complete disturbance history refers to all underlying wildfires and planned burns, and the last harvest that occurred. Wildfire and planned burn data is extracted from FIRE_HISTORY and harvest from LASTLOG25.

The maximum number of underlying wildfires and planned burns for all records is 3. Therefore, six additional columns were created: "Wildfire_1", "Wildfire_2", "Wildfire_3", "Planned_burn_1", "Planned_burn_2", "Planned_burn_3". In these columns, the dates of all underlying wildfires and planned burns are included. An example of this is shown in **Table 10.**

Table 10. Examples of fire history for imaginary records A, B, C, and D. Note that every record will have a wildfire footprint, regardless of planned burning.

Record	Wildfire_1	Wildfire_2	Wildfire_3	Planned_burn_1	Planned_burn_2	Planned_burn_3
A	13/01/1939	*NA*	*NA*	*NA*	*NA*	*NA*
B	13/01/1939	16/02/1983	*NA*	*NA*	*NA*	*NA*
C	13/01/1939	04/02/2009	*NA*	04/04/2017	*NA*	*NA*
D	13/01/1939	*NA*	*NA*	12/04/2005	13/03/2022	*NA*

In FIRE_HISTORY, the dates of the fires are not always available. However, the year of the fire and the type (wildfire or planned burn) is always available. In these cases, they were manually added according to the following rules.

The date of the 2009 wildfire was listed as 04/02/2009 in FIRE_HISTORY. Missing wildfire information was inferred from various sources listed in **Table 11**. Regeneration burns were informed from observation notes by VicForests where available. If these were not available, the date 12 April of the relevant year is used similar to the disturbance assessment in the field methodology.

Table 11. Dates used for wildfires with missing information in FIRE_HISTORY

Wildfire year	Date used	Source
1939	13/01/1939	(Forest Fire Management Victoria, 2021b)
1948	12/02/1948	(Canberra Times, 1948)
1983	16/02/1983	(Forest Fire Management Victoria, 2021a)
2007	16/01/2007	(ABC News, 2007; Switzer, 2007)

For the harvest data, the start and end date of the last harvest were directly extracted from LASTLOG25.

Merging FW, VF and UM into the combined database TG

The three databases FW, VF, and UM were merged into the combined database TG by the parameters shown in Appendix 7. The total number of records and individual TG is shown in Table 12.

Table 12. Final three databases of Tree Geebung records. Note that the number of records does not reflect the number of Tree Geebung individuals, as a single record may represent multiple individuals. Additionally, there may be overlap between records from FW and records from VF. This is because VF was consulted to inquire initial Tree Geebung presence for targeted surveys.

Database	n records	n individuals
FW	618	2,091
VF	7,315	20,789
UM	263	1,230
TG	**8,196**	**24,110**

2.6 Data Analyses

Relating age of Tree Geebung to disturbance history

Survey date ("Date_survey) and disturbance date ("Wildfire_1", "Wildfire_2", "Wildfire_3", "Planned_Burn_1", "Planned_Burn_2", "Planned_Burn_3", "start_harvest" and "end_harvest") were converted into Julian years using the "lubridate" package in R.

The age of Tree Geebung individuals was calculated using the age-size models developed by Kasel et al., 2023. The equations are shown below, and relate Tree Geebung age to one of two size parameters (either DBH in cm or height in m) and elevation in m.

Equation 1. Relationship between Tree Geebung age in Julian years and DBH in cm (sd = ±10 years):

$$Age\ (yrs) = 3.7 + \exp(4.22308 + \frac{0.0511(elev_m - 600)}{100}) * (1 - \exp\left(-\frac{log(2)}{12.3467} * DBH\ (cm)\right)$$

Equation 2. Relationship between Tree Geebung age in Julian years and height in m (sd = ±7 years):

$$Age\ (yrs) = \exp(4.57213 + \frac{0.02603(elev_m - 600)}{100}) * (1 - \exp\left(-\frac{log(2)}{10.64032} * hgt\ (m)\right)$$

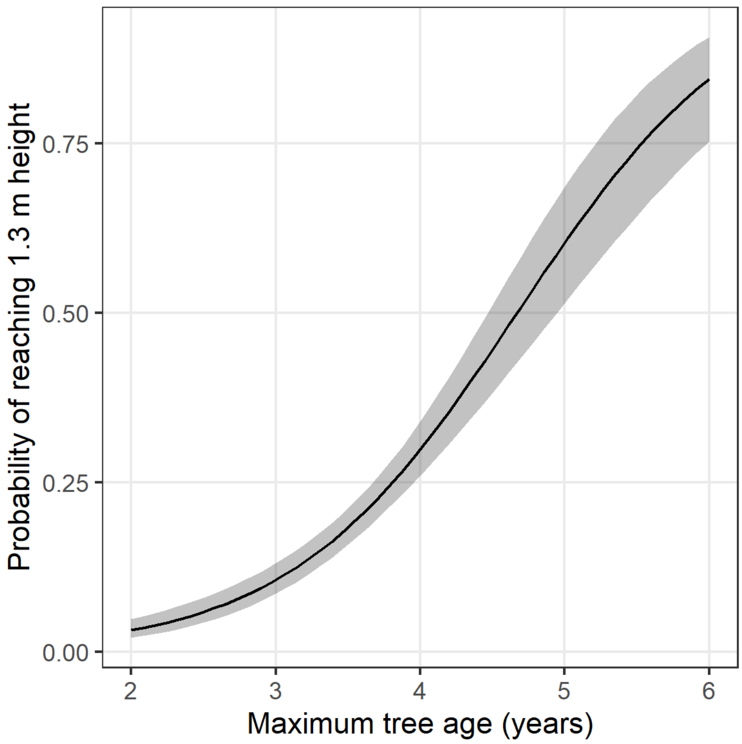

Figure 12. Probability of reaching breast height per age of Tree Geebung. At 0.5 probability, Tree Geebung seedlings take 4.7 years to reach breast height. Note that 3.7 years was used instead of 4.7 years to develop the radiocarbon model (Equation 1) to correct for the regeneration time of around one year.

Equation 1 was developed with the approximation that the time to reach breast height (1.3 m height) is 4.7 years – based on 50% probability (Figure 12). Primarily, **Equation 1** is used to infer the age of Tree Geebung because DBH is generally easier to measure than height for large trees, and some trees may be subject to broken tops. For individuals smaller than 1.3 m, **Equation 2** is used since these individuals have not reached breast height. **Equation 2** is also used when individuals have no DBH measurement, but do have a height measurement. Because ages from height (**Equation 2**) come out higher than ages from DBH (**Equation 1**), histograms will have a slight in-built bias where mainly seedlings will be overestimated (n=4912) and tree records with height measurements but no DBH (n=960).

Age of Tree Geebung

A histogram and a table of deciles of Tree Geebung ages was made from all records in TG using the package ggplot2 in RStudio version 2022.12.0+353 ('RStudio') (Posit, 2022). The data is classified by records which were directly measured (measured_DBH = 1 or measured_hgt = 1) and records which were not directly measured (measured_DBH = 0 or measured_hgt = 0).

Age at 10 cm DBH

The relationship of DBH in cm and the age derived from **Equation 1** and **Equation 2** was plotted for all records in TG using ggplot2 in RStudio. The data is classified by records which were directly measured (measured_DBH = 1 or measured_hgt = 1) and records which were not directly measured (measured_DBH = 0 or measured_hgt = 0). The age range at 10 cm DBH was derived from the minimum and maximum ages at 10 cm DBH obtained from **Equation 1**.

Age-maturity relationships

The relationships between flowering/fruiting and age were analysed for all records in TG by plotting the probability to flower/fruit with the age in a generalized linear model in Rstudio. From the resulting model, a table is drafted with Tree Geebung age from 0.1 to 0.9 (at 0.1

increments) probability of fruiting. A histogram of the frequency of survey timing per month is made using ggplot2 in RStudio.

Recruitment response to disturbance: alignment of past events

Histograms were made for all field surveyed coupes and five from UM using the ggplot2 package, with year of recruitment plotted on the horizontal axis. Year of recruitment was calculated by subtracting Age in Julian years from Date_survey in Julian years. Recruitment years are divided into 5-year bins. Years of disturbance events are plotted as vertical lines in the histogram with orange indicating a wildfire, grey a harvest, and red a planned burn.

Recruitment response to disturbance: Seedling density

Seedling density is obtained by dividing Plot_count (>0) where Plot_count_class is "seedling" with Plot_radius. This was done for all records in FW and UM. Subsequently, the data is grouped by LAST_DIST_EXP_TYPE and summarised with the mean seedling density. To obtain the seedling density in number of stems per hectare, seedling density is divided by $7.9 \cdot 10^{-5}$, given that a 1 m radius circle equals $7.9 \cdot 10^{-5}$ ha. The data is visualised in a box and whiskers plot using ggplot2.

Persistence response to wildfire disturbance

Year of last wildfire was determined for each record in TG from the most recent date out of "Wildfire_1", "Wildfire_2", and "Wildfire_3". A histogram was made with year of recruitment in 5-year bins on the horizontal axis, with bars coloured by year of last wildfire. Years of wildfires are plotted as vertical lines.

3. Results

3.1 How old is Tree Geebung?

The frequency of ages in TG is shown in **Figure 13** and **14**. The oldest Tree Geebung recorded in TG was 74.1 years old (SD = 10) based on DBH and 78.8 years old (SD = 7). This individual had a DBH 43.3 cm and a height of 24.1 m.

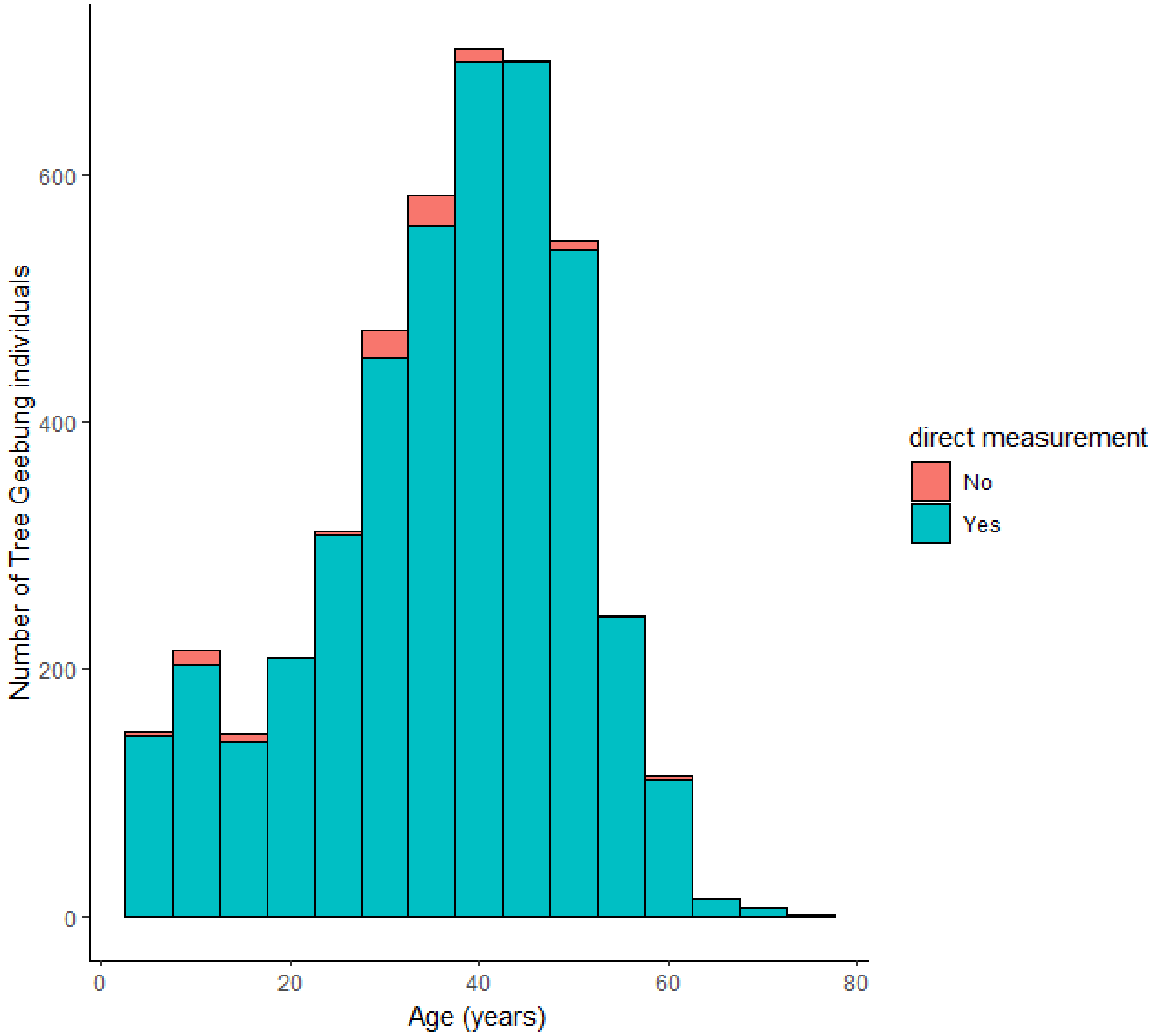

Figure 13. Histogram of Tree Geebung age (years) for all Tree Geebung records in TG with DBH data (n = 4,348)

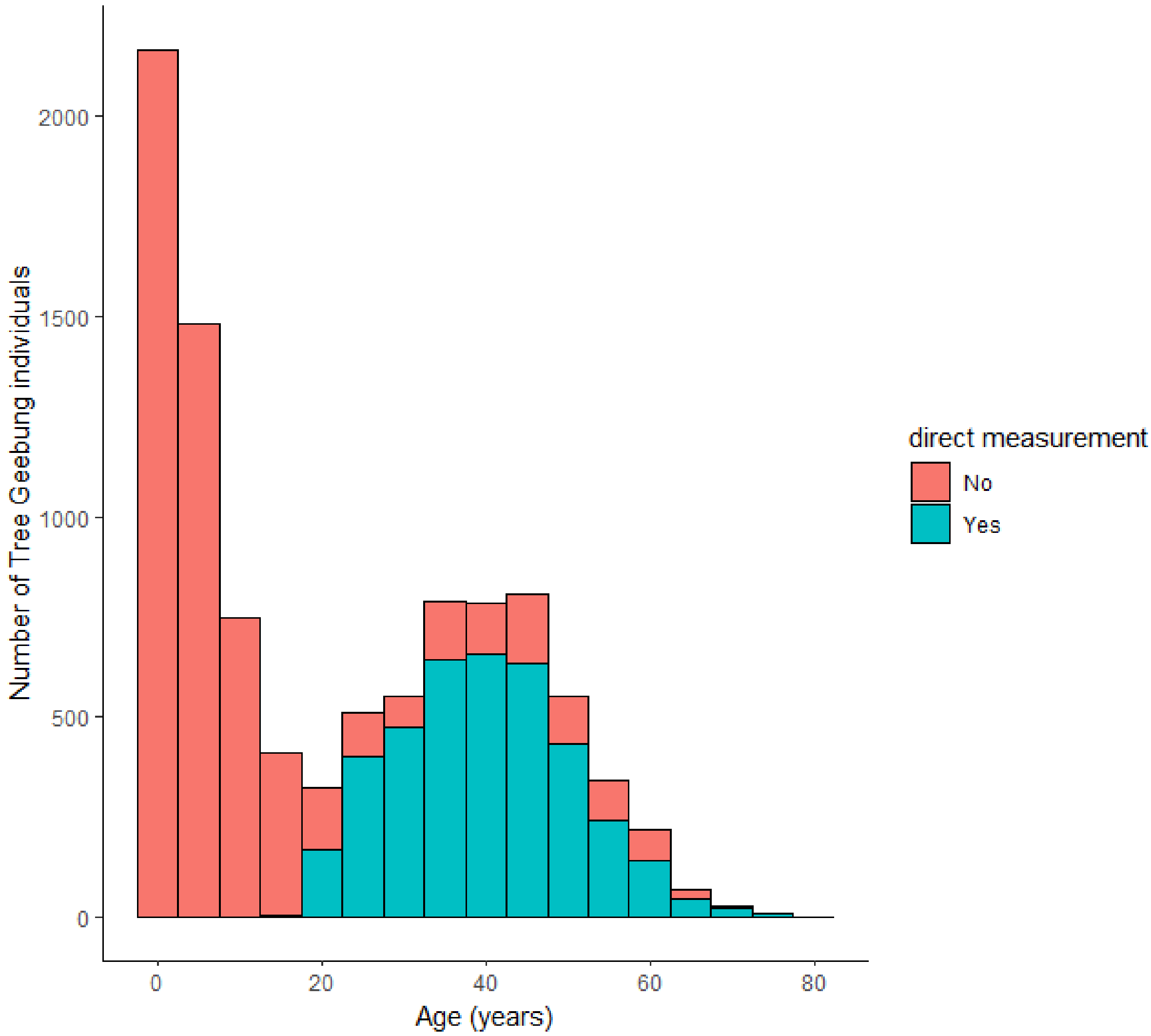

Figure 14. Histogram of Tree Geebung age (years) for all Tree Geebung records in TG with height data (n = 9,825)

The frequency of ages is binned into deciles from 0% to 100% (Table 14). The oldest and rarest individuals in the highest 10% decile are aged between 52.0 and 74.1 years old (SD = 10).

Table 13. Frequency of Tree Geebung ages in TG binned into deciles (n=4,537)

Decile	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Age (years)	4.1	20.9	27.5	32.2	36.0	39.1	42.0	44.9	48.1	52.0	74.1

3.2 What is the age of Tree Geebung at 10 cm DBH?

In **Figure 15,** the relationship between DBH and the age derived from the radiocarbon model (**Equation 1**) is shown based on the data in TG. In **Figure 16**, this relationship is shown for height and derived age (**Equation 2**). According to this relationship, the age of reaching 10 cm DBH in Tree Geebung ranges from 28.5 to 39.7 years.

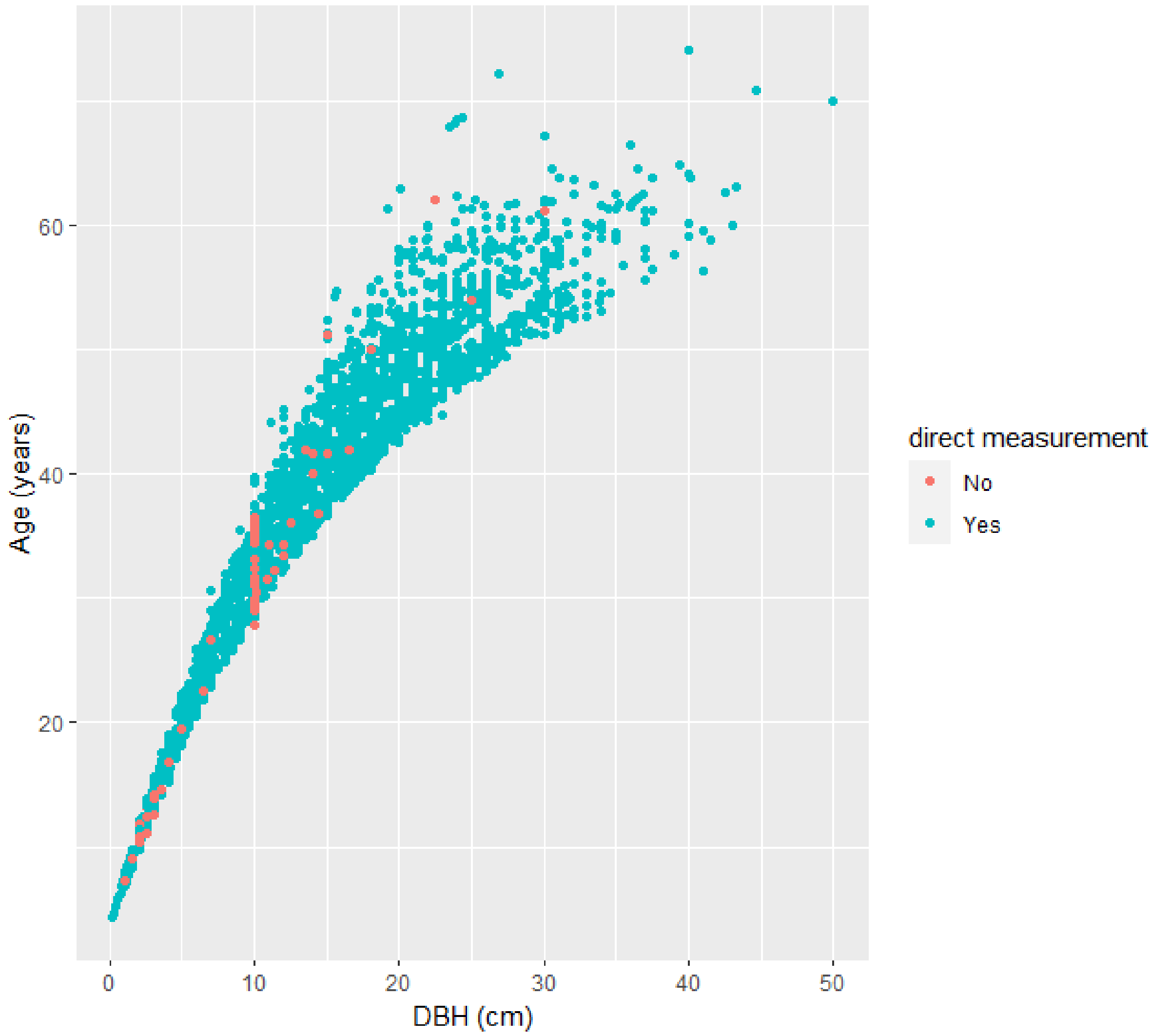

Figure 15. Relationship between DBH (cm) and the derived age from the radiocarbon model for all Tree Geebung records in TG with DBH data (n = 4,537)

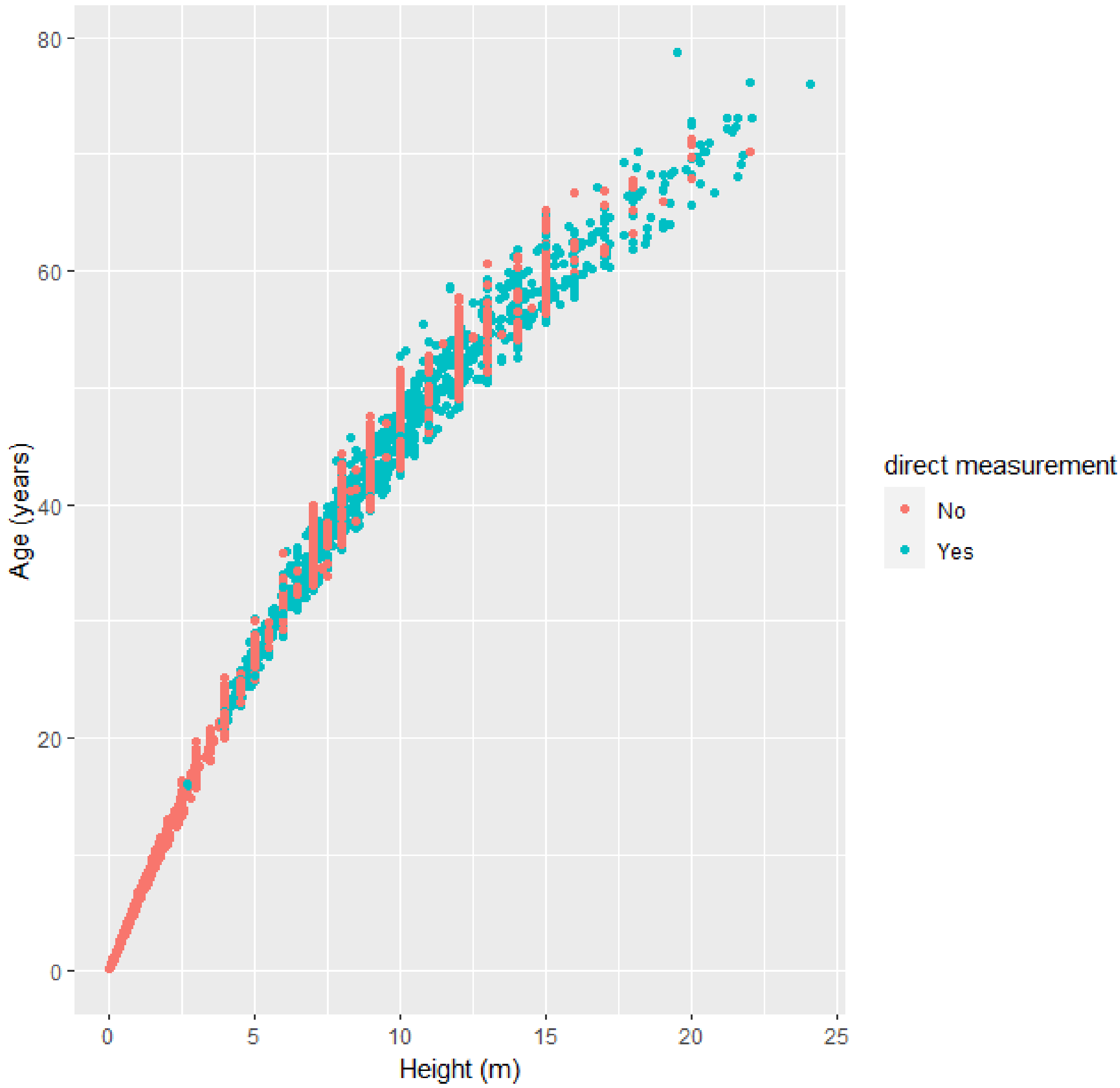

Figure 16. Relationship between height (m) and the derived age from the radiocarbon model for all Tree Geebung records in TG with DBH data (n = 9,825)

3.3 What is the age of flowering and fruiting in Tree Geebung?

A significant model between age and flowering in Tree Geebung could not be fitted from the available data in TG (**Figure 17**). The number of flowering individuals was 91 compared to 2712 individuals recorded as not flowering. The youngest flowering individual found was 11 years old and the oldest flowering individual found was 62 years old.

