Stems Per Hectare of Native Trees and Shrubs on Lowland Subtropical Rainforest Assisted Natural Regeneration Sites in north-east NSW

Funded by Ecosia

report by C. L. Stanley

Contents

Photos: (title page) Lowland Subtropical Rainforest
Rocky Creek Dam and Nightcap National Park

(below) Survey at Possum Creek

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Aim

The aim of this study was to investigate the native tree and shrub density (stems per hectare) and species diversity on LSTRf assisted natural regeneration sites in north-east NSW and calculate the average stems per hectare.

Introduction

Description of Lowland Subtropical Rainforest

Lowland Subtropical Rainforest (LSTRf) is an ecological community characterised by a closed canopy and shady forest floor, several layers of trees (e.g. emergent, canopy and mid-story), high diversity of species, and the presence of thick-stemmed vines, buttress roots and epiphytes such as orchids and ferns [1][2][3]. Common canopy species include White Booyong (*Argyrodendron trifoliatum*), Yellow Carabeen (*Sloanea woollsii*), Native Tamarind (*Diploglottis australis*), Pepperberry (*Cryptocarya obovata*), Black Bean (*Castanospermum australe*) and Strangler Fig (*Ficus watkinsiana*) [1][2][4]. LSTRf is usually found more than 2km from the coast, less than 300m above sea level and in areas with high annual rainfall (>1300 mm) [1][2]. It occurs in New South Wales (NSW) from the Queensland border to the Hunter River area near Newcastle (See Appendix 1) [4]. LSTRf is recognised as a critically endangered ecological community under the Commonwealth Environmental Protection and Biodiversity act of 1999 [1][4].

History of deforestation and afforestation of LSTRf in north-east NSW

From about 1860 to 1900 approximately 94% of the LSTRf in north-east NSW was cleared for agriculture including grazing and perennial and seasonal horticulture [1][5][6]. The remaining rainforest exists in mostly small (<10 ha) isolated patches known as “remnants” scattered in a largely cleared landscape [1].

Remnant LSTRf continues to be threatened: by invasive weeds including vines which smother and kill native trees, exotic ground covers which prevent the germination of native seeds and weedy shrubs and trees which compete with native plants for light, moisture and nutrients [1][5]. Other threats include: isolation from other remnants which limits pollination and seed dispersal; grazing and soil compaction by cattle, clearing (e.g. for roads or urban development), domestic and feral animals, fire, and impacts from surrounding land use (e.g. dumping of urban garden waste, nutrient runoff and pesticide drift from adjacent agricultural land) [1].

From 1900, due to loss of soil fertility, use of some land shifted from intensive crops such as maize and sugarcane to dairying [5][7]. Dairying declined in the mid 1900s due to economic changes [5]

[7]. Over a span of about 100 years, patches of marginal agricultural land became disused and overgrown with a mixture of invasive and native species [5][6]. Much of this regrowth came to be dominated by a few invasive species including Camphor Laurel (*Cinnamomum camphora*), Privet (*Ligustrum spp.*) and Lantana (*Lantana camara*) [1][5][6].

Since about 1990 a growing community-led effort has been made to protect and restore remnant rainforest, re-establish rainforest on cleared land by planting, and convert weedy regrowth to rainforest [1]. It is difficult to determine how many ha of LSTRf are currently actively being restored, re-established and converted in north-east NSW as this work is being done by numerous organisations, companies and individuals with varying levels of reporting. In 2019 it was estimated 400 ha of rainforest trees had been planted in the area known as the Big Scrub [1]. In July 2022, the NGO Reforest Now reported they had planted 66 ha of mostly rainforest trees to date (~2018 to July 2022) [7].

Planting of rainforest trees is the beginning of an ecosystem restoration process which may take decades or centuries to approximately replicate the ecosystem that existed before clearing [1][3]. However, partially restored rainforest can provide important habitat for LSTRf species within 5 – 10 years [1][5].

Natural regeneration and succession

Ecological communities have ways to naturally recover from disturbance. In LSTRf this involves a succession of tree and shrub species with different germination, growth and reproductive characteristics which allow them to thrive in different conditions [1][5].

Succession in LSTRf is usually described as occurring in three phases; pioneer, secondary, and mature phase [1][5]. Species with characteristics that allow them to thrive early in the natural regeneration process (in the pioneer phase) are referred to as “pioneer species”, those that come to be dominant next as “secondary species”, and those that are dominant in the final phase as “mature phase species” [1][5]. Pioneer and secondary phases can be thought of as transitional, and mature phase as describing the dynamic ongoing state of most of the intact rainforest [1][5]. Healthy intact rainforest has patches where pioneer and secondary species are temporarily dominant e.g. after a large tree has fallen and created a sunny opening in the canopy [1][5]. This ability to recover naturally from disturbance (referred to as ecosystem resilience) has allowed LSTRf to exist in the area currently known as north-east NSW for at least 40 million years [1][5].

Because the trees and shrubs that make up healthy intact rainforest are mostly mature phase species, an important indication of progress of a regeneration site towards recovery is the relative stem density of mature phase species (in relation to total native tree and shrub stem density) [1][5][6].

Mature phase species tend to germinate in deep shade (a condition created over time by pioneer and then secondary species), grow slowly, and take a long time to start fruiting compared to other LSTRf species [1][5]. The seeds of mature phase species tend to have shorter viability [1] and may be large in size or wind-dispersed, limiting their potential for long-distance dispersal [6]. Consequently the process of natural regeneration may take an inestimably long time, particularly in areas where the damage, degradation or destruction is extensive [8].

Assisted natural regeneration

Assisted natural regeneration of LSTRf describes human effort to remove obstacles to natural regeneration and accelerate the process [1][8]. It commonly includes controlling weeds which suppress the germination and growth of rainforest species, and may involve infill planting to enrich species diversity and relative density of mature-phase species [1][6]. Key components of assisted natural regeneration of LSTRf are; protecting and restoring remnant rainforest, re-establishing rainforest by planting, and converting weedy regrowth to rainforest.

Remnant rainforest protection and restoration is first priority, as remnants shelter and sustain the remaining populations of flora and fauna species which are essential for restoring LSTRf to the level of complexity and biodiversity of this ecological community [1].

Re-establishment of rainforest by large-scale planting of diverse species is used in areas that have been highly disturbed for a long time to kick-start the natural regeneration process by creating shade to retard weed growth and providing food and habitat for seed-dispersing fauna [1].

When converting weedy regrowth areas, large woody weeds (especially Camphor laurel) are often killed and left standing to provide habitat for fauna which bring seeds from the surrounding landscape [1][6].

The density and diversity of native species which naturally recruit to a regeneration site is likely to depend on proximity to, and integrity of, remnant rainforest [6]. Tree and shrub species cannot recruit from a nearby remnant if that remnant doesn’t contain the species, or if