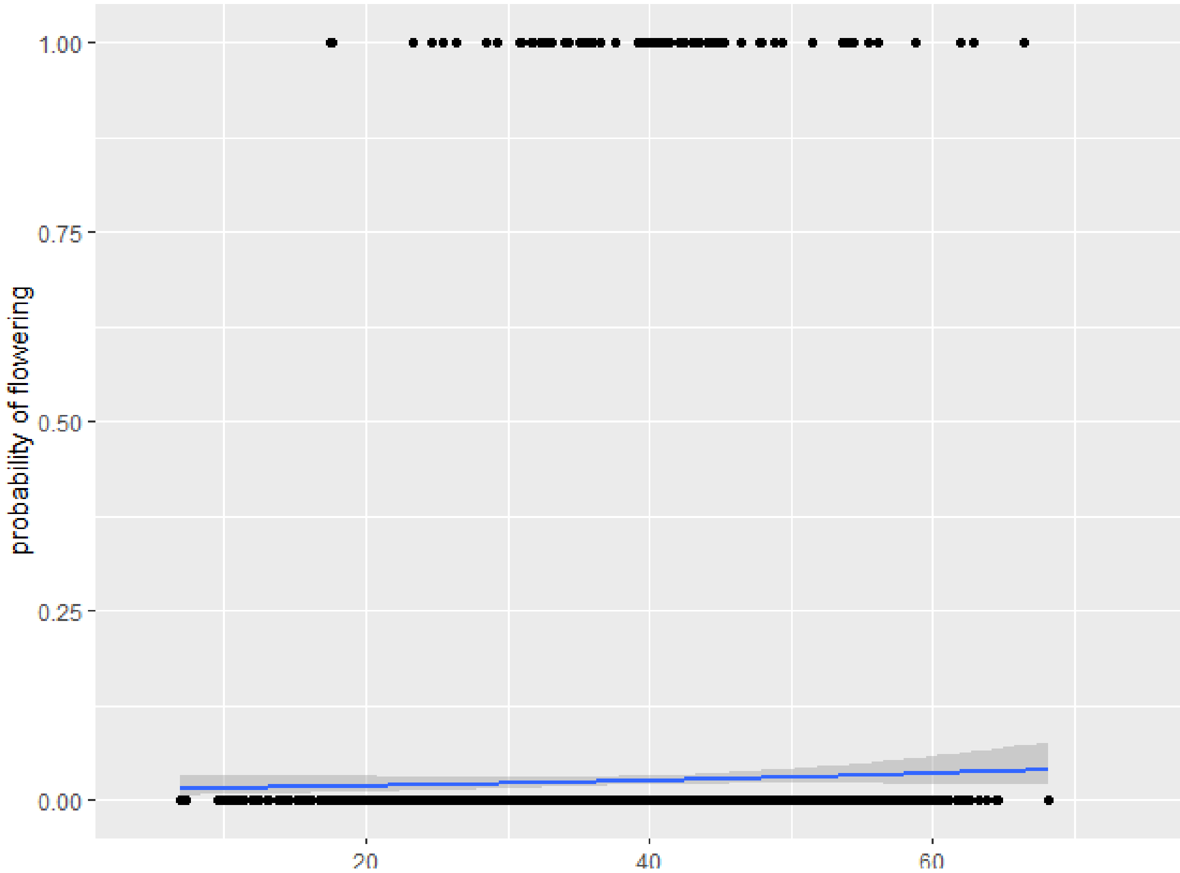

Figure 17. Probability of flowering plotted against age of Tree Geebung. The data was strongly dispersed towards 0 ("No Flowers"), limiting the ability to compute a relationship between flowering and age.

The relationship between age and fruiting is shown in **Figure 18** and is described by **Equation 3**. Based on this relationship, the age of 50% probability to fruit in Tree Geebung is 32.8 years. In **Table 15**, the probability of fruiting is divided into deciles from 0.1 to 0.9, with associated Tree Geebung age based on the relationship in **Equation 3**.

Figure 19 shows the frequency of survey timings in VF per month of the year. Most surveys occurred in December (n = 1,266).

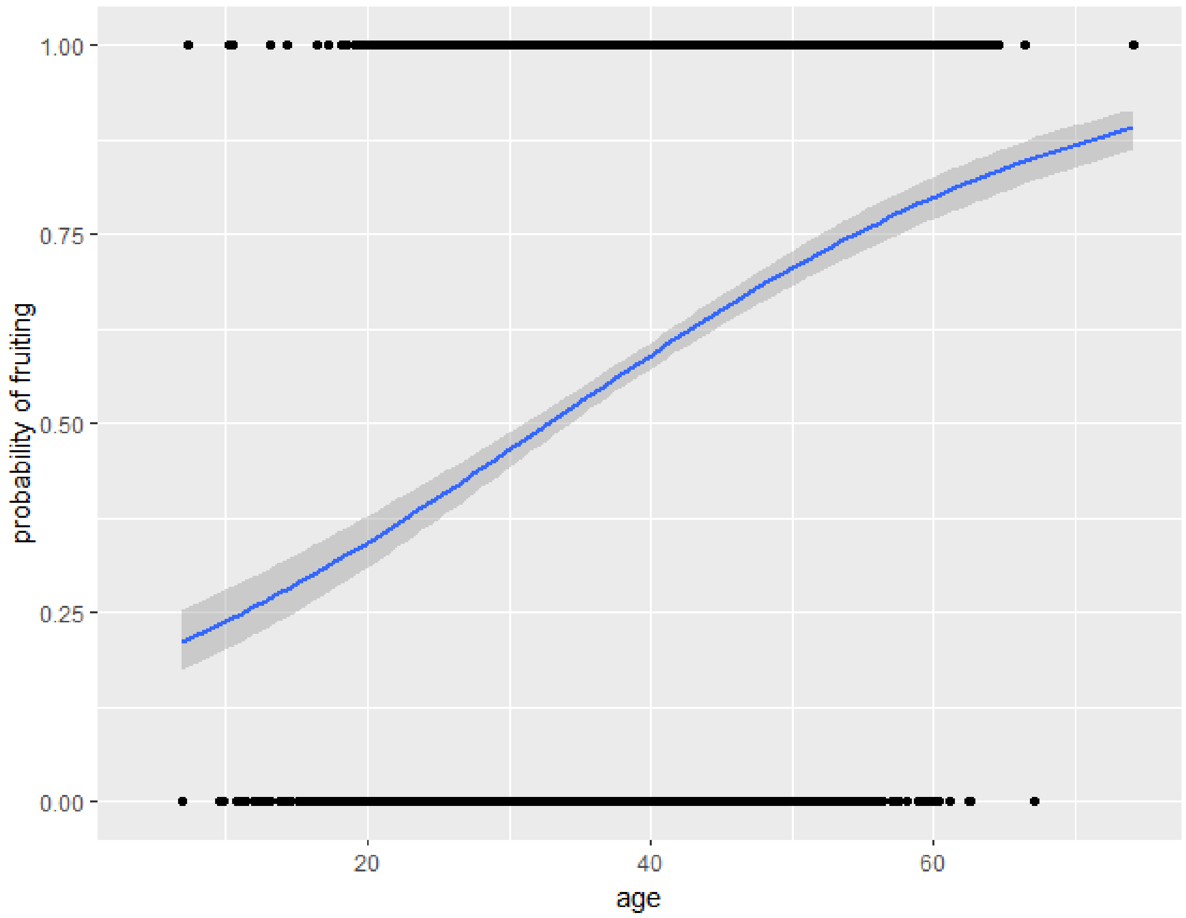

Figure 18. Relationship between age and probability of fruiting in Tree Geebung based on 1928 records of fruiting individuals ("1") and 1441 records of non-fruiting individuals ("0") (n=3368).

Equation 3. Relationship between age of Tree Geebung in years and probability of fruiting

$$Log\left(\frac{P_{fruit}}{1-P_{fruit}}\right) = 0.051 * age - 1.665$$

Table 14. Probability of fruiting in deciles from 0.1 to 0.9, with associated Tree Geebung age based on the relationship in Equation 3.

Probability of fruiting	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Age (years)	13.9	20.8	25.4	29.2	32.8	36.1	39.9	44.5	51.4
Minimum DBH at associated age (cm)	2.7	4.5	6.2	8.0	9.5	10.0	11.0	13.5	17.5
Maximum DBH at associated age (cm)	3.0	6.0	8.0	9.6	12.0	14.0	16.0	21.5	27.0

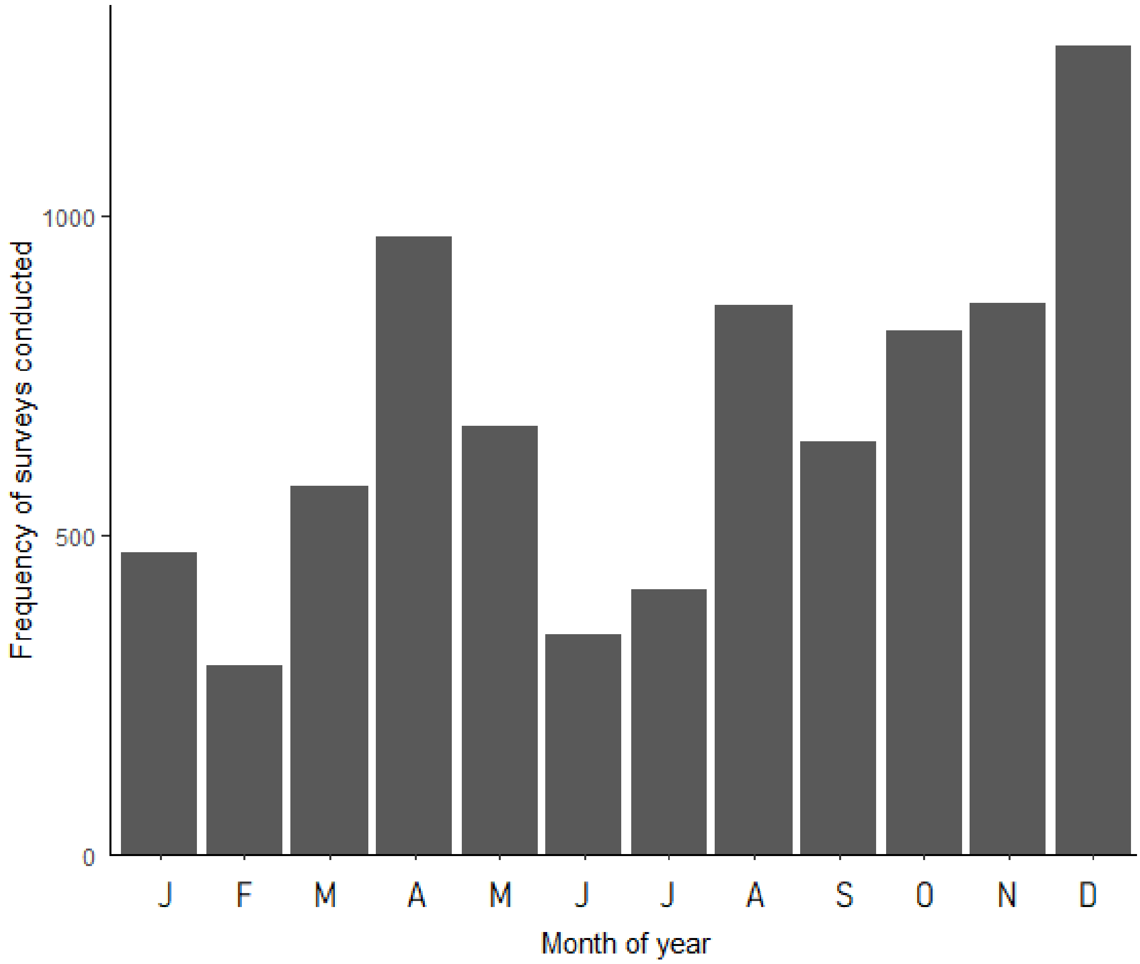

Figure 19. Histogram of survey timings in VF per month of the year. Frequencies per month (Month, Frequency): January, 472; February, 295; March, 664; April, 965; May, 671; June, 343; July, 413; August, 860; September, 645; October, 821; November, 861; December, 1,266.

3.4 Does Tree Geebung respond to disturbances from wildfire and harvest?

Recruitment response to disturbance events from wildfire and harvest (with or without regeneration burn)

Recruitment maxima were consistently within the error range (10 years) of at least one disturbance event of either wildfire, harvest or regeneration burn (**Figure 20, 21, 22** and Appendix 8). This applied to all 24 coupes except one: Christian Road, South (462-510-0026) (Appendix S8e).

An example of a significant recruitment response following harvest is Christian Road, North (**Figure 20**). Recruitment maxima are consistent with bins 1972-76 and 1977-82, with the harvesting occurring within this period (1975-78).

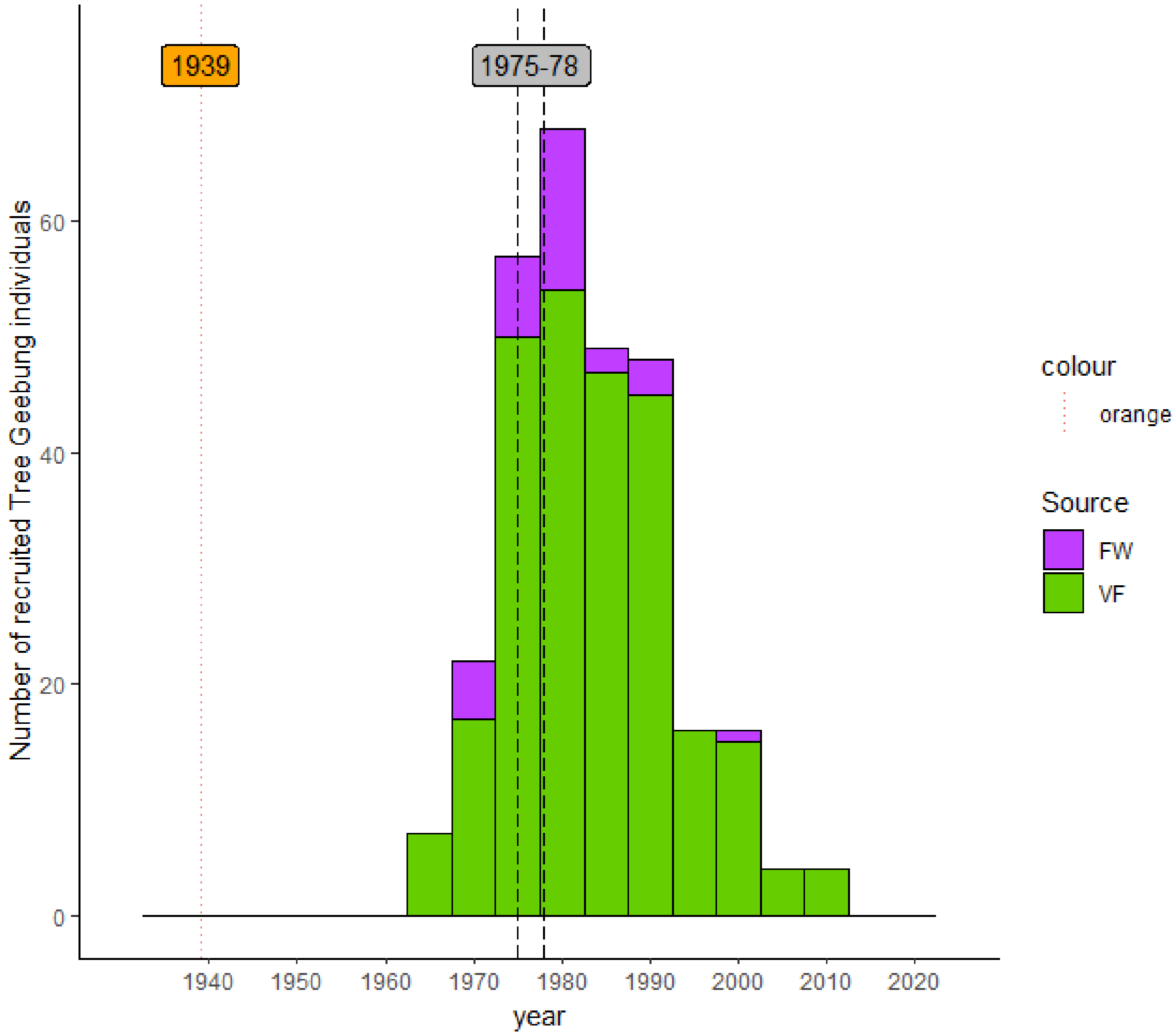

Figure 20. Recruitment of Tree Geebung in Christian Road, North (462-507-0012) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and forest harvest between 1975-78.

An example of a significant recruitment response following a planned burn is Jumping Jack Flash (**Figure 21**). The recruitment maximum was identified as bin 2018-2022, consistent with the disturbance from harvest and planned burn in 2020.

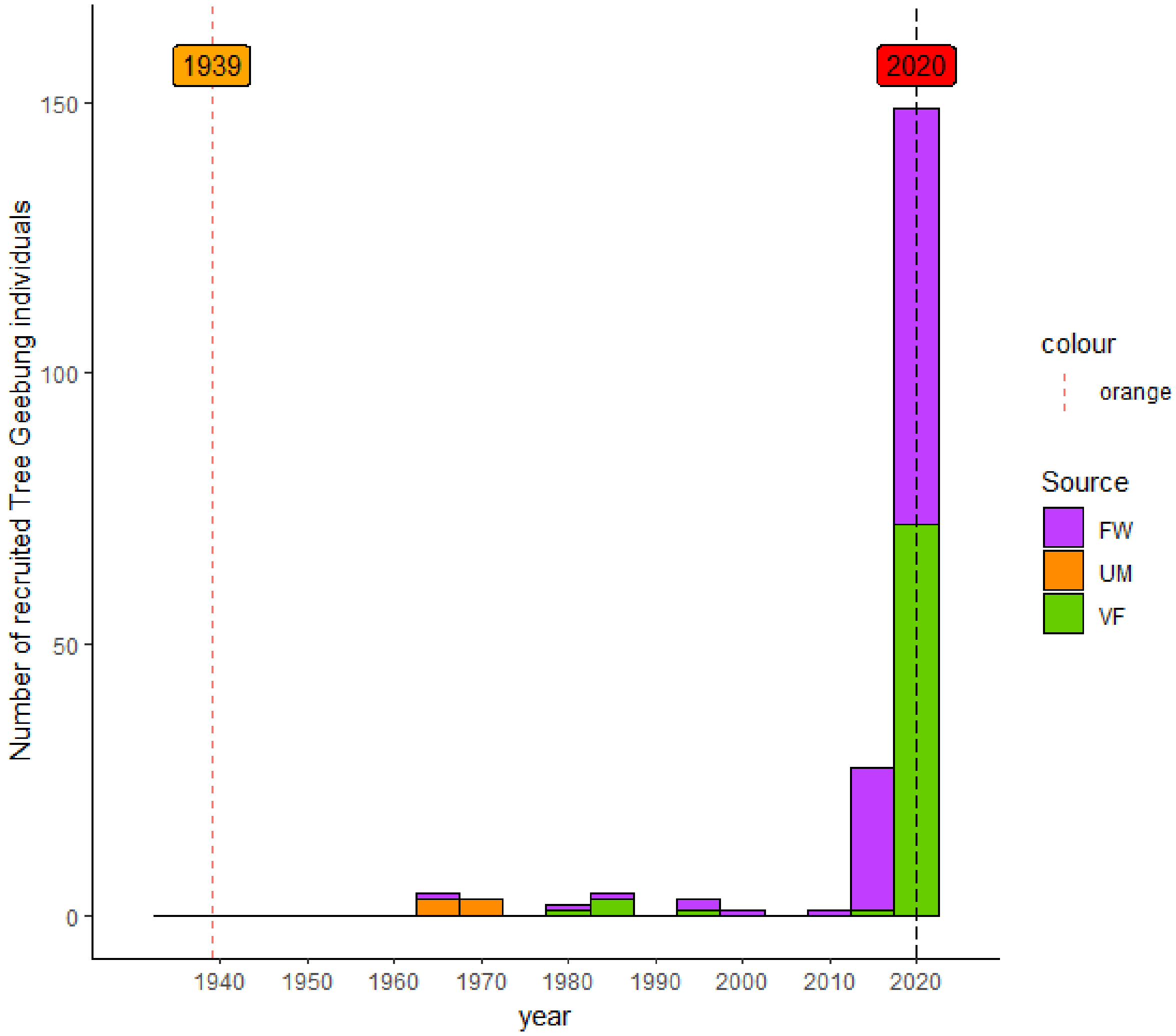

Figure 21. Recruitment of Tree Geebung in Jumping Jack Flash (347-520-0008) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, and a planned burn following harvest in 2020.

An example of a significant recruitment response following a wildfire is Fishernak (**Figure 22**). The recruitment maximum occurred in bin 2009, which is not consistent with the wildfire disturbance events. Continuous recruitment is, however, observed following both the 1939 and 2009 wildfire.

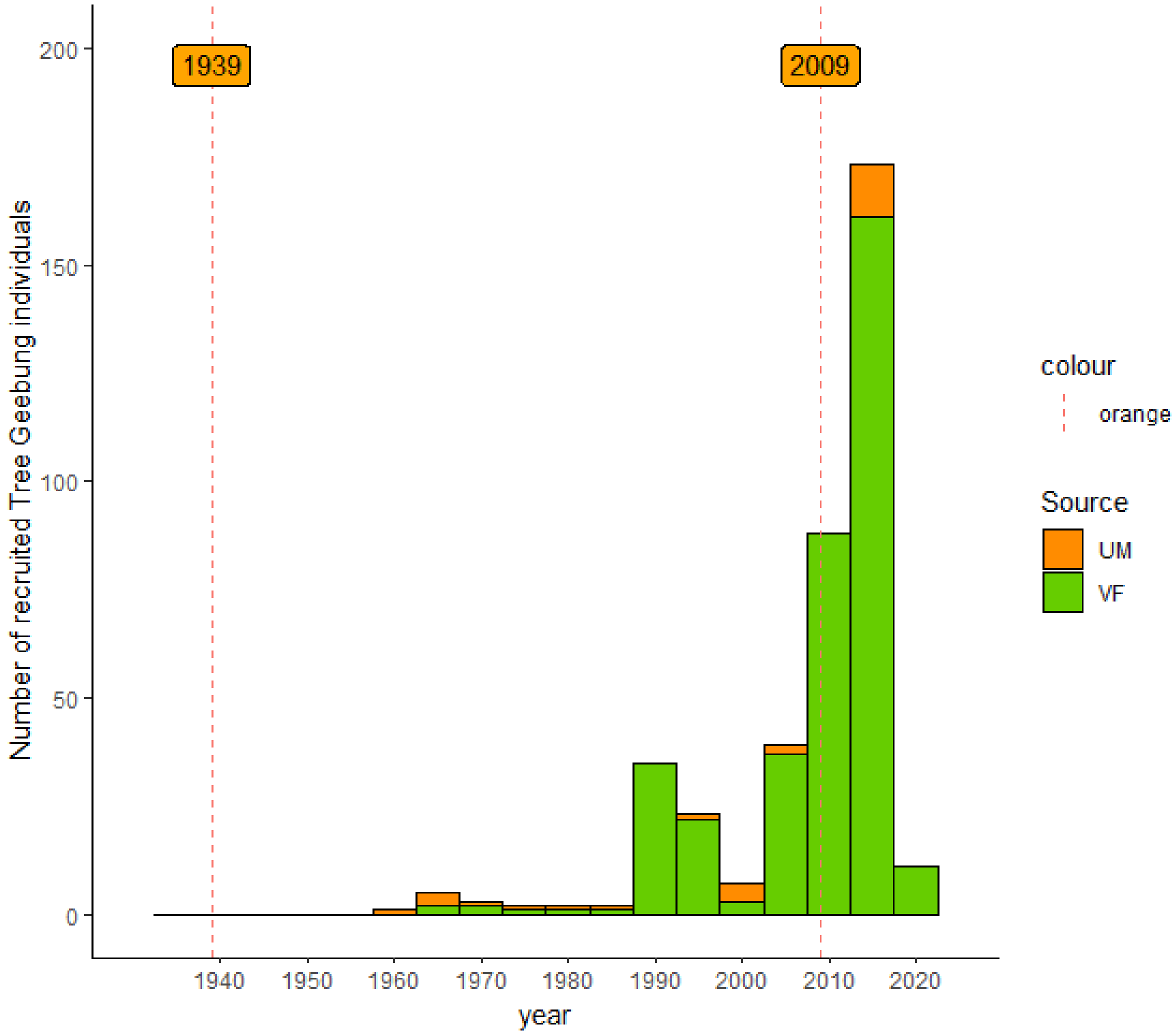

Figure 22. Recruitment of Tree Geebung in Mozambique (309-507-0014) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and the 2009 wildfire.

The remaining 21 coupes are shown in Appendix 8.

Recruitment density following disturbance

Mean seedling density following forest harvest (ρ = 46,480 ha^{-1}) was significantly higher than the mean seedling density after wildfire (ρ = 30,127 ha^{-1}) and after planned burning following harvest (ρ = 33,420 ha^{-1}) (**Figure 23** and **Table 16**).

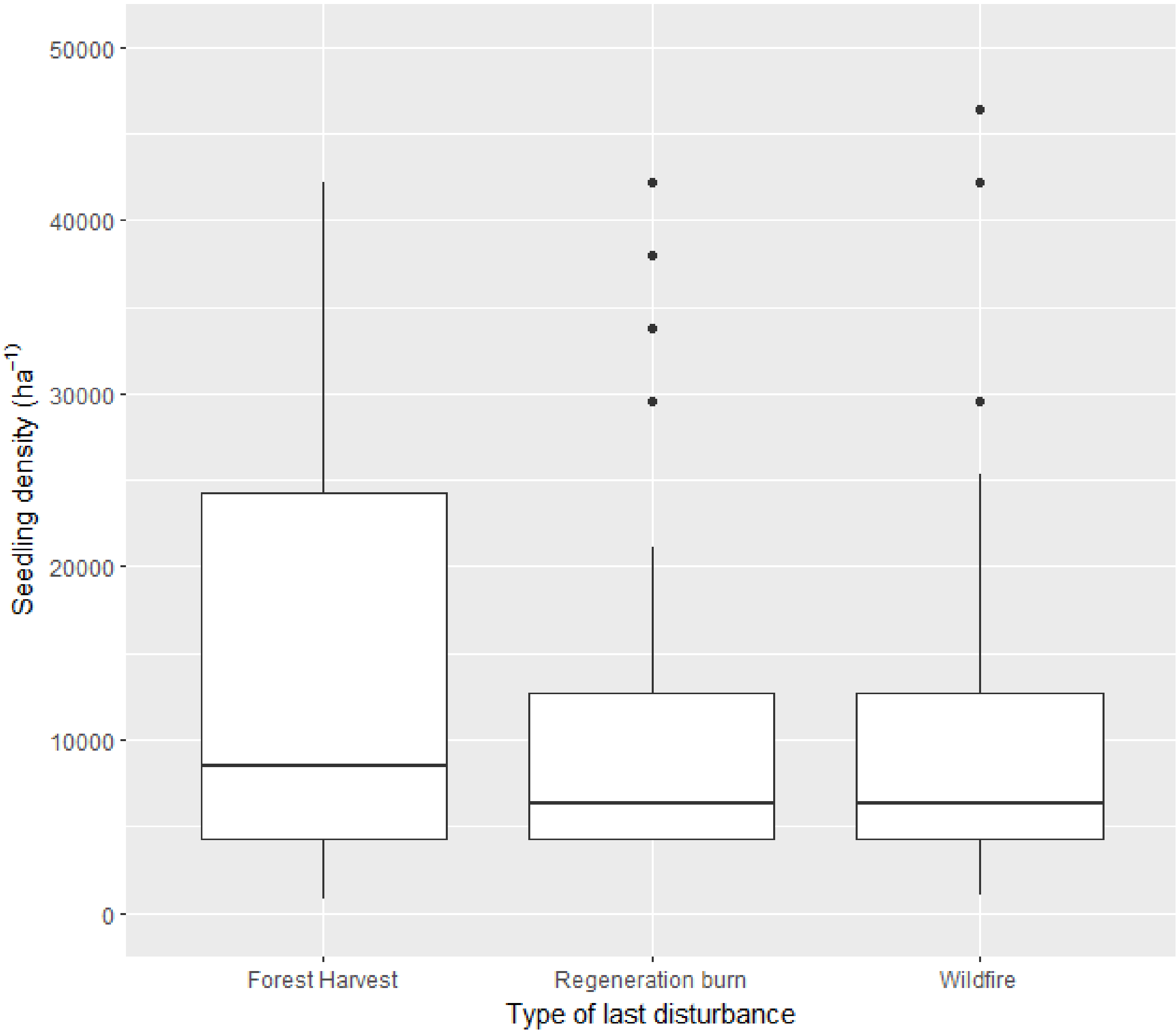

Figure 23. Seedling density m^{-1} radius following the three analysed disturbances: forest harvest, regeneration burn after harvest, and wildfire.

Table 15. Seedling densities in m-1 converted to number of stems per hectare, given that 1 m radius equals 7.9·10-5 ha.

	Forest Harvest	Regeneration Burn	Wildfire
No. stems per ha (ha^{-1})	46,480	30,127	33,420

Persistence to wildfire

Numerous Tree Geebung individuals with a last wildfire footprint of 1983 or 2009 were recruited before the associated disturbance (**Figure 24**), suggesting Tree Geebung is capable of surviving wildfire. All Tree Geebung individuals in TG were recruited after the 1939 wildfire.

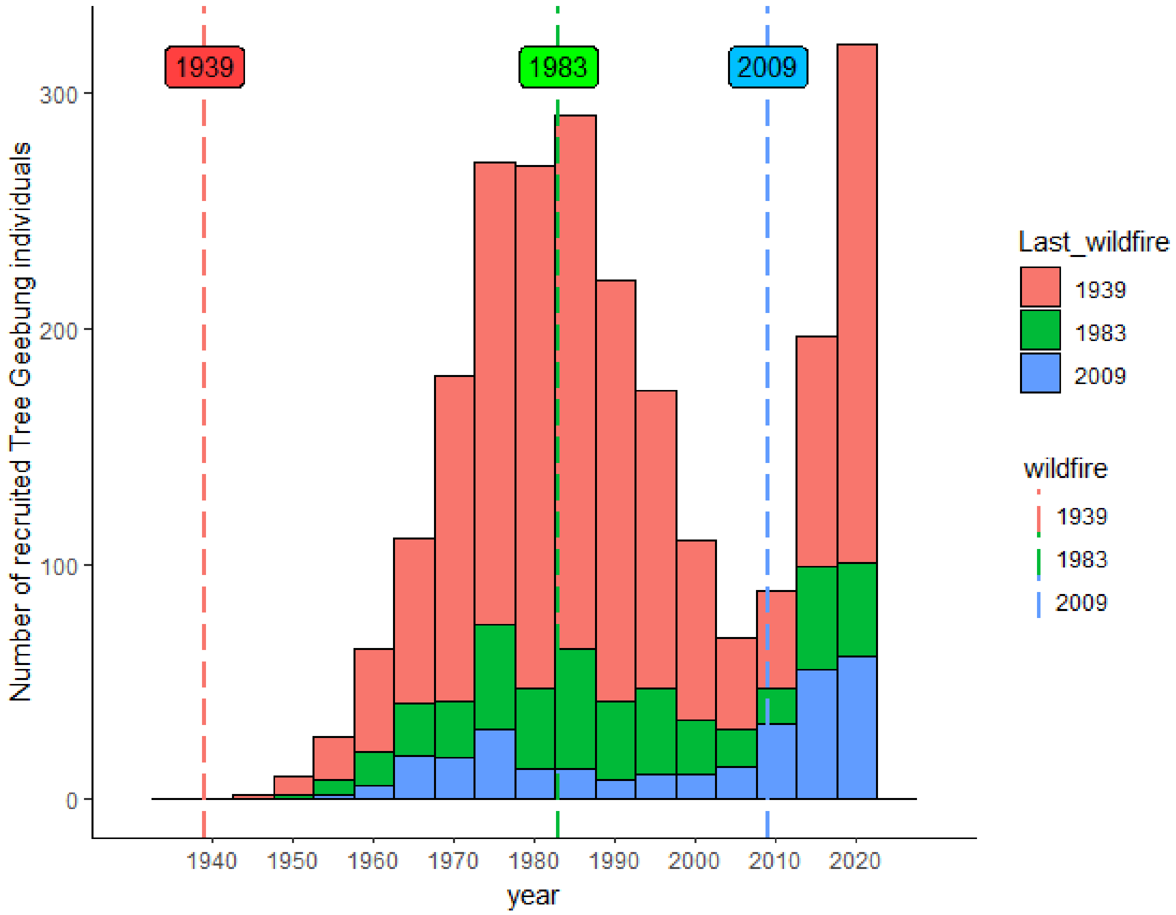

Figure 24. Recruitment of Tree Geebung individuals in TG, coloured by the last wildfire which occurred in their region.

4. Discussion

4.1 How old is Tree Geebung?

The oldest known Tree Geebung in the Central Highlands is 74 years old, having recruited in 1949 $\pm$10 years. All of the recorded Tree Geebung therefore recruited after the widespread Black Friday wildfire of 1939. This is consistent with findings from tree ring counting where in four sites, no trees were found from before 1939 (Xiang & Kasel, 2021). These results also suggests that any individuals recruited before 1939 perished in the Black Friday wildfire. This is in line with Tree Geebung being considered a fire sensitive obligate seeder, due to its thin bark and lack of a lignotuber (Mueck et al., 1996). Data from the University of Melbourne CORE studies show the mean bark thickness for Tree Geebung to be 2.4 mm, which is in the range of 2.5$\pm$1.1 cm mean bark thickness for fire-sensitive woody vegetation species in Brazilian savanna (Souchie et al., 2017). Species with thick barks are most resistant to topkill from fire, and Tree Geebung ranks below other species in Pilliga reserves (mean bark density = 8.0 mm) which are considered least resistant to topkill (Nolan et al., 2020). In the Sydney basin region, most (76%) of the 35 *Persoonia* species are obligate seeders as opposed to resprouters (Auld & Ooi, 2008).

Considering the fire sensitivity of Tree Geebung, it is highly unlikely that individuals which established before the 1939 wildfire are still alive assuming all of them were subjected to this disturbance. The pre-bomb radiocarbon dating of two Tree Geebung individuals at 300-400 years old by Mueck et al., 1996 is therefore dismissed. Instead, the peaks in the lower age class - which would date the individuals at 55 years maximum - are more in line with the response of Tree Geebung as an obligate seeder (Kasel, 2022).

The most plausible clarification that could date the two individuals in Mueck et al., 1996 at 300-400 years old, is if these individuals were unaffected by the 1939 wildfire. This may be possible if these individuals occurred in fire refuges, which would be limited to only extremely sheltered, fire-resistant regions of the landscape (Berry et al., 2015). Such regions are associated with high rocky cover and elevated topographical positions, in which trees grew twofold older than in fire-affected regions (Landesmann et al., 2015).

To find these fire-resistant regions, perhaps the attention should be directed towards Yarra Ranges National Park ('Yarra Ranges'). Blank records from the Atlas of Living Australia depict that Tree Geebung individuals were observed in Yarra Ranges. At a maximum elevation of 1,245 m, Mount Donna Buang in Yarra Ranges may exhibit such fire-resistant regions (Parks Victoria, 2023). Because all records in TG are directly collected from VF or inferred from VF locations (i.e., FW and UM), the data which was available for this analysis is limited to State Forest, even though 60% of Tree Geebung habitat is estimated to be in Yarra Ranges.

The likelihood of finding these old and rare individuals in Yarra Ranges, as opposed to State Forest, is probably low. There is nothing to suggest that environmental conditions are different in Yarra Ranges than in State Forest. **Figure 25** also shows that the entire area of Yarra Ranges (including Mount Donna Buang) was burnt at least once since 1939, suggesting that these older individuals should have perished here as well.

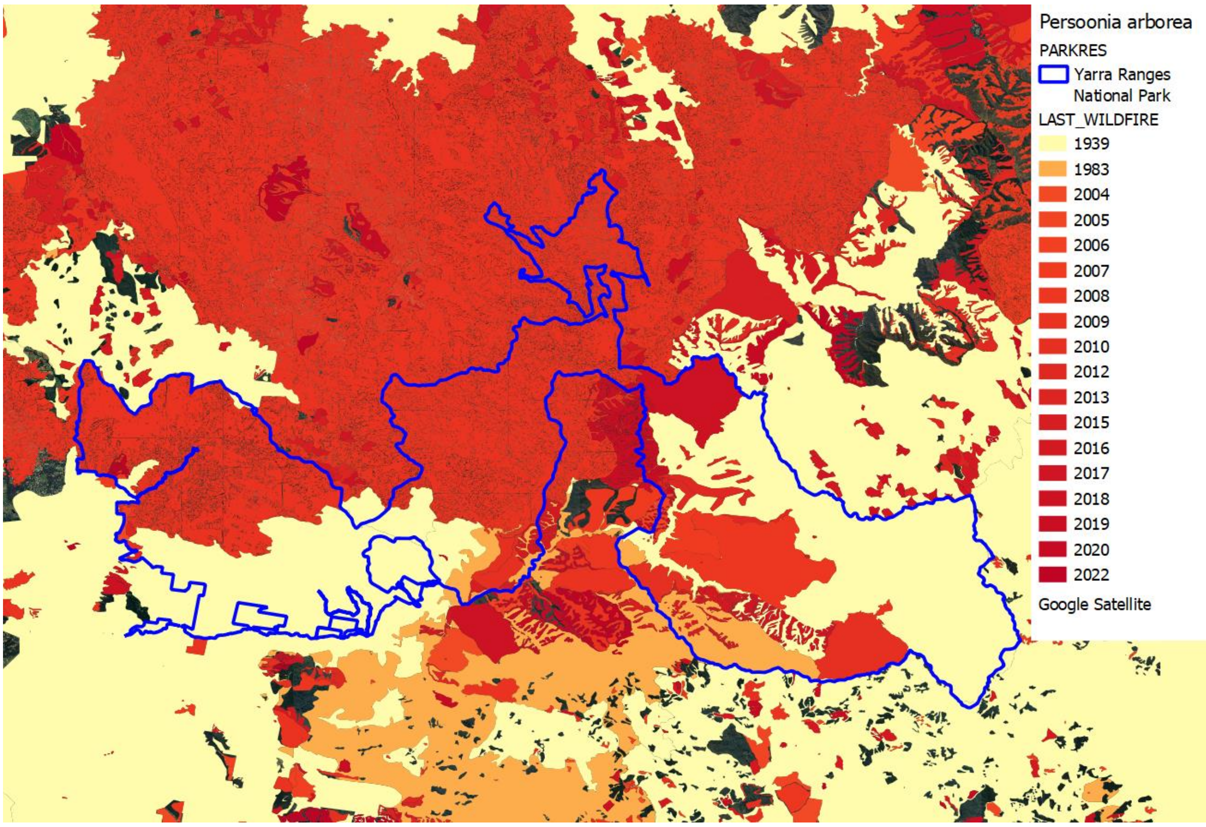

Figure 25. Fire history in Yarra Ranges National Park. The area was predominantly burnt in the 1939 and 2009 wildfires.

The top 10% oldest individuals based on the data in TG are between 52 and 74 years old. As these individuals would typically be expected to have the greatest seed set, a feature not characteristic of younger aged trees (Lindenmayer, 2017), they should be a prime target for conservation by management parties.

4.2 What is the age of Tree Geebung at 10 cm DBH?

At 10 cm DBH, a Tree Geebung individual is 28-40 years old. Forest harvesting cycles are based on a range of factors including the type and quality of timber (VicForests, 2022). The primary focus of timber harvesting for the past two decades (2000-10 and 2010-20) has been the 1939 cohort of Mountain Ash, placing forest harvesting cycles at 60-80 years (Flint, 2007; Trouvé et al., 2021). If disturbances do not occur within these harvesting cycles, Tree Geebung individuals of the immediate post-harvest cohort will have enough time to reach 10 cm DBH. Within the age range of 10 cm DBH, Tree Geebung has a 40-70% probability of fruiting. 90% probability of fruiting will be reached at 51 years, meaning at least 90% of individuals can contribute to the next cohort when a harvesting cycle of 60-80 years is complied with given no disturbances happen in between.

4.3 What is the age of flowering and fruiting in Tree Geebung

TG contained 91 flowering individuals compared to 2712 non-flowering individuals. The data was therefore too dispersed towards ‘0’ to develop a significant relationship between age and the probability of flowering. The relative lack of flowering records may have various underlying causes. Tree Geebung flowers from late summer to autumn and develops fruit from winter until summer (French, 1992). Because the fruiting time is longer than the flowering time, the probability to find a fruiting individual is higher than for a flowering individual. The timing of survey may also play a role. Most surveys in TG were conducted during spring and summer when the probability of fruiting is already higher than flowering (French, 1992) (**Figure 19**).

Another contributor may be the manner of recording in VF. In several instances, solely the presence of fruit was recorded (simply as “Fruit”). While this confirms the presence of fruit, an inference on flowering status cannot be made unless a blank field indicates absence. A recommendation for management would be to record not just presence but also absence of flowers and fruit.

Several species of *Persoonia* have shown great variability in flower/fruit production. In Chia et al., 2015, Spreading Snottygobbles were observed to bear more flowers in the second year (45 plants) compared to the initial year (30 plants) of the study. This may suggest that *Persoonia* species are capable of mast seeding (Kelly, 1994), with the second year of the study possibly being a mast year for this species. The relative lack of flowering may be explained by the presence of mast years in Tree Geebung, and could mean Tree Geebung may produce fewer reproductive structures in some years, meaning less potential contribution to the next cohort.

Observations of young individuals have shown that Tree Geebung is capable of flowering from as young as 3 years of age, but never produce fruit (Kasel, pers. comm.). A flower may therefore not always develop into fruit in Tree Geebung. This may be explained by several complexities in the reproduction of other *Persoonia* species. Limited pollen supply is identified as a potential constraint of fruit set in Rigid Geebung (*P. rigida*) (Trueman, 1999). Pollen limitation is also identified as a significant contributor to low fruit-set in rare *Persoonia* species, which applies to Tree Geebung, compared to common *Persoonia* species (Rymer et al., 2005). Similar to at least 20 other *Persoonia* species in eastern Australia, Tree Geebung is primarily pollinated by bees (Bernhardt & Weston, 1996). Tree Geebung specifically grows in an area, however, which is visited by swarms of *Leioproctus (Filiglossa) davisi* – a species which has shown to be poor pollen vectors (Bernhardt & Weston, 1996).

If cross-pollination is not effective for Tree Geebung, could autogamy then constitute a solution to the reproduction paradigm? Many species of *Persoonia* exhibit the ability to self-pollinate, including Small-Leaved Geebung (*P. virgata*) (Wallace et al., 2002), Rigid Geebung (Trueman, 1999), and Hairy Geebung (Emery & Offord, 2021). In all cases, however, self-pollination resulted in lower fruit-set compared to cross-pollination. Bargo Geebung (*P. bargoensis*) is uncapable of self-pollination and requires pollinators to reproduce (Field et al., 2005). As complex as cross-pollination is for Tree Geebung, inferences from other *Persoonia* species do not suggest autogamy as an effective strategy for reproduction.

Individuals of Tree Geebung with a DBH of 10 cm were aged between 28-40 years old and are prescribed to be protected from disturbance during harvesting. The probability of fruiting at DBH 10 cm ranges from 0.4 to 0.7 and increases with size. Tree Geebung, however, may be able to produce fruit well before reaching 10 cm DBH with individuals as young as 14 years (DBH range 2.5-3.5 cm) having a 10% of producing fruit. The focus of the Standards to protecting individuals with DBH >10 cm (where reasonably practicable) will result in the potential loss of the smaller cohort of individuals which these results show are also capable of contributing to the seedbank. What is unknown, is the relative size of the fruit crop in cohorts of different sizes. In Small-Leaved Geebung, the total fruit set per stem was 41.6% and 36.1% in two subsequent winter months, but a partition into different cohorts was not made other than individuals ranging in height from 1.8 to 4.3 m (Bauer et al., 2001). In general, mean annual fruit and/or seed production increases with tree size of basal diameter or leaf area (Greene & Johnson, 1994). Because basal diameter and DBH are correlated in Tree Geebung (S. Kasel, pers. comm.), it is possible that older individuals may produce more fruit than younger individuals.

4.3 Tree Geebung recruits in response to harvest and fire disturbance

Recruitment of Tree Geebung was consistent with timing of wildfire and harvest. For 20 of 24 coupes, recruitment maxima were consistent within the 10-year error range of a wildfire or harvest disturbance. This is consistent with findings of the Royal Botanic Gardens Sydney, which identified mechanical disturbance as a genus-wide catalyst for germination by breaking the woody endocarp and specific temperatures (which may be achieved through wildfire) as a species-specific catalyst to relax dormancy (The Royal Botanic Garden Sydney, 2023). Tree Geebung is often found in dense thickets along roads which have been cleared through the forest (Gullan, 2021; J. Voet, pers. obs.), consistent with results from Pat's Corner (Kasel, 2020). Indeed, this appears a genus-wide trait as this also holds true for other *Persoonia* species, for instance Hairy Geebung (Emery & Offord, 2018). Tree Geebung recruitment is also thought to be cued to wildfire denoting a temperature requirement for germination, a trait which was observed in other *Persoonia* species (Atchison, 2009; Auld et al., 2007; Chia et al., 2015; McKenna, 2007; Nield et al., 2015). In Snottygobble, this temperature component was successfully overcome using gibberellic acid as a catalyst (Mullins et al., 2002; Norman & Koch, 2008). Also this was achieved for Tree Geebung, with a single seedling germinating following a gibberellic acid treatment (Kasel, pers. comm.).

Regeneration pulses are continuously observed following disturbance at increasing rates until 20-25 years, consistent with dendroecological findings of Tree Geebung recruitment dynamics (Xiang & Kasel, 2021). As far as is known, long-term regeneration in Tree Geebung and other *Persoonia* species is seldom studied. Lance-leafed Geebung were found to continuously recruit up until 6 years post-fire (Auld et al., 2007), which supports that Tree Geebung can recruit for some time after disturbance. The post-disturbance recruitment surge until 20 years may be explained by increased light availability from lack of overstorey, as well as increased nutrient availability from wildfire (Sethi & Howe, 2009). Mountain Ash will reach a height of 15 m in approximately 10 years (Vertessy et al., 2001), at which point Tree Geebung reaches around 2 m in height (**Figure 16**). This means that within 20 years after disturbance, Mountain Ash will outgrow and limit light availability of Tree Geebung, resulting in a reduction of the recruitment rate. Past the 20–25-year point, Tree Geebung will still continue to recruit albeit at a lower rate. This may be explained by the finding that individuals of the post-disturbance cohort become capable of reproduction within the 20 years after disturbance (10% of individuals after 14 years), resulting in new cohorts 20 years post-disturbance.

The only coupe where the recruitment maximum was not consistent within the error range of 10 years was Christian Road, South (462-510-0026) (Appendix S8e). The disturbance history of this coupe was limited to the 1939 wildfire. The disparity between the recruitment maximum and disturbance events might be a result of absent disturbance data. This is mainly inferred from field observations made in Christian Road, South. The disturbance data in FIRE_HISTORY and LASTLOG25 indicates this area was only burnt in the 1939 wildfire and subsequently never harvested. During the survey of this coupe, numerous traces of historical logging were observed including historical roading and old clean-cut stumps (**Figure 26**), which could be traced back to the 1950s (Ben Smith, pers. comm.). This anomaly is also thought to be relevant for Pat's Corner, where strong regeneration of Tree Geebung was observed along an old logging road despite no recorded logging data in this coupe (Kasel, 2020).

Figure 26. Clean-cut stump found in Christian Road, South (462-510-0026) on 5 Dec 2022. LASTLOG25 showed no data of harvesting in this coupe, despite multiple traces of historical logging such as stumps and historical roading (Photo by Ben Smith).

4.4 Tree Geebung recruits stronger following harvest compared to fire

The recruitment response of Tree Geebung was stronger following harvest (ρ = 46,480 ha^{-1} radius) than following a wildfire (ρ = 30,127 ha^{-1}) and a planned burn after harvest (ρ = 33,420 ha^{-1}). The stronger response to harvest is consistent with field observations from past surveys, where mass regeneration was detected in areas subjected to mechanical disturbance (ex. Pat's Corner, **Figure 8**), and from other species of *Persoonia*, for instance Hairy Geebung (Emery & Offord, 2018). Wildfire produced a slightly higher recruitment response than regeneration burns, but both responses were lower than harvest. This does not necessarily entail that there is no difference in seedbank dynamics between wildfires and regeneration burns. Indeed, the regeneration burn is likely to have weakened the seedbank compared to wildfire by either killing the post-harvest flush or damaging the seedbank due to its high-intensity nature (Watson, 2001; Whelan, 2002).

Observations made during the fieldwork surveys might suggest that the measured individuals were recruited after the harvest, but were subsequently unaffected by the regeneration burn. This is inferred from the frequent occurrence of seedlings on snig tracks (J. Voet, pers. obs.) (**Figure 27**). In a regeneration burn, the slash and the remaining vegetation is burnt. Inside coupes, these structures often manifest as patches separated by relatively bare snig tracks. Seeds and germinants located on snig tracks are relatively safe from intensive fire of planned burning (Rab, 1996). As a result, the seedling density in coupes last disturbed by a regeneration burn is likely a consequence of survivor bias from seedlings which escaped the fire by germinating on unburnt patches such as snig tracks. Persistence of Tree Geebung seedlings in relation to fire severity may be inferred from other *Persoonia* species. Narrow-leaved Geebung (*P. linearis*) showed some degree of tolerance to high-intensity fire but persisted better in low-intensity fire, with 20-30% stem survival following high-intensity fire compared to 40-80% survival following low-intensity fire (Morrison & Renwick, 2000). This is consistent with findings for Hairy Geebung, where moderate severity plots were 1.28 times less likely to experience severe seedling dieback than very high severity plots, and low severity plots 1.40 times less dieback than very high severity plots (Andres et al., 2022).

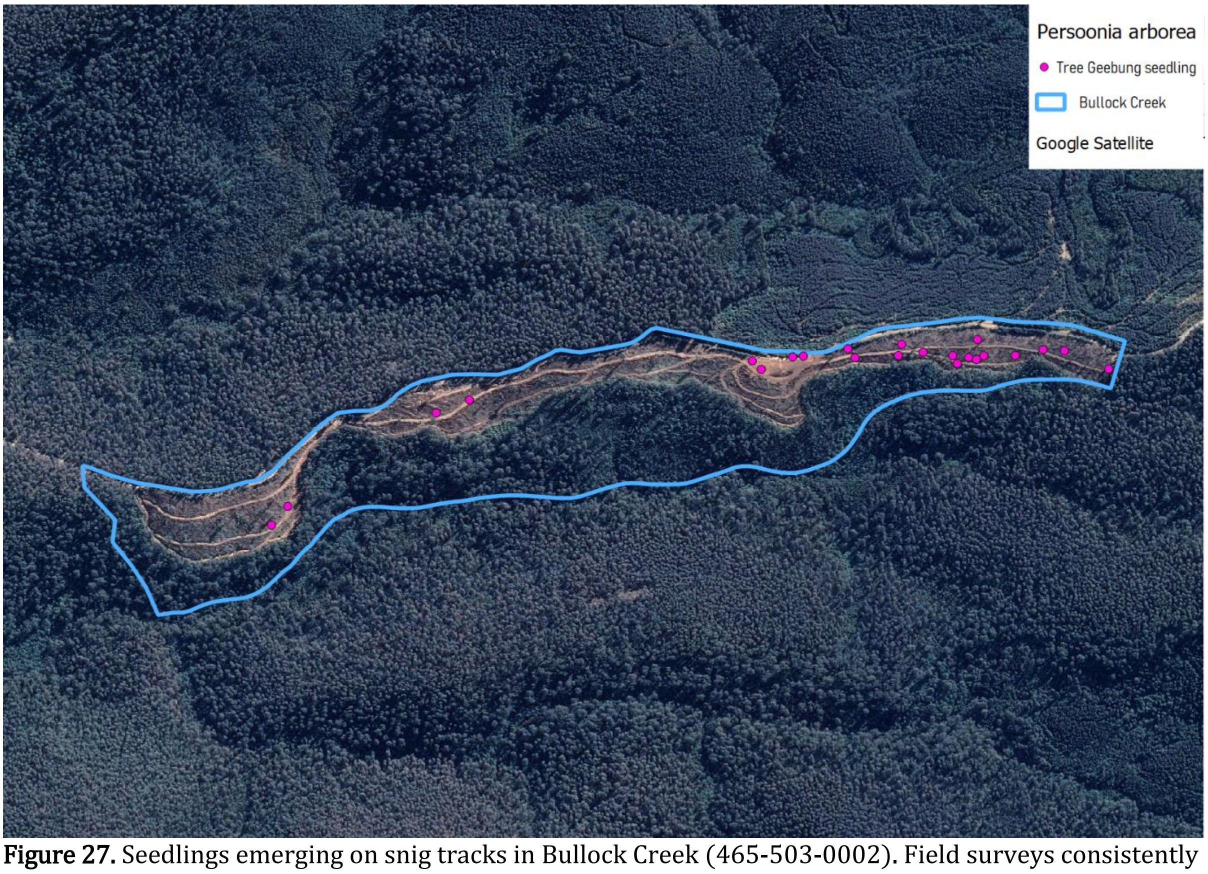

Figure 27. Seedlings emerging on snig tracks in Bullock Creek (465-503-0002). Field surveys consistently confirmed absence of seedlings in patches that were burnt

Research by The University of Melbourne shows that regeneration burns can lead to surface temperatures of 700-800 °C and <100 °C at 5 m depth (Kasel, pers. comm.). When slash is heaped instead of being spread out before burning, this can exceed these temperatures (Burrows & Smiih, 1988; Kasel, pers. comm.). In many of our harvest coupes, traces of slash heaping practices were found (J. Voet, pers. obs.; B. Smith, pers. comm.) (**Figure 28**). Heaped slash burning can produce high intensity fires, which can result in substantial seed mortality (Donovan & Brown, 2007; Etchells et al., 2020; Keeley et al., 1999; van Oldenborgh et al., 2021). High-intensity fires may furthermore result in negative impacts on diversity (Shi et al., 2022) and increased recruitment in several species of *Acacia* in Warrumbungle National Park (Palmer et al., 2018), though fire severity has also been reported as non-significant to recruitment for Mountain Ash (A. L. Smith et al., 2014). Nevertheless, we may infer from Narrow-leafed Geebung and Hairy Geebung how seedling recruitment in *Persoonia* relates to fire severity. Seedling recruitment and growth of Narrow-leaved Geebung varied across sites, but showed no relationship to fire severity (Morrison & Renwick, 2000). In Hairy Geebung, a significant relationship between recruitment and fire severity was also not found (Andres et al., 2022). This suggests Tree Geebung recruitment may not be affected by fire severity, other than simply the occurrence of fire. This is consistent with recruitment dynamics of Mountain Ash (A. L. Smith et al., 2014), which often co-occurs in Tree Geebung habitat (Gullan, 2021).

Figure 28. Remains of a slash pile in Opposite Fitzy's (345-506-0004), harvested in 2016 but not burnt (Photo by J. Voet, 08 Dec 2022).

Recruitment density was derived from plot counts and the associated plot radius. Because this information was largely absent from VF, as VicForests' seedling counts did not follow standard survey procedures (Ben Drouyn, pers. comm.), only data from FW and UM was used (n records =216). A recommendation for management is to apply a methodology that allows for some assessment of recruitment density, for instance a methodology modelled after TSS where seedlings within x m on either side of a transect with specified length are recorded.

4.5 Tree Geebung persists through low-intensity wildfires, but not high-intensity

Tree Geebung showed to be capable of surviving wildfire, seeing as individuals subject to the 1983 or the 2009 wildfire were recruited prior. All records in TG were, however, recruited after the 1939 wildfire. These findings suggest that Tree Geebung is capable of surviving low intensity wildfire, but not a high intensity wildfire given it is located in burnt areas of the wildfire and not in unburnt refuges.

In Mozambique – one of the 2009 wildfire-affected coupes, there is data to suggest the wildfire was of low intensity (**Figure 29**). Observations made in Mozambique showed that numerous live individuals had been directly affected by the fire, bearing fire scars of up to 1 m (J. Voet, pers. obs., **Fig. 6**). Based on this information, it can be concluded that Tree Geebung is capable of surviving low intensity fire.

Although no quantitative data of the 1939 wildfire is available, we may infer from the Eucalypt stands in the region the severity of this fire. Since the majority of Mountain Ash individuals established immediately after the 1939 wildfire (Simkin & Baker, 2008), this fire was capable of consuming an immense proportion of the overstorey – characteristic of high intensity fires (Ryan, 2002). Because all Tree Geebung individuals in TG were recruited after 1939, it can be concluded that either Tree Geebung is not capable of surviving high intensity fire or are nearing end of life at the age of 84 years.

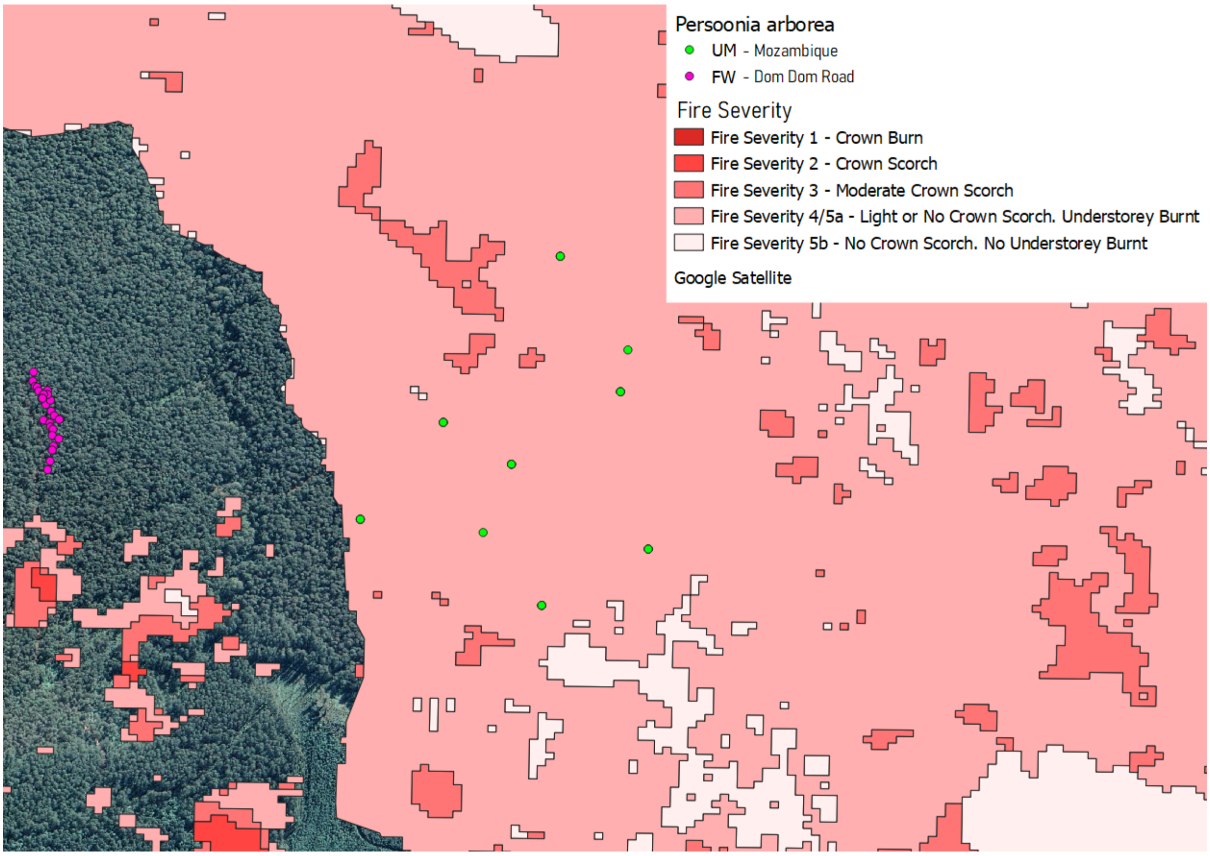

Figure 29. Fire Severity of the 2009 wildfire in Mozambique (309-507-0014). Fire severity in Mozambique (green) was mainly consistent with Fire severity class 4/5a.

4.6 Implications of findings

The results of this study depict that Tree Geebung can become at least 74 years old. Whether they are capable of becoming older will depend on our ability to find larger individuals and likely those not affected by the 1939 wildfire. Our findings also indicate that Tree Geebung is capable of producing fruit at a relatively young age, with a 50% probability of fruiting at 32 years of age (9.5-12 cm DBH) and 90% probability at 55 years (17.5-27.0 cm DBH). This is much younger than the previously suggested 150 to reach maturity. Tree Geebung's longevity is often cited as a critical risk factor for its conservation (Mueck, 2020; Warburton Environment, 2021). Although our results suggest that Tree Geebung does not reach an age in the magnitude of hundreds of years, Tree Geebung may still be at risk of (local) extinction from disturbance due to seedbank exhaustion, particularly where further disturbances take place within the juvenile period and prior to soil seed bank replenishment.

Tree Geebung recruits in response to disturbance from wildfire and harvest. The response is significantly stronger following forest harvest compared to wildfire. Coupes are subjected to significant mechanical disturbance during a harvest, resulting in mass regeneration of Tree Geebung. The problem in this case, is the subsequent exhaustion of the seedbank. The surge of germinants following mechanical disturbance will expose these individuals to post-harvest disturbances. The real question one should ask themselves, rather than how old Tree Geebung can become, is how likely it is that a next disturbance can occur following an initial disturbance – mainly from forest harvesting. Considering wildfire frequency and intensity are expected to increase in temperate forests of south-east Australia (Fairman et al., 2016; McColl-Gausden et al., 2022), an untimely follow-up disturbance capable of decimating Tree Geebung populations (e.g., within 25-30 years) is likely.

In the event of harvesting, the key to maximising persistence of Tree Geebung will be to retain as many individuals as possible capable of contributing to the next cohort (i.e., those individuals which are capable of producing fruit). At a cut-off point of 10 cm DBH currently referred to in the Standards, a Tree Geebung will be 28-40 years old. My findings show that individuals of this size will have a probability of 0.4-0.7 to produce fruit. While a significant number of fruiting trees will be retained at this cut-off point, smaller trees may still produce fruit.

4.7 Summary of recommendations for management practices

To find specific answers to the research questions of this thesis, specific data is needed that must be collected in a minimal adequate manner. Suggestions for these were mentioned throughout the body of the discussion, and will be repeated and elaborated here.

In 8 of 24 coupes, data was solely used from either UM or FW because there was no data for DBH in the records of VF. Though this did not affect the alignment of recruitment with disturbance events, an increased sample size may have provided a more informative image of the disturbance history. Measurements of DBH will require consistency and accuracy to provide the best information for age calculations. The age of Tree Geebung is a principal component to answer the research questions. Of the two models developed from radiocarbon dating, the relationship between age and DBH was used to for the age analyses for practicality reasons, as accurate DBH measuring is generally easier and cheaper than height.

Fruits should be recorded for presence and for absence. It is also recommended to apply this same level of detail for flowers, though they are of lower priority to record. Fruits were frequently recorded without inference of flowering status, creating ambiguity as to whether flowers were absent or not assessed. To avoid ambiguity, recording absence should have the same priority as recording presence.

Seedling counts should be recorded in a systematic matter that provides scope to assess recruitment density and proximity to trees, for example with transect counts for seedlings, similar to TSS for mature trees.

Currently, many seedlings are likely unjustly classified as last disturbed by regeneration burn. Our field observations suggest many of these seedlings may have been unaffected by the regeneration burn, as they germinated on snig tracks which were relatively safe from fire. The recommendation is to account for soil disturbance classes during post-harvest surveys, whether immediately after harvest of after the regeneration burn. This way, classification occurs from direct observation rather than being indirectly deduced from data layers.

4.8 Recommendations for further research

Conservation of Tree Geebung should carefully consider its complex ecology. Despite my efforts to uncover key life history traits of Tree Geebung, several points of discussion were brought up as a result. Below are some recommendations for further research which could support my findings and further exploration into the complex life history traits of Tree Geebung.

- Targeted surveys of fire refuges not subjected to the 1939 wildfire to determine whether larger (and older) Tree Geebungs exist in the landscape.
- Assessment of the size of the fruit crop in relation to tree size – is there a 'sweet spot' where trees reach maximum fruit production and then potentially decline with age, or does fruit production keep increasing with size?
- Assessment of the residual soil seed store of Tree Geebung following mechanical disturbance and disturbance from fire – is the soil seed store exhausted following disturbance from harvesting?
- Assessment of survival rates of translocated Tree Geebung to determine whether this would be a viable conservation strategy.
- Assessment of other threatening processes, including damage by deer. The database TG has 97 confirmed cases of deer damage, 73 cases of fire damage, 13 cases of herbivory damage, 46 cases of broken tops, 9 cases of snapped a main stem, 4 cases of individuals which were pushed over, and 46 cases of miscellaneous forms of damage (e.g., vine, borer damage)

5. Conclusion

Tree Geebung can become at least 74 years old ($\pm$10 years). Older individuals were not found and all those currently documented were recruited post-1939. At the 10 cm DBH cut-off, Tree Geebung is 28-40 years old. In this age range, the probability of fruiting in Tree Geebung is between 0.4 and 0.7. Tree Geebung recruits in response to disturbances related to wildfire and harvest, but recruits stronger following harvest compared to wildfire and regeneration burns after harvest. Tree Geebung is also capable of surviving wildfire, provided that it is a low-intensity wildfire. Tree Geebung does not become hundreds of years old, but its response to disturbance may still have implications for its conservation considering projected climate change and the potential for increased intensity and frequency of wildfire.

6. References

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Appendix

APPENDIX 1. Complete list of VicForests coupes in the Central Highlands Forest Management Area. The number of Tree Geebung individuals recorded within each coupe is provided.

Coupe_Number	Coupe_Name	n
200_503_0009	Devil's Staircase, Toolangi	2
286-505-0021	Tolshers Road, Rubicon	71
286-505-0021/286-505-0020	Tolshers Road, Rubicon	1
286-505-0026	High Voltage-286-505-0026	1
297-501-0006	Victoria Range road, Toolangi	16
297-507-0003	Sun Downies	2
297-538-0004	Sylvia Creek Road, Toolangi	7
297-538-0005	Slaw	4
297-542-0001	Sylvia Creek Road, Toolangi	37
297-542-0001/297-542-0002	Sylvia Creek Rd	41
297-542-0002	Sylvia Creek Road, Toolangi	21
297-542-0004	Monda Rd, Toolangi.	14
297-542-0007	Monda Road, Toolangi	5
298-515-0001	'Zinger', Kalatha Rd, Toolangi	2
298-519-0002	Horseyard Creek Road, Toolangi	2
299-510-0007	Yellowdindi Road, rbethong	4
300-503-0008	Bungalow	290
300-503-0009	Devils Staircase trk, Toolangi.	38
300-524-0002	Waves-300-524-0002	31
300-530-0003	Monda Road, Toolangi	13
300-539-0001	Surfing-300-539-0001	6
300-541-0002	Black Range Track, Toolangi	21
300-545-0003	Monda Road, Toolangi	47
300-545-0004	Quarterback	48
305-502-0007	Head Creek track, Powelltown	2
307-503-0003	'Flow Zone', Toolangi	1
307-503-0005	Stoney Creek Road, rbethong	34
307-503-0030	Witchety Thinnings	1
307-503-0031	County Clare	23
307-504-0001	Puff Adder Research	8
307-504-0002	Black Flag Research	7
307-504-0003	Black Star Research	8
307-504-0004	Black Pearl Research	46
307-504-0006	Off Wattle Path Spur Road, Toolangi	1
307-504-0033	Black Link Research	18
307-504-0036	Gaboon	27
307-505-0001	Rouch road, Toolangi	4
307-505-0009	Rouch road, Toolangi	123
307-505-0010	Carson Track, Toolangi	104
307-505-0011	'Guitar Solo' Plantation Rd, Toolangi	2
307-505-0012	Kings	3

Coupe_Number	Coupe_Name	n
307-505-0016	Racecourse creek	30
307-505-0017	Duet	11
307-507-0001	Ponderosa	6
309-501-0004	Banjo	31
309-502-0008	Dom Dom Rd rbethong	361
309-507-0010	Uganda	147
309-507-0013	Malawi	9
309-507-0013, -0014, -0011	Malawi, Mozambique, Congo	12
309-507-0014	Mozambique	313
312-011-0015	Dejavu - 312-011-0015	1
344-509-0009	Ginger Cat	553
344-511-0006	Uncle Tobys	79
344-512-0001	Burn Creek	2
344-520-0003	Pieces of Eight-344-520-0003	3
344-527-0003	Brahams rd, Warburton.	19
345-501-0001	Oat Patch Track	2
345-501-0006	Braid	2
345-503-0005	Bullseye	93
345-506-0004	Opposite Fitzys	204
345-506-0008	Fitzies Hat	114
345-506-0010	Strom City	32
345-507-0005	Liittle Block	40
345-507-0008	Qantas	113
345-511-0004	Pat's Corner	67
345-511-0005	Bluey Creek Track	150
345-513-0001	Dragon Ball Z	426
345-513-0002	Smythe Creek Road	186
345-513-0003	Fireman Sam-345-513-0003	81
345-513-0005	Deadshot-345-513-0005	18
345-515-0005	Dwyer Gully PCL	126
345-522-0002	Smythe Creek RDI	86
345-526-0003	Louisia	1
346-508-0003	Shifting Sands	9
347-513-0003	Turner Road	7
347-514-0001	Learmonth Creek Road	2
347-515-0002	Below Learmonth	3
347-515-0012	Upper Learmonths	2
347-517-0003	Bunyip Road	1
347-517-0004	Worlley Track	1
347-518-0003	Beer Creek	1
347-518-0005	Learmonth Creek Road, Powelltown	96
347-519-0003	Torbetts Road	1
347-519-0004	Geary Track	1
347-520-0004	Settlement Creek Track	4
347-520-0007	Jack Attack	47
347-520-0008	Jumping Jack Flash	264

Coupe_Number	Coupe_Name	n
348-506-0003	Federal Road	327
348-514-0001	New Turkey Spur Road	7
348-514-0003	New Turkey Spur Road	144
348-514-0061	Ada River Road	114
348-515-0004	Greendale	98
348-516-0005	Heartbeat	9
348-517-0005	Tarzan	76
348-517-0008	New Turkey Spur Road	1
348-519-0008	Turducken	1
348-524-0003	New Turkey Spur Rd	9
348-531-0003	Empire	10
349-502-0014	Latrobe	12
349-502-0015	Blaxland - 349-502-0015	21
349-502-0018	Ricotta	10
349-503-0010	Flagstaff	18
349-503-0011	Governor	149
349-503-0014	Jolimont	32
349-509-0003	Grimace	29
349-509-0006	Biggy	125
349-509-0007	Limberlost Road	52
349-509-0008	Pioneer Creek Road	6
349-510-0003	Columbus	138
349-510-0005	Columbus RDC	108
349-511-0006	Outlook Track	12
349-511-0012	The Shard	47
349-511-0015	Magellan	1
349-512-0008	Herrod Fireline, Gentle Annie	163
349-512-0009	Cuppa Tea	232
349-513-0001	Savin Creek road, Gentle Annie	559
349-513-0013	Bennetts Track	2
349-514-0009	Limberlost Rd	1
349-515-0001	Even Steven	466
349-515-0007	Wanderlust PCL	44
350-501-0004	Bunyip Rd	176
350-501-0008	Chancellor Spur Track, Powelltown.	7
350-501-0009	Chancellor spur trk, Powelltown	60
350-502-0005	Head Creek track, Powelltown	98
350-502-0007	Head Creek Road, Powelltown	11
350-502-0009	Chancellor Spur Track, Powelltown	12
350-503-0001	Bunyip Road, Powelltown	193
350-503-0006	Upper Moomba	88
350-513-0002	East Beek Rd	255
350-513-0005	Fishers Track	593
350-513-002	East Beenak Rd	31
409-502-0014	Limberlost Road, Noojee	11
459-503-0003	Saxtons Road	21
460-501-0007	Rowleys Ridge Rd, Tanjil Bren	14

Coupe_Number	Coupe_Name	n
460-509-0006	Lemonwood	45
460-509-0010	Salt Shore	38
460-510-0007	Faith Creek	23
460-510-0033	Loose Change	27
460-510-0034	Bren Gun	1560
460-510-0035	Wispy	616
460-510-0038	Benefactor	8
460-510-0039	Tanjil River East Branch	12
460-510-0040	Peaches	30
460-511-0007	Land Down Under	103
460-511-0012	Be Good Johnny	31
461-502-0003	Ballantynes Road	343
461-502-0013	Over The Hedge-461-502-0013	23
461-503-0005	Castletown	219
461-503-0006	Glanworth	288
461-503-0009	Martel	692
461-504-0002	Regpas	76
461-504-0003	Cogc	72
461-505-0001	Dyers Winchline	12
461-505-0002	Dyers-Link-461-505-0002	36
461-505-0010	Dyers Traits	12
461-507-0015	Stony Creek Road	555
461-510-0003	TaylorMade	7
461-512-0012	Mistwood-461-512-0012	27
461-512-0020	Blackhall-461-512-0020	23
462-503-0006	Road 20	6
462-503-0009	Flataza	33
462-503-0011	Carters Hat	191
462-503-0031	Fetlock	3
462-504-0002	Gittens	472
462-504-0003	Loch River	42
462-504-0004	Skerrys Reach	1417
462-504-0005	Skerry Spice	43
462-504-0006	Very Skerry-462-504-0006	36
462-504-0007	Lake	12
462-504-0008	North Loch Road	2
462-504-0010	Crasters Keep	11
462-504-0011	Top Rd, Loch Valley.	106
462-504-0026	Litaize Road	251
462-505-0034	Kings Landing-462-505-0034	47
462-505-0036	Rosby	32
462-505-0037	Duskendale	43
462-505-0038	Lone Ranger Thinning	88
462-505-0039	Pyke	23
462-505-0040	Harlaw-462-505-0040	25
462-505-0041	Castle Black	39
462-505-0042	Eastwatch	90

Coupe_Number	Coupe_Name	n
462-506-0003	Tropical	171
462-506-0016	Antarctic-462-506-0016	7
462-506-0017	Teamwork	96
462-506-0019	'Brugha', Boundary Road, Noojee	7
462-506-0020	Pearse	125
462-506-0023	Sharp Point	24
462-507-0008	Estate	251
462-507-0011	Kika	110
462-507-0012	Christian Road, North	577
462-508-0006	Christian Break	20
462-508-0007	Christian Road	9
462-510-0026	Christian Road, South	608
462-511-0012	Bright Ideas	102
462-511-0013	Maxibon PCL	65
462-512-0002	'Backdoor', McCarthy Spur Rd, Noojee	2
462-512-0016	Quail	33
463-502-0014	Bennie Creek, Noojee	10
463-503-0017	Bostitch	2
463-503-0021	Davis road, Powelltown	17
463-503-0022	Davis Road, Powelltown	6
463-504-0013, 463-504-0015	Togo, Balto	37
463-504-0014	McCarthy Spur Road, Noojee	91
463-504-0015	Balto	26
463-504-00153	McCarthy Spur Rd, Noojee	13
463-504-0016	McCarthy Spur rd	12
463-505-0012	New Turkey Spur Track	208
463-505-0013	Lower Bennies rd, Noojee	22
463-505-0016	New Turkey track, Noojee	17
463_502_0014	Bennies Creek Rd	1
464-504-0017	Spencer Road	36
464-505-0044	Jesse James	29
464-506-0007	Silvertop Ridge Track	4
464-506-0018	Annex	13
464-506-0022	Bunyip Rd, Gentle Annie.	1
464-507-0008	Silvertop ridge track, Gentle Annie	35
465-503-0002	Bullock Creek	78
469-501-0006	Hazel Lavery/Limberlost Rd	1
469-502-0014	Limberlost Road, Noojee	141
469-502-0015	Davis Track, Piedmont	183
469-502-0019	Davis Road	1
483-501-0011	Buddies Quarry	15
483-501-0012	Buddys Track	11
483-501-0026	Ladder	83
483-501-0027	Spiral staircase	34
483-501-0035	South Face Rd	4
483-503-0003	Upper Stockpile	4

Coupe_Number	Coupe_Name	n
483-503-0006	Chopper	17
483-504-0011	Growlers gap	11
483-505-0017	Sailor Jerrys	3
561-507-0015	Bens Reward	17
-	Black Sands Road, Three Bridges	2
-	Forbidden Road	16
-	Roman Creek	94
-	Yellow brick road	1
	Total:	**20879**

APPENDIX 2 Complete list of parameters as they originally appear in VF with descriptions

Parameter	Description	Examples of values	Matching FW parameter
FID	Number identifier		
SurveyData	-	-	-
surveyDe_1	-	-	-
SurveyID	Survey Type	FPSP, Pre-Harvest, Post-Harvest	
packageNo	Survey Name	CHASS, FLORA	
responsibl		DELWP, VicForests, Third Party	
surveyProv		ARI, Austral Ecology, Ecology and Heritage Partners, WOTCH	
Surveyor	Name surveyor	B Drouyn, Michael Ryan	Personnel
surveyMeth		Fixed Transect, Sportlight survey, Opportunistic	
cameraID		1A, 1B, 2A, 2B, 2C	
photoFolde		Floraphotos	
coupeNumbe	Coupe Number	483-504-0011, 462-506-0019	Coupe_Number
locationDe	Coupe Name	Growlers gap; 'Brugha', Boundary Road, Noojee	Coupe_Name
dateReceiv	Date the observation was recorded in VF	18/11/2020, 29/01/2018	
startDate	Start date of survey	06/10/2020, 21/01/2018	
endDate	End date of survey	06/10/2020, 24/01/2018	
year	Year of survey	2020, 2018	
temperature	Temperature in °C	0, 13, 17, 23	
rainfall	Presence of rain at time of observation	0, 1	
wind	Wind strength	1, 2, 3	
cloudCover	Cloud cover %	0, 20, 40, 100	
humidity	Humidity %	0, 58, 64, 77, 86	
moonPhase	Phase of moon at time of observation	First quarter, half, third quarter, unknown,	
SurveyComm	Alternative coupe name	Basan, Blue Vein, Even Steven	
Observatio	-	-	
observat_1	Unique identifier	114677, 5431, 68181	PA_plot
dateObserv	Date of observation	06/10/2020, 21/01/2018, 02/10/2018	Date_survey

Parameter	Description	Examples of values	Matching FW parameter
referenceI	Reference ID	FPSP_4139, S123_2040	
Taxon_id	Taxon ID in VicForests system	502459	
Scientific	Scientific Name	*Persoonia arborea*	
commonName	Common Name	Tree Geebung	
observat_2	Observation method	Visual, Vocal, Media	
Status	Verification status	Not Verified, Awaiting Verification, Verified, Verified Duplicate	
photoID	Photo ID in VicForests system	401, 111111, BI007, DSC06716	
countNumbe	Number of individuals	1, 2, 3, 4, 5…	n_tree / plot_count
coordinate	Coordinate Reference System	GDA94, MGA54, MGA55, MGA56, VicGrid94	
observerEa	X-coordinate record	145.5607233, 145.6181929	lon_plot
observerNo	Y-coordinate record	-37.9678522, -37.9672357	lat_plot
distance	Transect distance	1, 2, 3, 4, 5…	
bearing	Aspect	0	
speciesEas	Easting	438023, 406096	
speciesNor	Northing	5805249, 5815773	
Observat_3	Observation notes	"Sexually mature. Approximately 15m"	Notes
Fpsp_resul	-	-	-
THREATENED	Conservation Status	Y	
VBAStatus	Status in Victorian Biodiversity Atlas	Not Applicable, Not submitted, Submitted	
ESRI_OID	Shape identifier in GID	510, 781, 227, 1071	

APPENDIX 3 List of coupes, some corresponding to VicForests coupes, with Tree Geebung individuals that were used for research by University of Melbourne surveys (UM).

Coupe Name	n Tree Geebung individuals	Nature of Research
AB2*	1	CORE
AB3*	4	CORE
Ada*	8	CORE
Big Creek Road*	2	CORE
Billowcase	3	CORE
Blacksands Road	2	CORE
Blue Vein	1	CORE
Bren Gun	9	CORE
Brittannia Creek	5	CORE
Bunyip_BUER*	3	CORE
BVA_UH60*	4	CORE
Fishernak	27	PLOT
Ginger Cat	91	PLOT
Jumping Jack Flash	6	CORE
Kobiolke Rd*	1	CORE
LE_REG2*	2	CORE
LM2*	1	CORE
MIRM3*	3	CORE
Mozambique	107	PLOT
OW_SW_21*	3	CORE
PA71*	1	CORE
PA75*	1	CORE
Pats Corner	22	CORE
Pioneer Creek Road*	1	CORE
SK_MA*	2	CORE
Skerry's Reach	476	PLOT
Stoney Creek Road	13	CORE
Tanjil Bren	2	CORE
Teamwork	3	CORE
Toorongo Road*	9	CORE
WF7*	1	CORE
WF8*	1	CORE
Wispy	2	CORE
Woorley Track	1	CORE
YSK	1	CORE

*indicates the location is a research site and is not part of the VicForests coupe system (and therefore, does not contain a coupe ID), and was named by researchers from the University of Melbourne itself

APPENDIX 4 Complete list of parameters from UM which were classified as CORE, with matching parameter in FW

UM parameter	**Matching FW parameter**
Site	PA_Plot
Latitude	Lat
Longitude	Lon
Elevation(m)	Elev_m
Slope(degrees)	Slope_deg
Plot_radius	Plot_radius
DBH_cm	DBH_cm
Height_m	hgt_m
Location	-
Date	Date_Survey
Notes	-
Person	Personnel
Coupe	CoupeNumbe

APPENDIX 5 Complete list of parameters from UM which were classified as PLOT, with matching parameter in FW

UM Parameter	Matching FW parameter
Coupe	CoupeName
Date	Date_survey
Personnel	Personnel
Latitude	Lat
Longitude	Lon
Elevation_m	Elev_m
Retained_Tree_ID	PA_Plot
DBH_cm	DBH_cm
Height_m	Hgt_m
Basal_Diam_mm	Dbase_cm (Basal_Diam_mm converted to cm by multiplying with 0.1)
Live	-
Dead	-
Standing	pushed
Fallen	pushed
Flowering	Flower
Fruiting	Fruit
LAI_height_m	-
LAI_photos	
General_photos	
Burnt/Unburnt	Fire_dam
Soil_Disturbance_Class	Soil_dist_Class
Dominant_Veg	-
Height_cm	-
Cover_%	-
Notes	-

APPENDIX 6 Soil Disturbance Class Descriptors (source: VicForests, Regeneration Surveys Instruction, Feb 2017, Version 2.0).

Soil Disturbance Class	Description
LL, Log Landing	Substantial disturbance and subsoil exposure unless corded and matted
ST, Snig Track	Primary of Secondary Snig Track. Major snig track with substantial compaction and generally subsoil exposure
SD, Subsoil Disturbance	Exposure of subsoil by machinery or from pushing trees
TD, Top soil disturbed	General logging area where there has been disturbance from harvesting or snigging but no subsoil disturbance
LD, Litter disturbed	Litter layer disturbed or partially removed
UD, Undisturbed	No disturbance by machinery but may be burnt

APPENDIX 7 Overview of FW parameters used to record data from the field surveys. All data from VF and UM are merged into FW according to these parameters, to form the final database TG.

Parameter	Short name	Unit / Classes	Degree of accuracy	Description	Specificity of parameter
Date survey	Date_survey			Date at which measurements were conducted	All plots
Personnel	Personnel			Initials of the personnel that conducted the measurements	All plots
Coupe Number	CoupeNumbe			Unique 10-number code for a coupe in the format xxx-xxx-xxxx assigned by VicForests	All plots
Coupe Name	CoupeName			Name of the coupe to which the plot belongs	All plots
Plot ID	PA_Plot			Name of the plot	All plots
Type	Type	Tree or Seedling	-	Type of the plot; whether it is a tree plot or a seedling plot	All plots
Diameter class	Diam_class	"Individual" or "Multiple leaders"	-	To denote whether diameter measurements are from separate trees/seedlings or from the same tree/seedling	All tree plots, all seedling plots where diameters are measured
Size class	Size_class	S M L	-	S = Small (<0.25 m height), M = Medium (0.25 m≤ 1 m height), L = Large (1 m< 4 m height)	All seedling plots
DBH	DBH_cm	cm	1 decimal for trees and seedlings	Diameter over bark at breast height (1.3 m)	All individual trees and seedlings with a minimum height of 1.66 m
Height	Hgt_m	m	1 decimal for trees 2 decimals for seedlings	Vertical height of the plant from the base to the tallest point in the canopy	All individual trees and a maximum of five representative seedlings

Parameter	Short name	Unit / Classes	Degree of accuracy	Description	Specificity of parameter
					per size class for one plot
Basal diameter	Dbase_cm	cm	1 decimal for trees and seedlings	Diameter around the base of the plant	Every seedling for which the height was measured in Dom Dom Road, Estate, and Tropical. Other coupes, random seedlings with a minimum height of 2 m.
Plot count	Plot_count	-		Number of individuals within the radius of the plot centre (excluding the central tree where present)	All plots
Plot count class	Plot_count_clas s	Tree or Seedling	-	Class of individuals within the radius of the plot centre	All plots
Plot radius	Plot_radius_m	m	0 decimals	Radius of the plot from the centre, standard 3 m	All plots
Nearby count	Nearby_count	-	-	Number of individuals outside the radius of the plot centre (excluding the central tree where present), but within the maximum radius of 15 m	All plots
Nearby count class	Nearby_count_ class	Tree or Seedling	-	Class of individuals outside the radius of the plot centre, but within the maximum radius of 15 m	All plots
Nearby radius	Nearby_radius _m	m	0 decimals	Radius of the extended plot to include individuals	All plots

Parameter	Short name	Unit / Classes	Degree of accuracy	Description	Specificity of parameter
				outside the 3 m plot, maximum 15 m	
Flower	Flower	1/0	-	Presence or absence of flowers	All trees
Fruit	Fruit	1/0	-	Presence or absence of fruit	All trees
Fire damage	Fire_dam	1/0	-	Presence or absence of fire damage (fire scar/scorch)	All trees
Deer damage	Deer_dam	1/0	-	Presence or absence of damage from deer rubbing	All trees
Herbivory	Herbivory	1/0	-	Presence or absence of damage from herbivore browsing	All trees
Damage other	Dmg_other	1/0	-	Presence or absence of damage from an unknown source	All trees
Dead top	Dead_top	1/0	-	Presence or absence of a dead or broken top	All trees
Snapped	snap	1/0	-	Presence or absence of a snapped main stem	All trees
Lean	Lean	1/0	-	Presence or absence of a lean in the main stem	All trees
Pushed over	pushed	1/0	-	Presence or absence of a decumbent main stem (as a result of being pushed over from harvesting activity)	All trees
Soil type disturbance	Soil_dist_class	Undisturbed (UD) Litter disturbed (LD) Topsoil disturbed (TD) Subsoil disturbed (SD)	-	Classification of the soil disturbance in a plot according to Soil Disturbance Class Descriptors of VicForests (see Appendix 6)	All plots

Parameter	Short name	Unit / Classes	Degree of accuracy	Description	Specificity of parameter
		Snig Track (ST) Log Landing (LL)			
Elevation	Elev_m	m	0 decimals	Elevation of the plot centre above sea level	All plots
Slope	Slope_deg	degrees (°)	0 decimals	Tangent of the plot terrain angle to the horizontal, from 0 to 90	All plots
Aspect	Asp_deg	degrees (°)	0 decimals	Azimuth that the plot terrain faces, from 0 to 359	All plots
Leaf Area Index (LAI)	LAI	-	1 decimal	Leaf area per unit ground surface area	All tree plots
Longitude	Lon	degrees (°)		X-coordinate in WGS84 Coordinate Reference System	All plots
Latitude	Lat	degrees (°)		Y-coordinate in WGS84 Coordinate Reference System	All plots

APPENDIX 8. Recruitment of Tree Geebung in all FW coupes (except Christian Road, South; Jumping Jack Flash, and Mozambique – Figures 20, 21 and 22 respectively) and all UM sites which corresponded with coupes from VicForests.

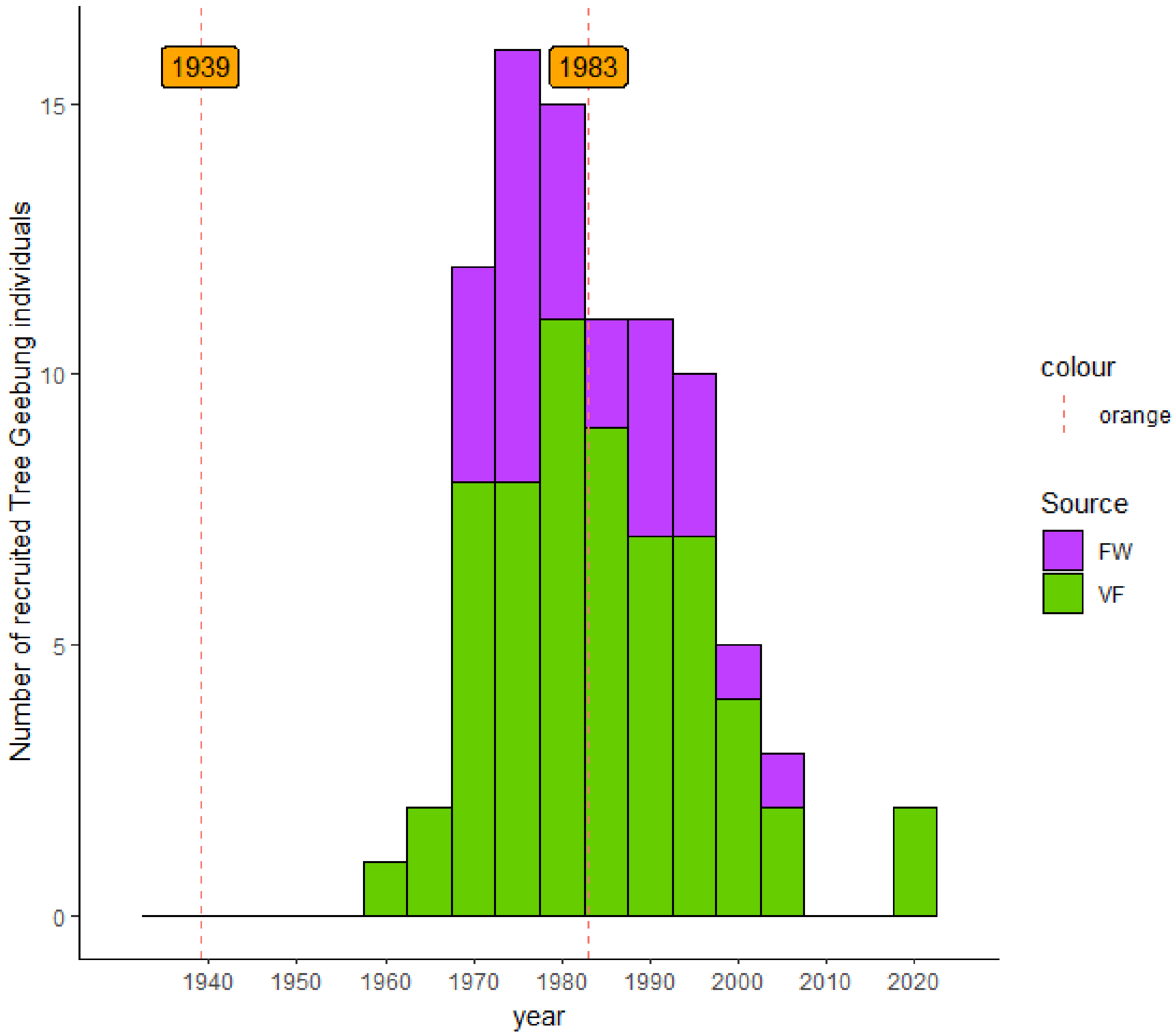

Figure S8a. Recruitment of Tree Geebung in Bluey Creek Track (345-511-0005) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and the 1983 wildfire.

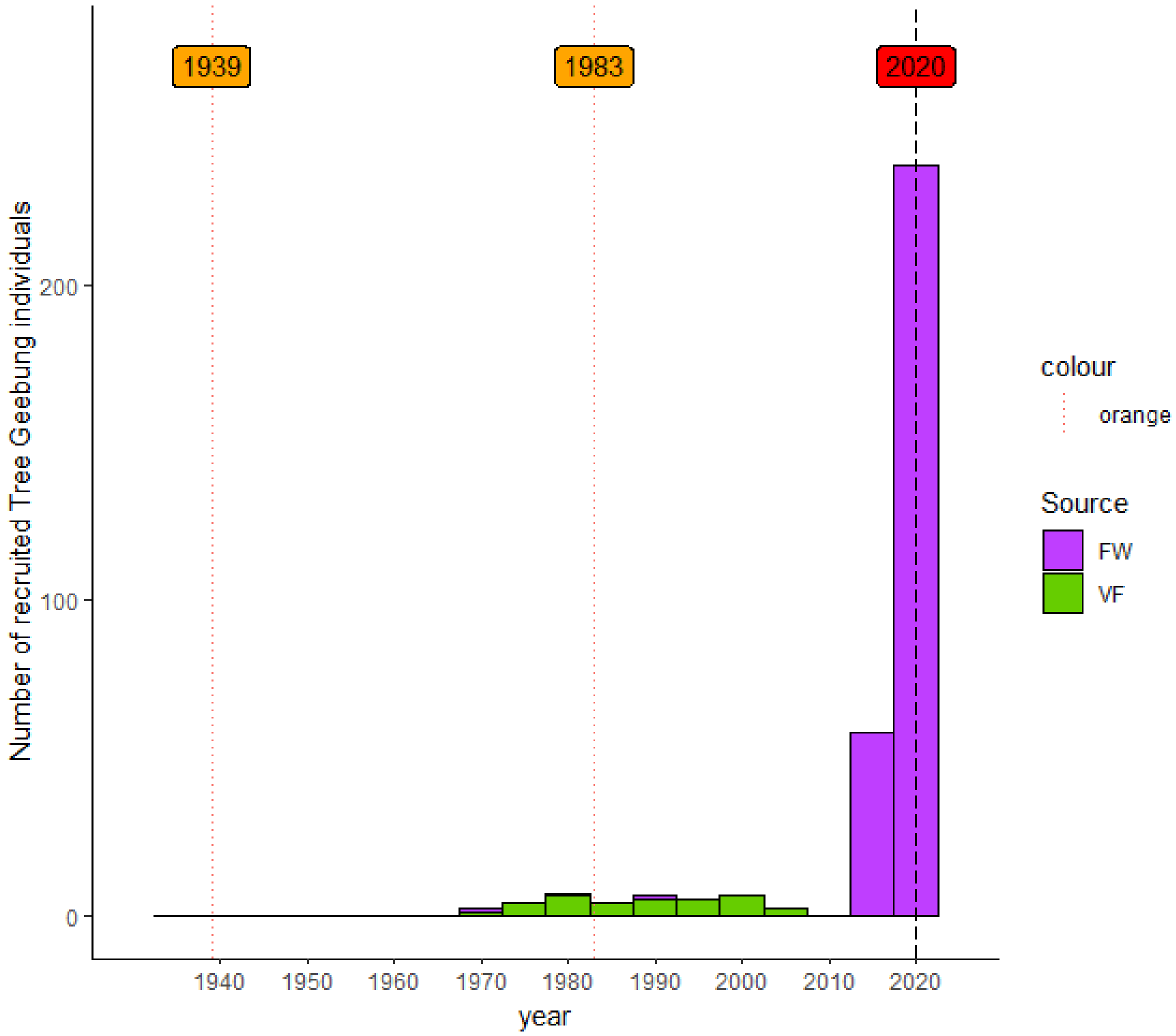

Figure S8b. Recruitment of Tree Geebung in Dragon Ball Z (345-513-0001) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, the 1983 wildfire, and a planned burn following harvest in 2020.

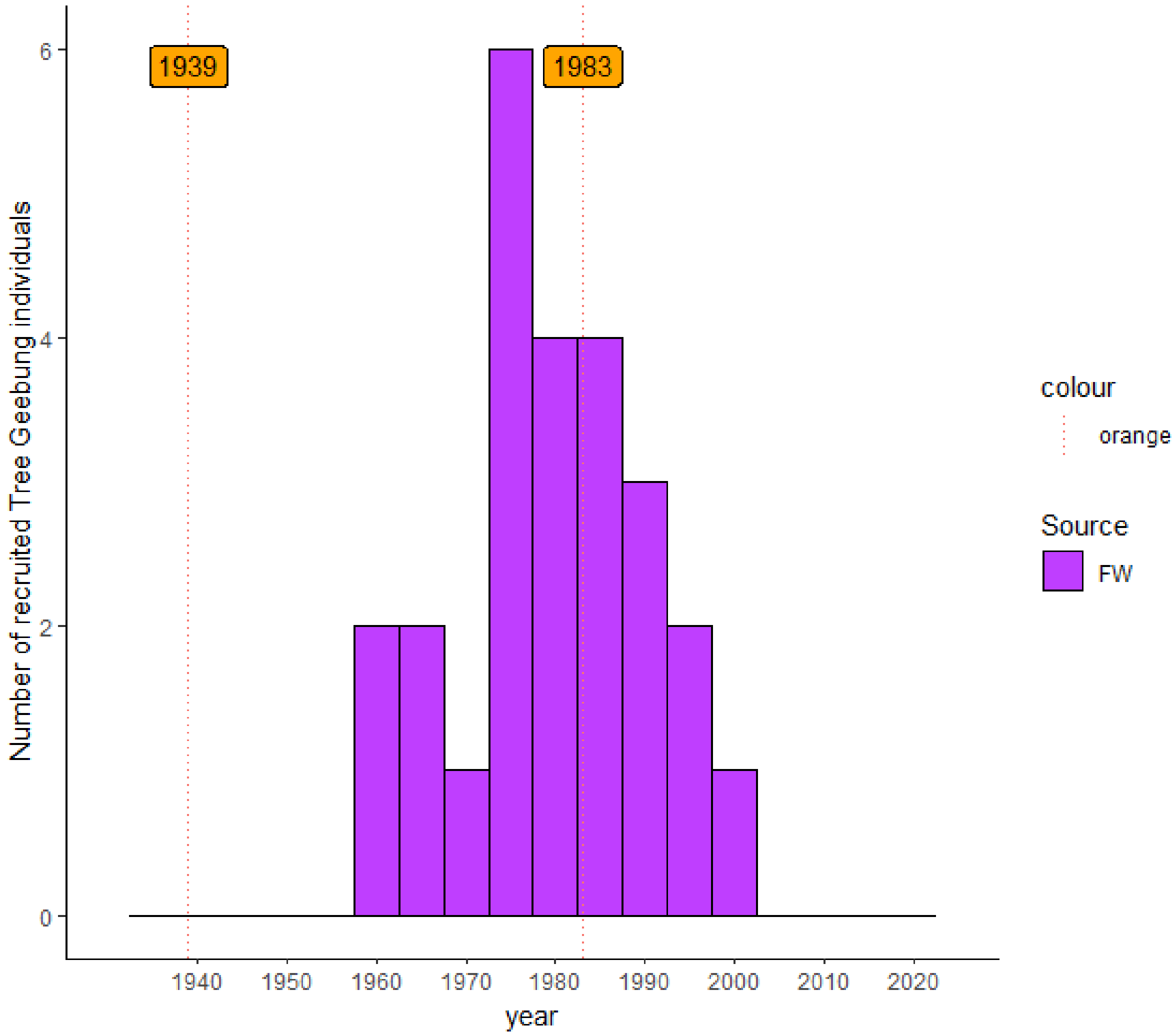

Figure S8c. Recruitment of Tree Geebung in Smythe Creek RDI (345-522-0002) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and the 1983 wildfire.

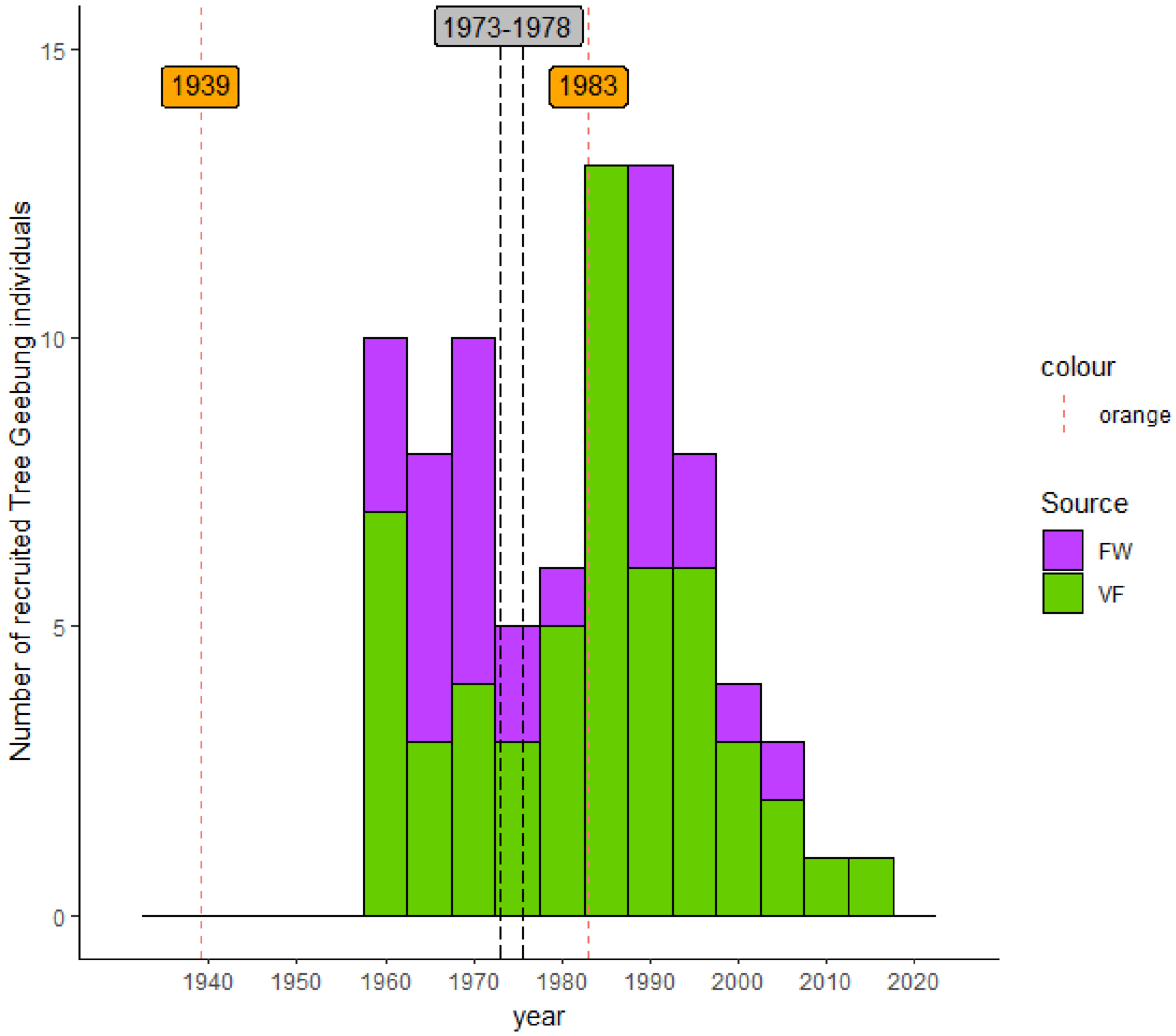

Figure S8d. Recruitment of Tree Geebung in Qantas (345-513-0008) and Liittle Block (345-507-0005) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, the 1983 wildfire, and a harvest between 1973 and 1978.

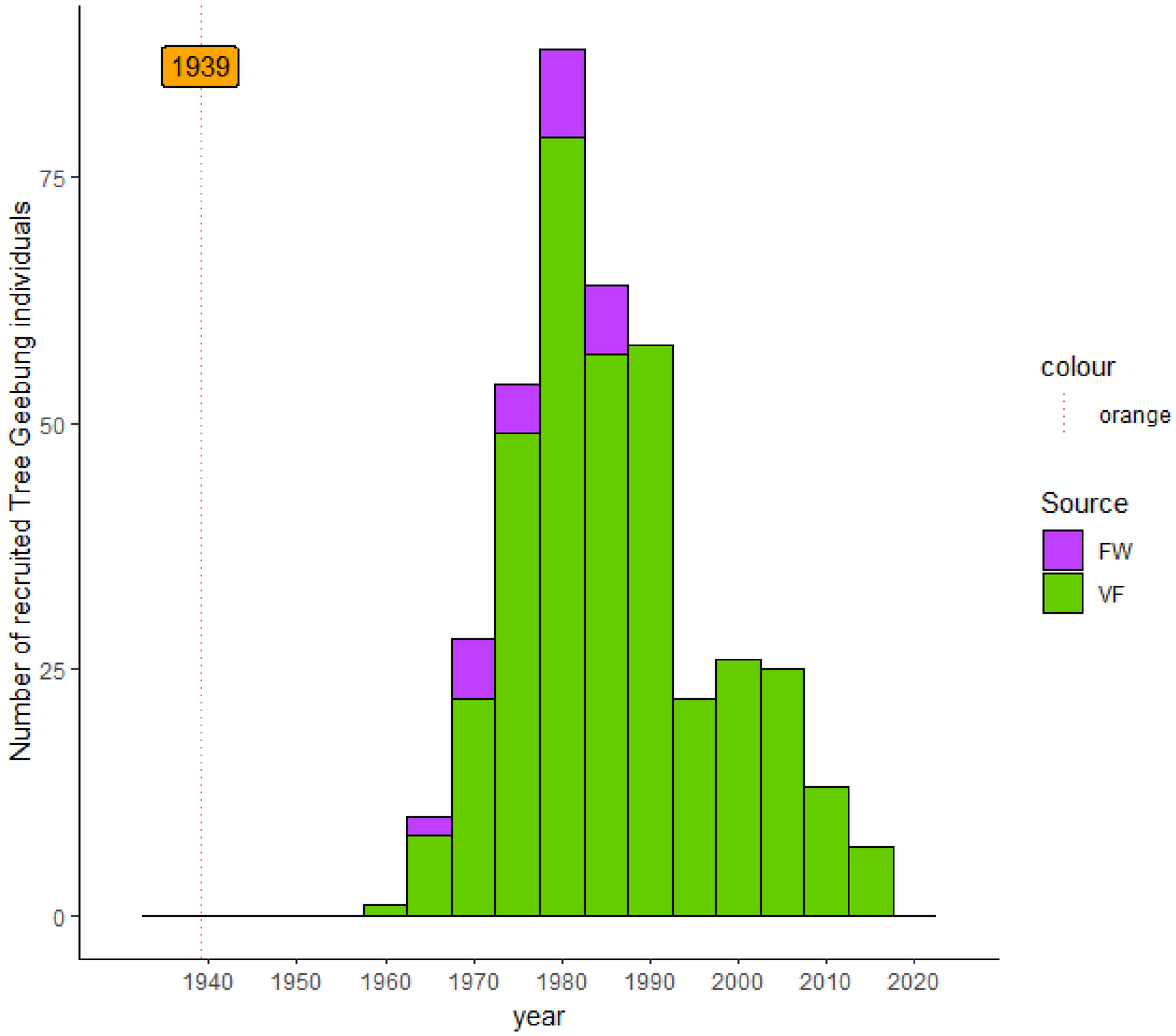

Figure S8e. Recruitment of Tree Geebung in Christian Road, South (462-510-0026) overlaid with disturbance history from 1930 to 2022. The disturbance event was the 1939 wildfire.

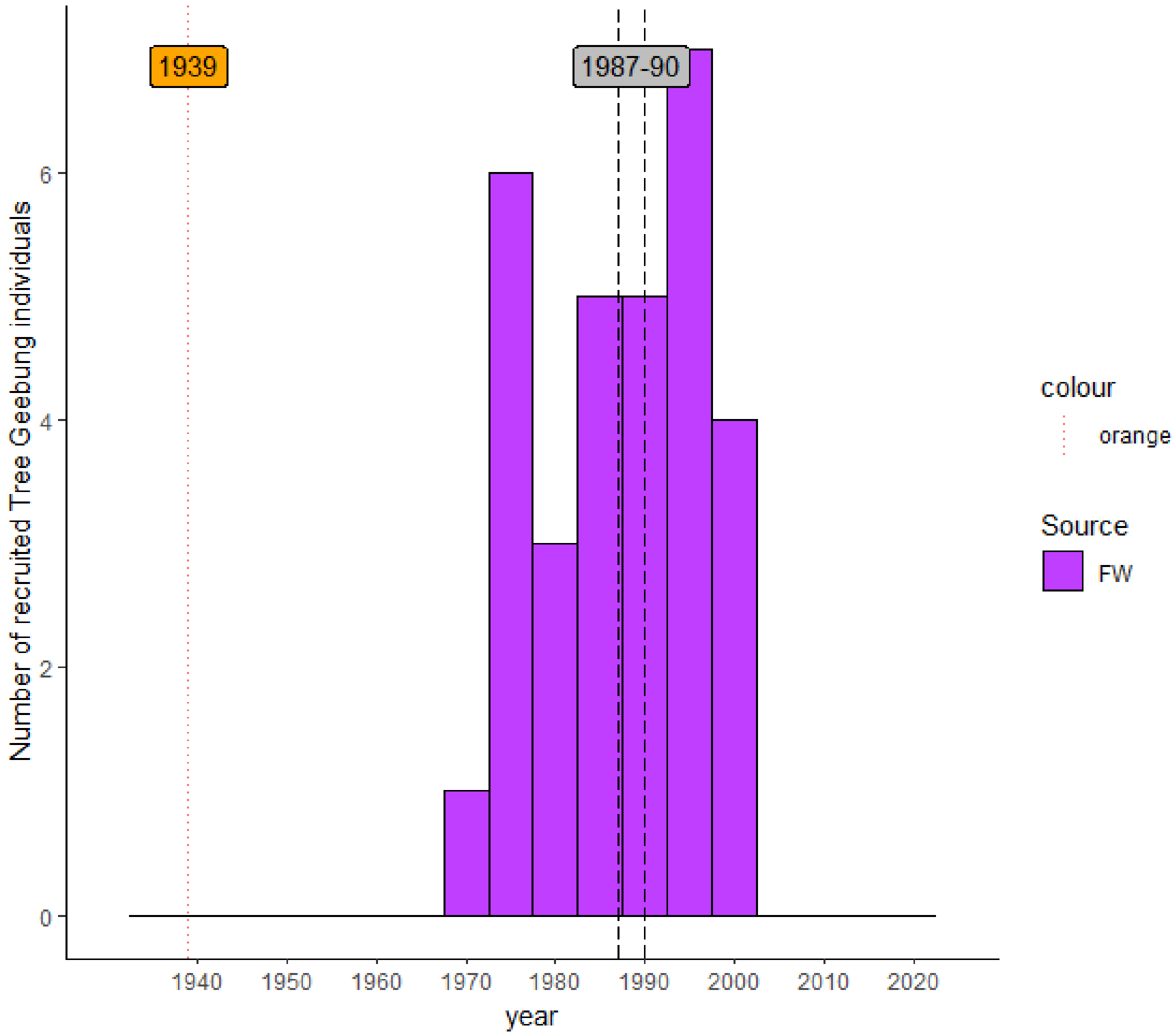

Figure S8f. Recruitment of Tree Geebung in Pyke (462-505-0039), Harlaw (462-505-0040) and Eastwatch (462-505-0042) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, and a harvest between 1987 and 1990.

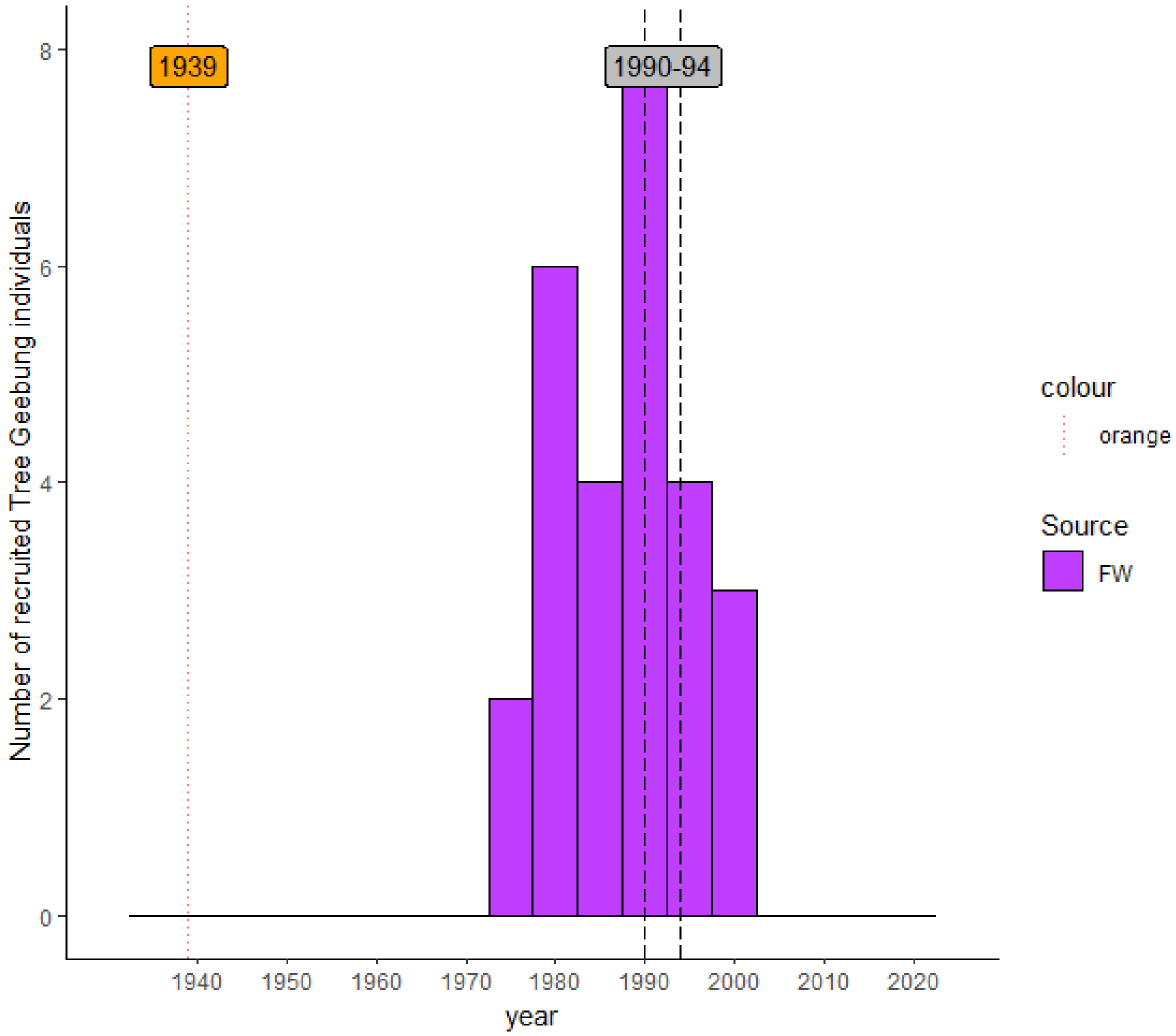

Figure S8g. Recruitment of Tree Geebung in Lone Ranger Thinning (462-505-0038) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, and a harvest between 1990 and 1994.

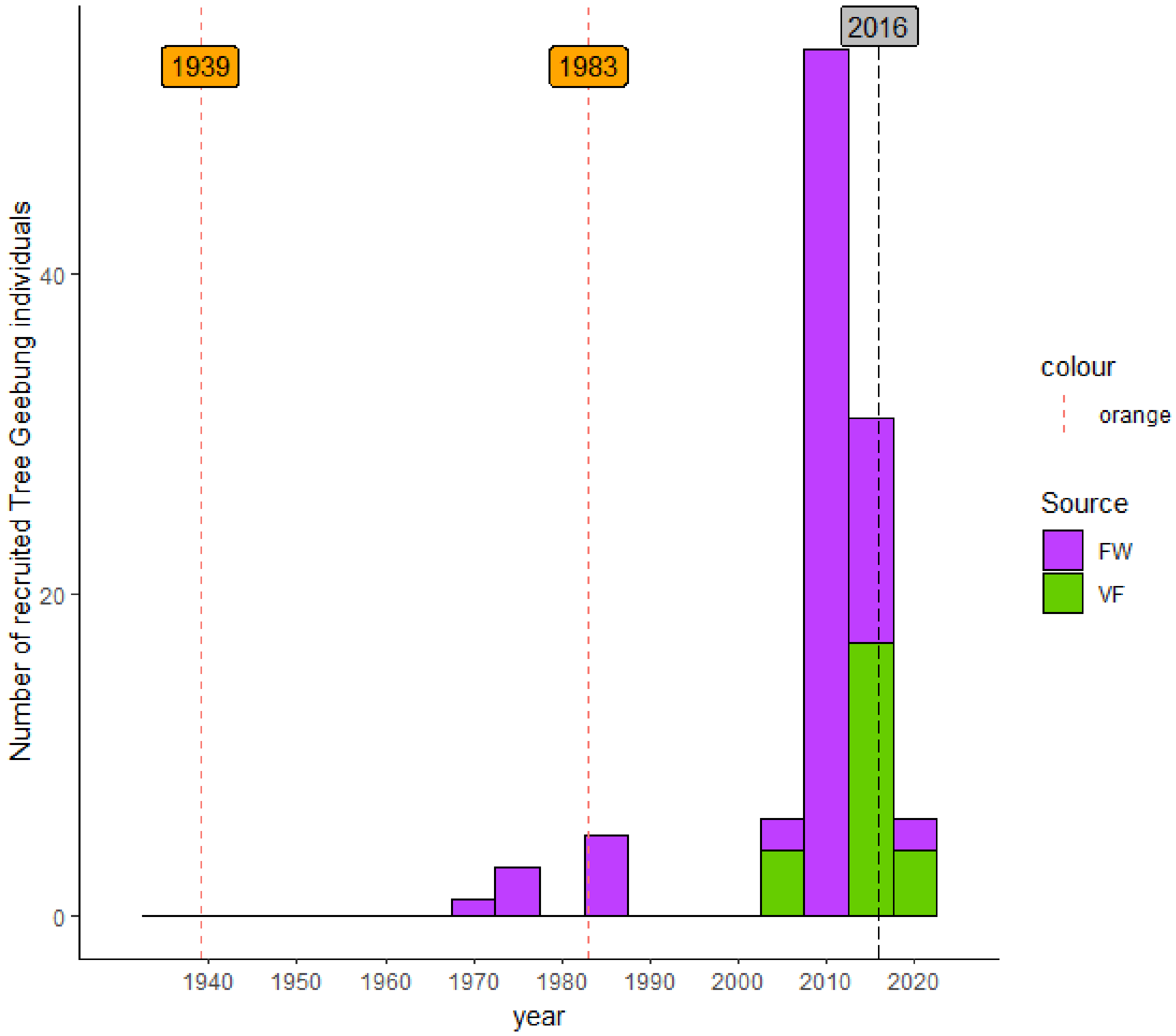

Figure S8h. Recruitment of Tree Geebung in Opposite Fitzy's (345-506-0004) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, the 1983 wildfire, and a harvest in 2016.

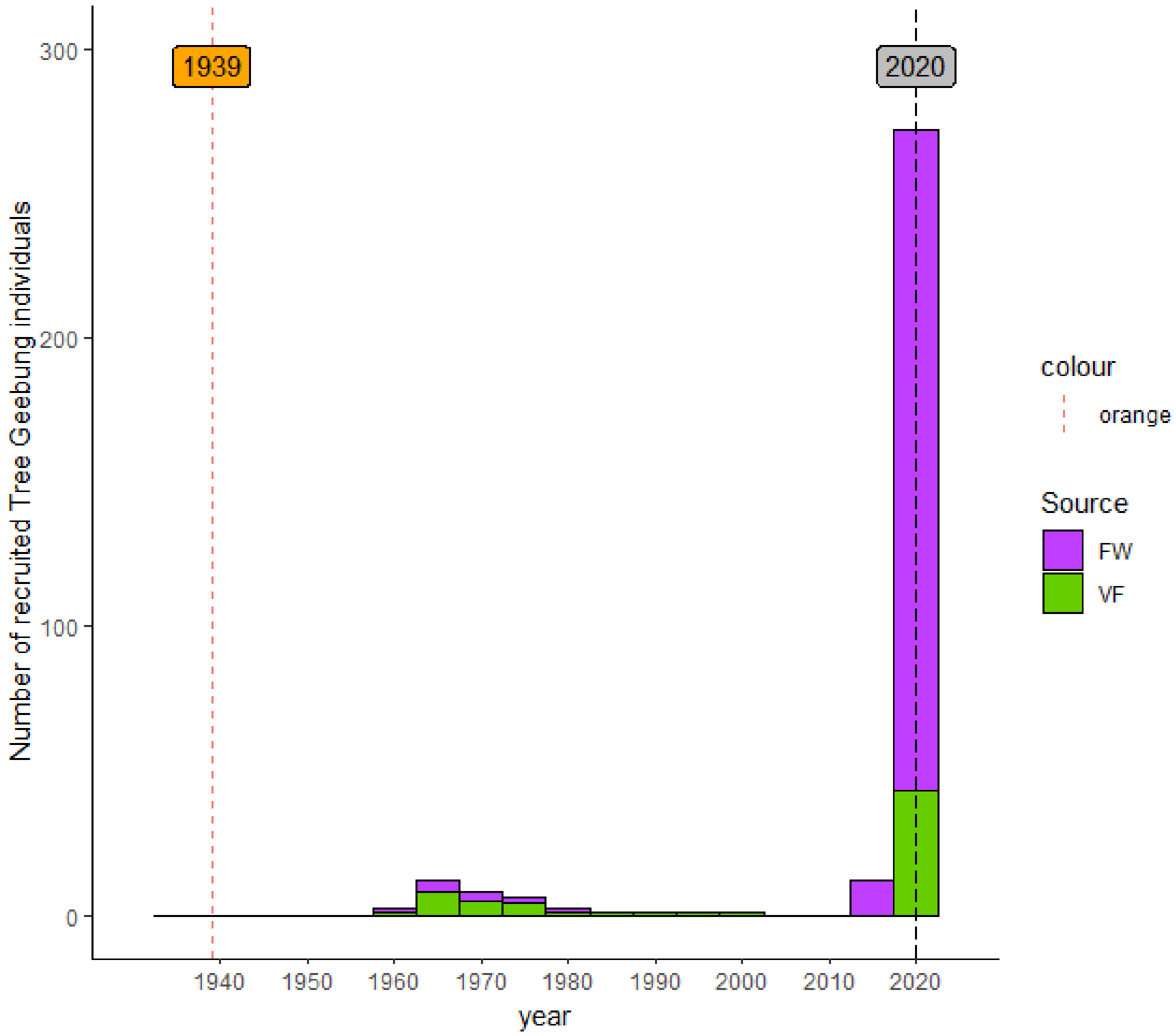

Figure S8i. Recruitment of Tree Geebung in Even Steven (349-515-0001) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, and a harvest in 2020.

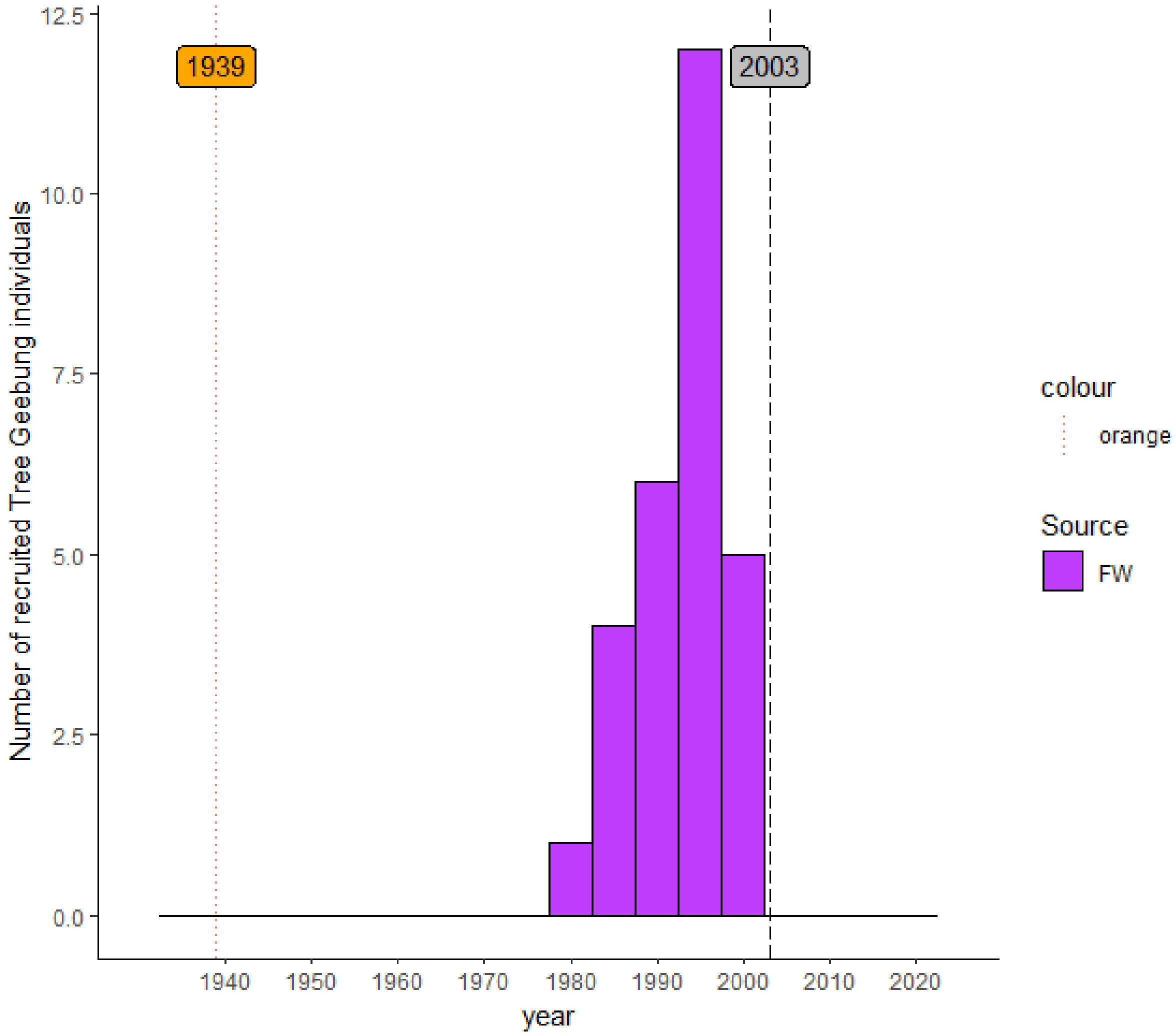

Figure S8j. Recruitment of Tree Geebung in Columbus RDC (349-510-0005) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, and a harvest in 2003.

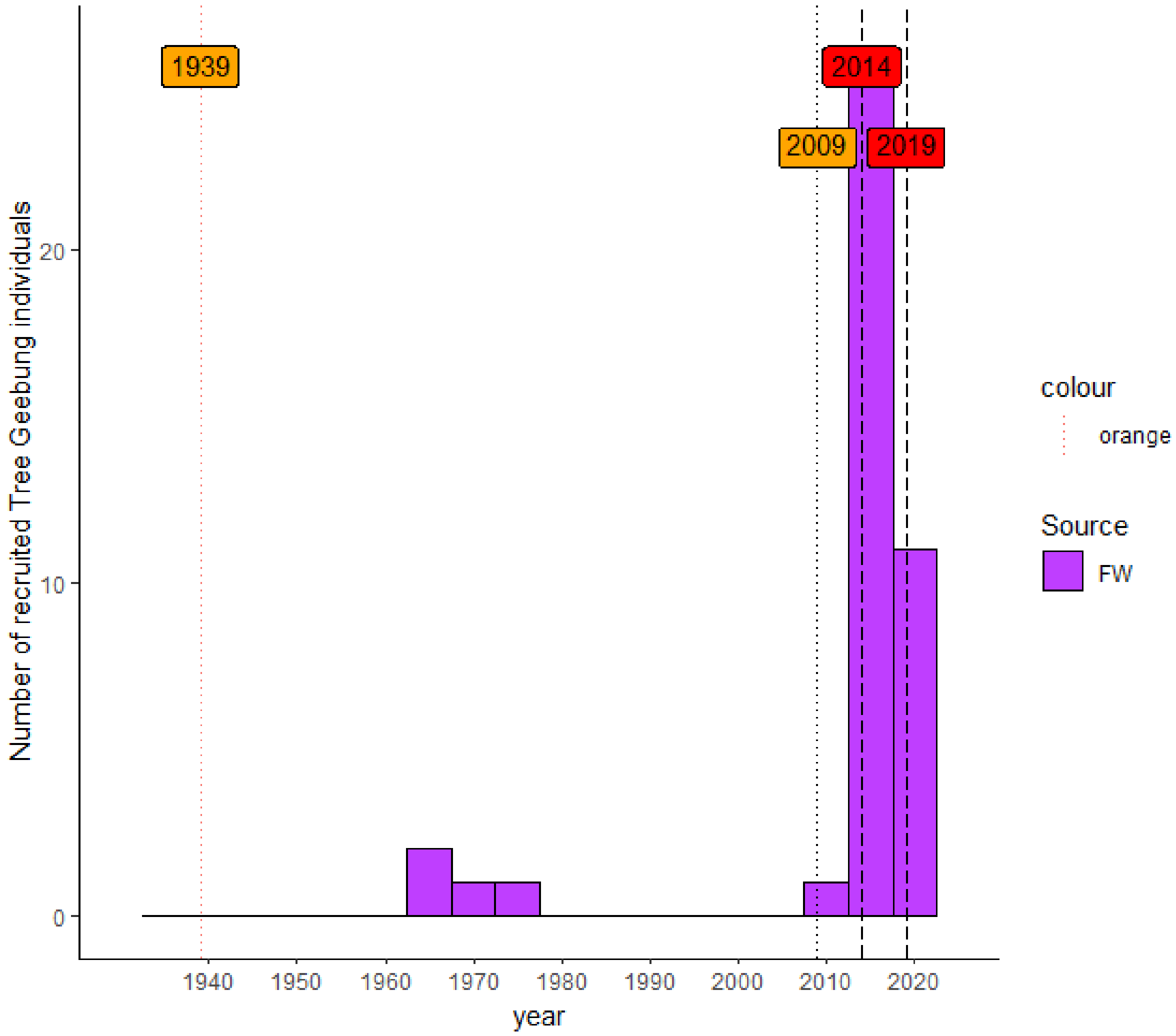

Figure S8k. Recruitment of Tree Geebung in East Beenak Road (349-513-0002) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, the 2009 wildfire, a planned burn in 2014, and a planned burn following harvest in 2019.

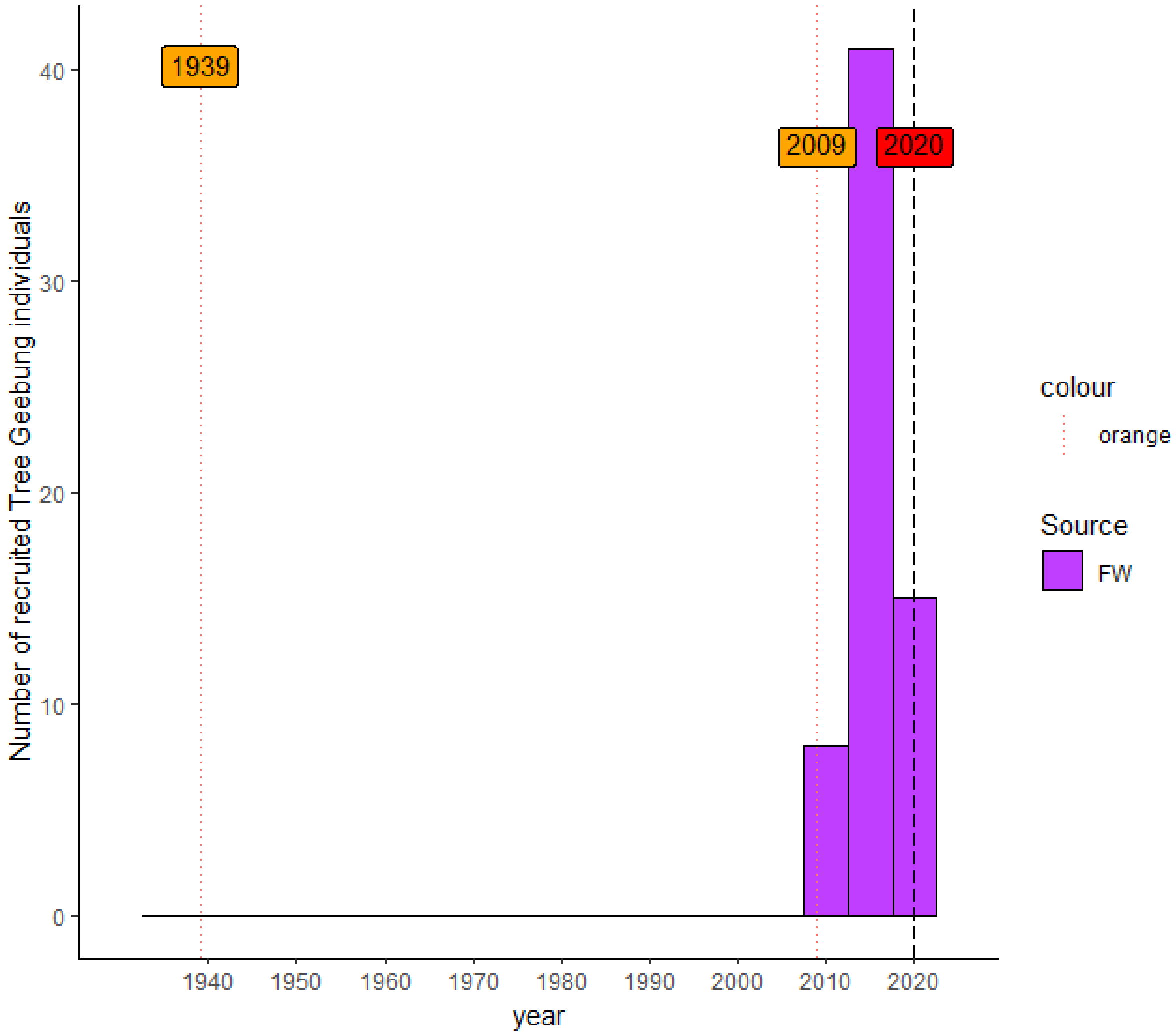

Figure S8l. Recruitment of Tree Geebung in Bullock Creek (465-503-0002) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, the 2009 wildfire, and a planned burn following harvest in 2020.

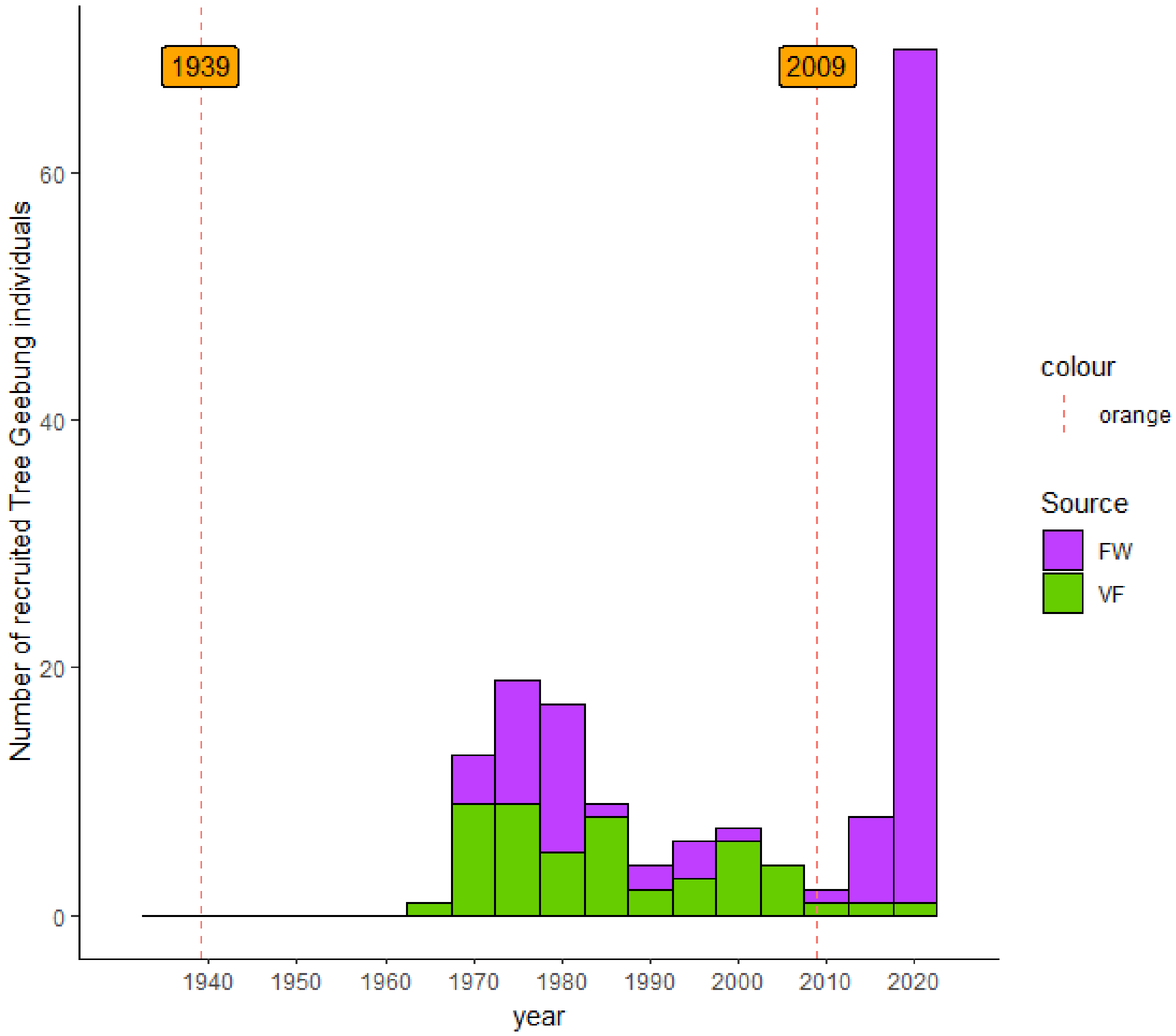

Figure S8m. Recruitment of Tree Geebung in Dom Dom Road (309-502-0008) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and the 2009 wildfire.

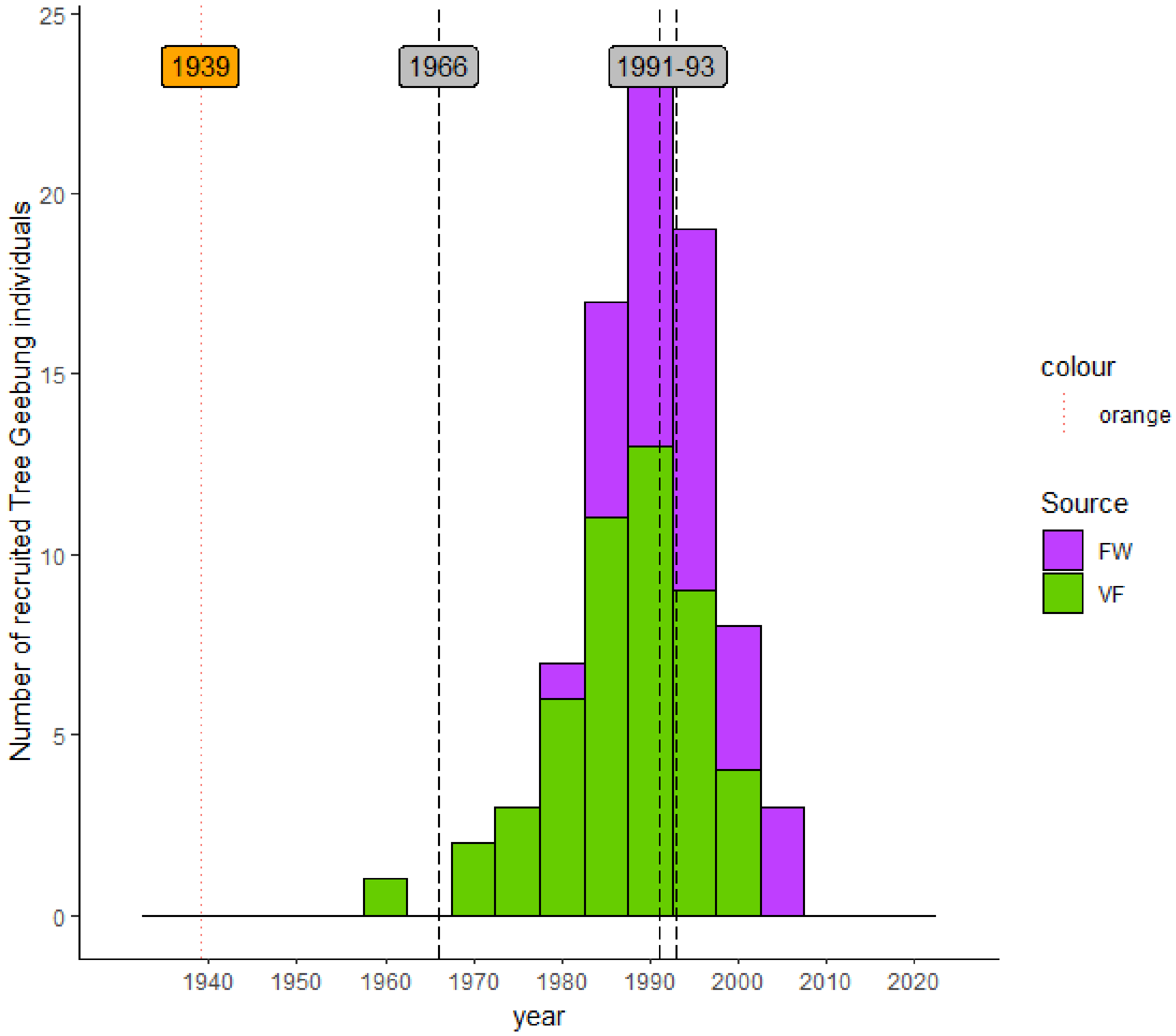

Figure S8n. Recruitment of Tree Geebung in Sylvia Creek Road (297-542-0001/297-542-0002) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, a harvest in 1966, and a harvest between 1991 and 1993.

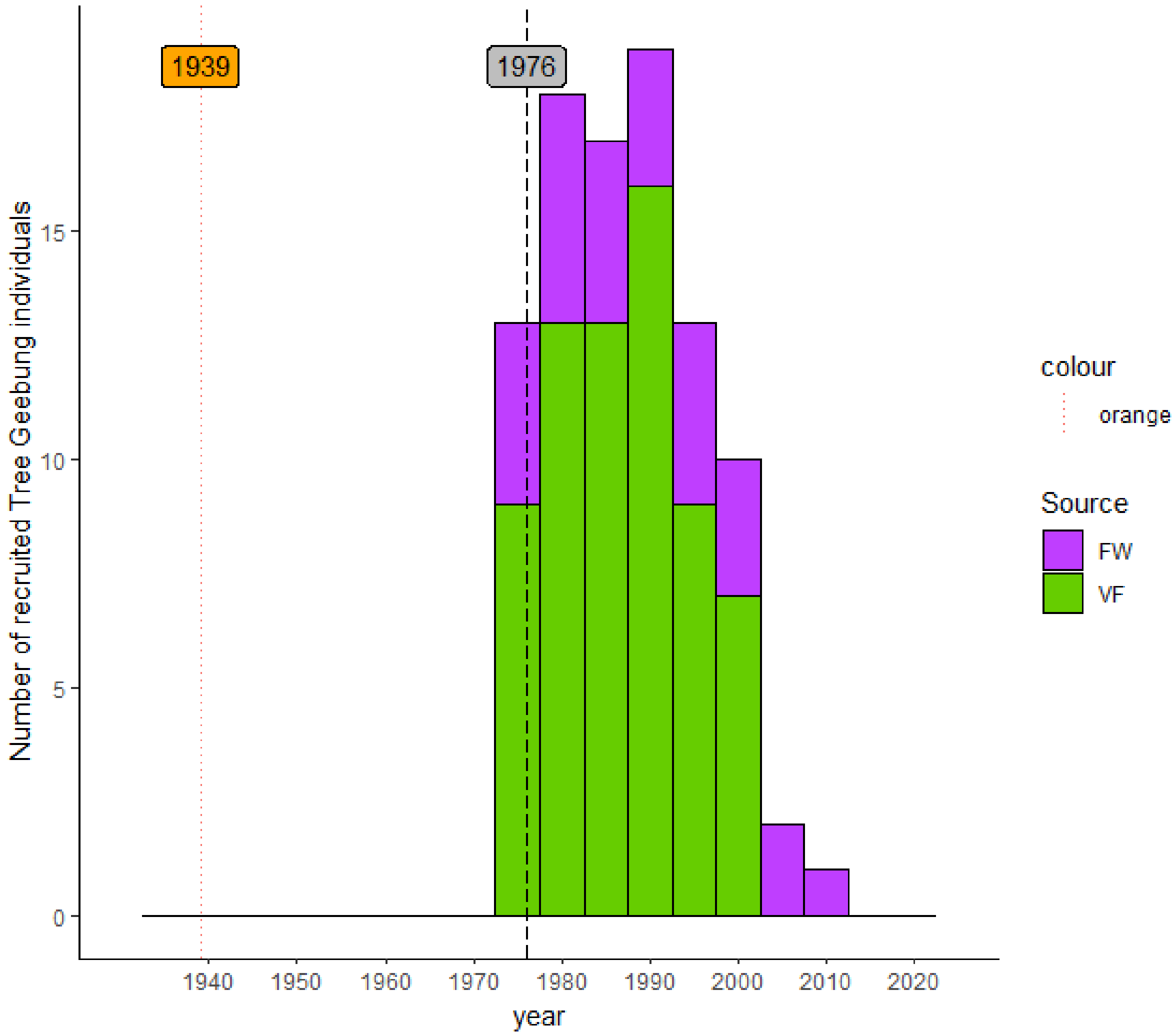

Figure S8o. Recruitment of Tree Geebung in Yellowdindi Road (300-503-0008) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and harvest in 1976.

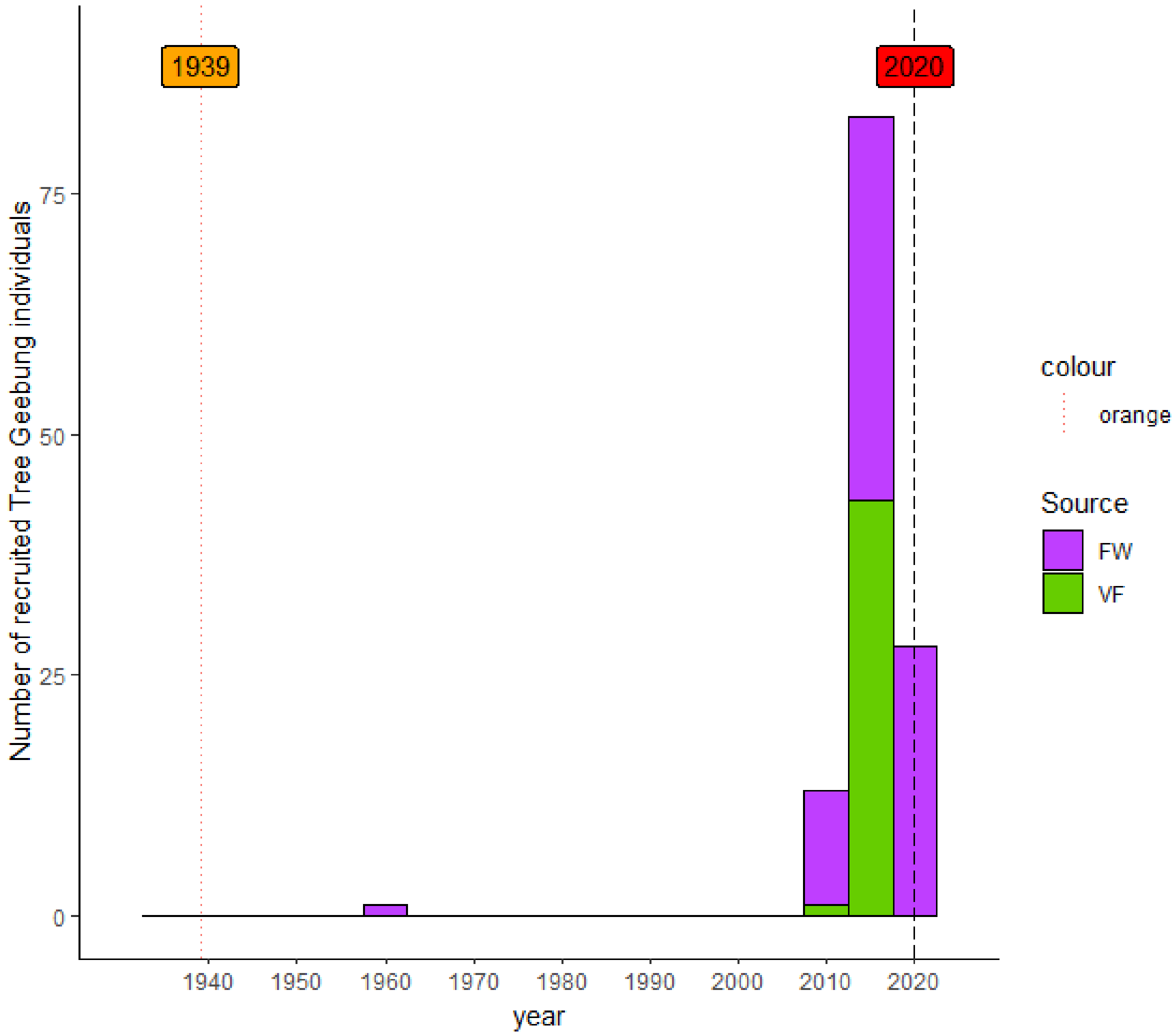

Figure S8p. Recruitment of Tree Geebung in Tropical (462-506-0003) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire, a planned burn in 2016, and a planned burn following harvest in 2020.

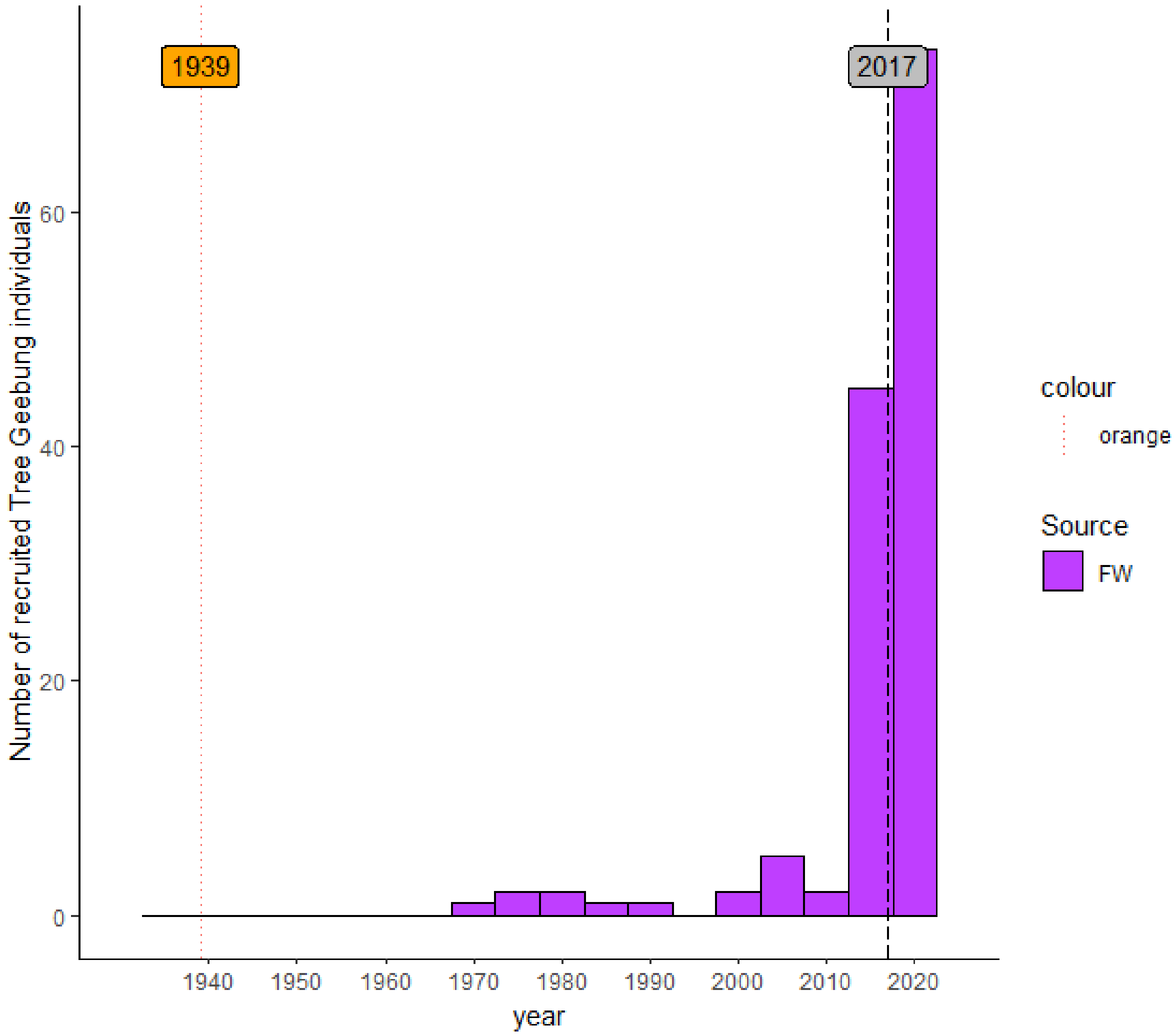

Figure S8q. Recruitment of Tree Geebung in Estate (462-507-0008) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and harvest in 2017.

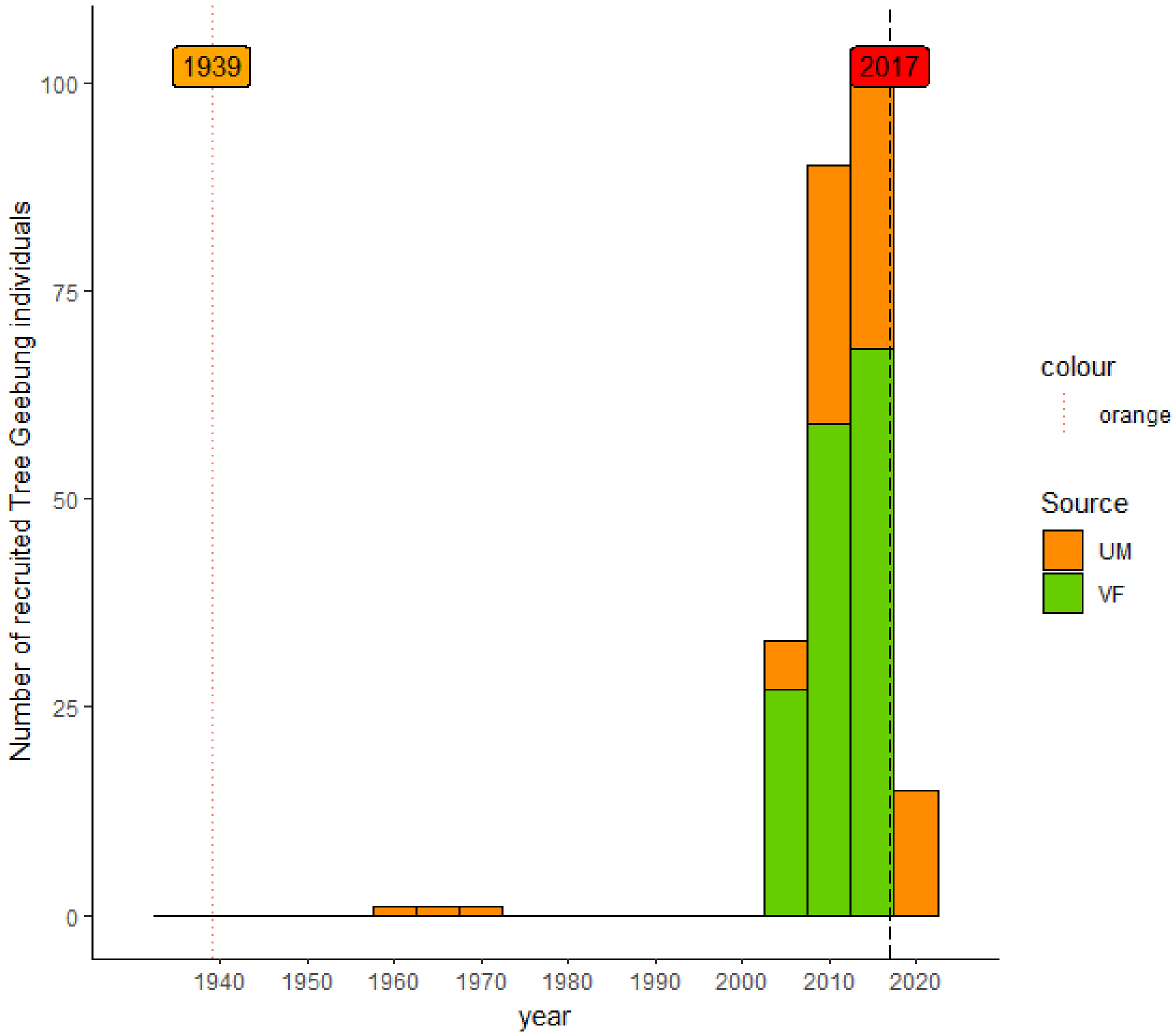

Figure S8r. Recruitment of Tree Geebung in Ginger Cat (344-509-0009) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and a planned burn following harvest in 2017.

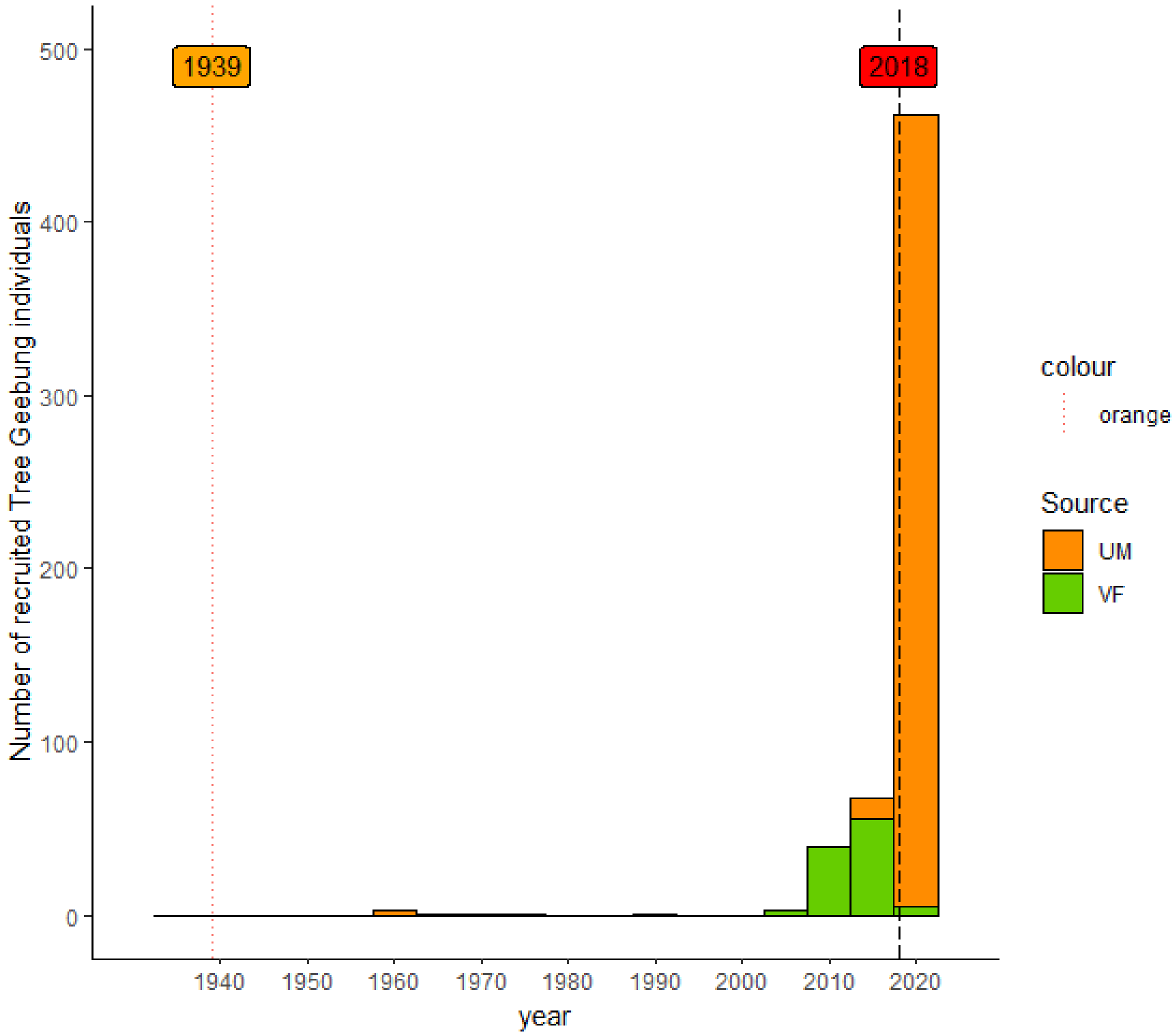

Figure S8s. Recruitment of Tree Geebung in Skerry's Reach (462-504-0004) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and harvest in 2018.

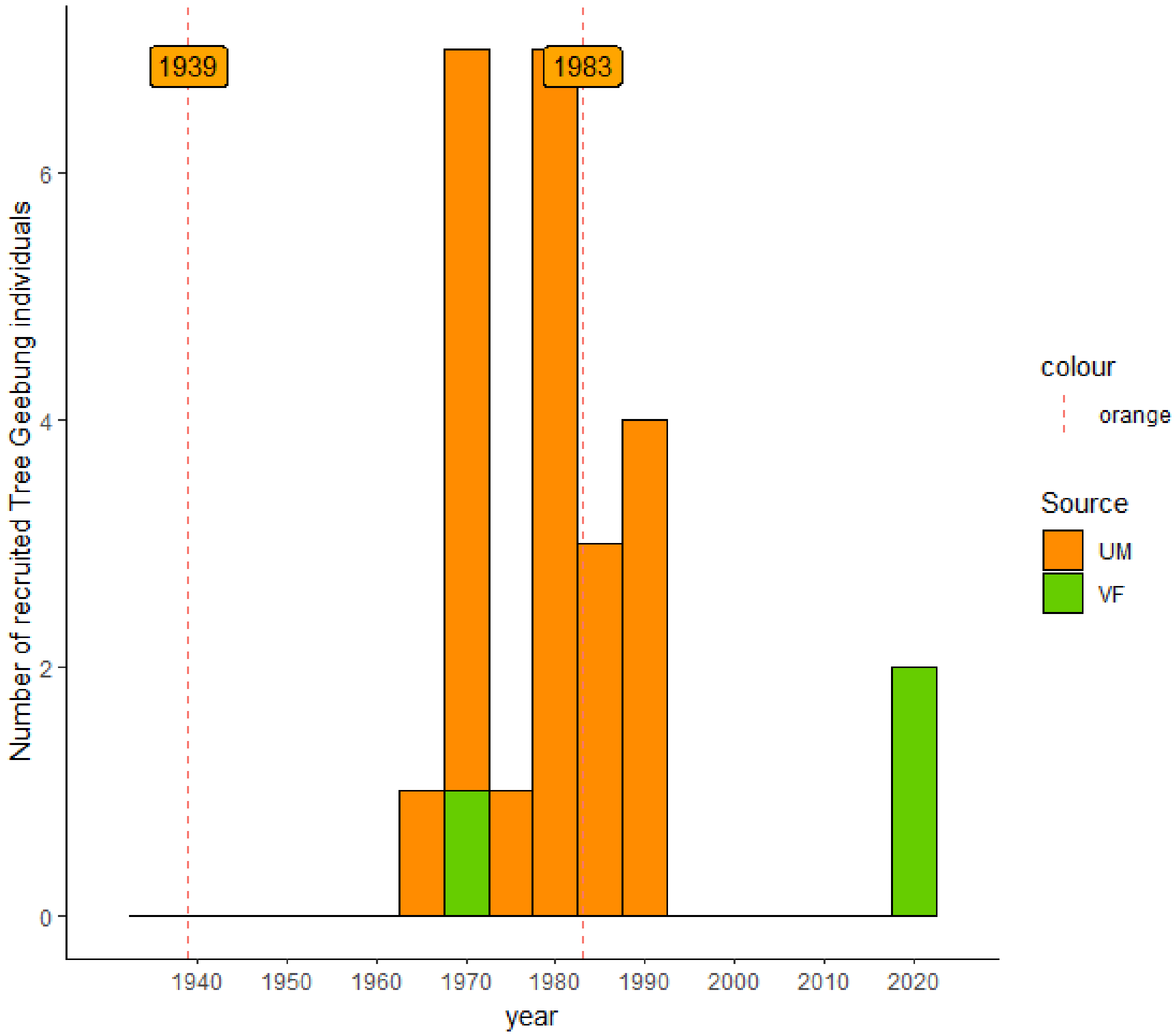

Figure S8t. Recruitment of Tree Geebung in Pat's Corner (345-511-0004) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and the 1983 wildfire.

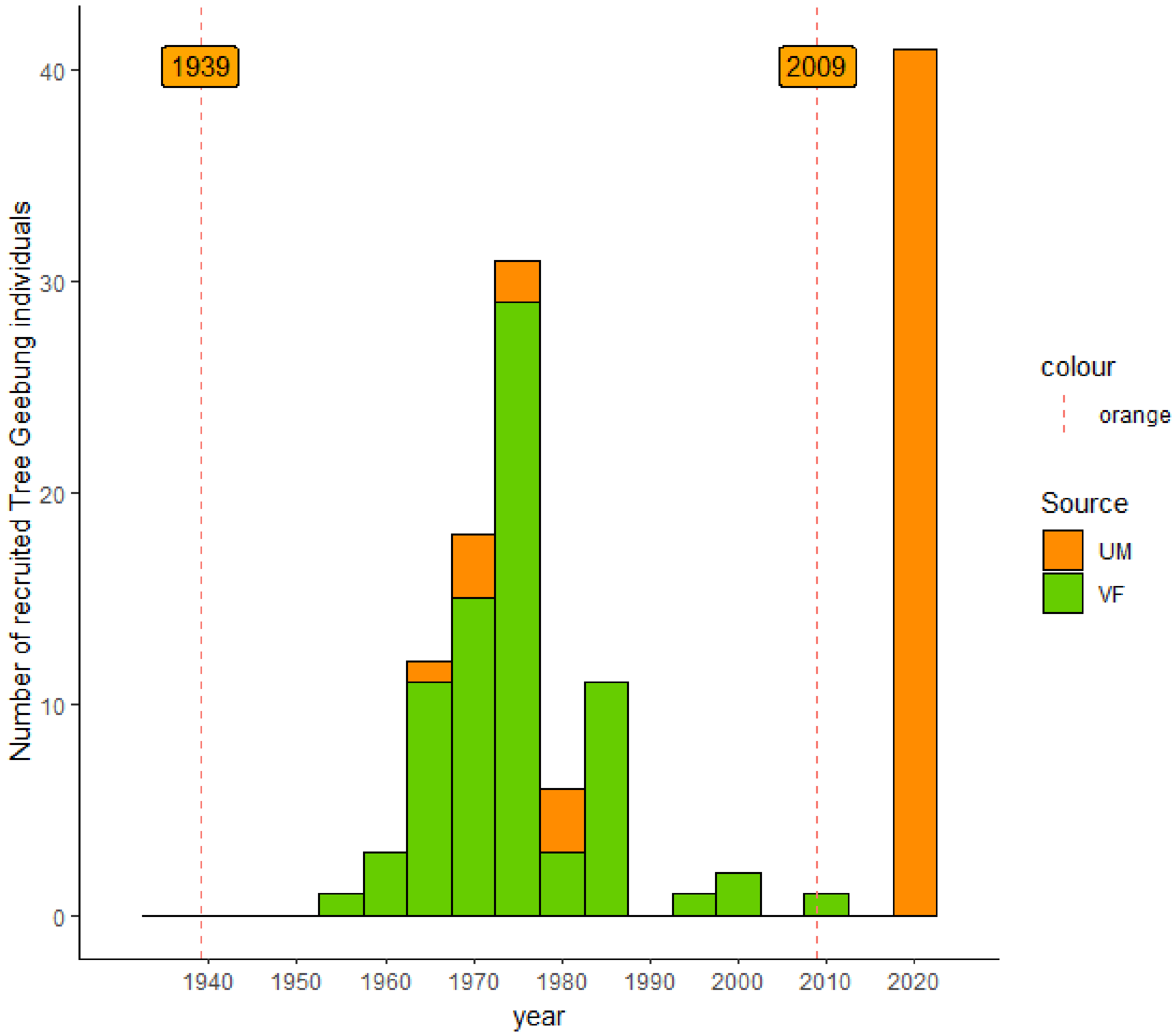

Figure S8u. Recruitment of Tree Geebung in Mozambique (350-513-0005) overlaid with disturbance history from 1930 to 2022. Disturbance events were the 1939 wildfire and the 2009 wildfire.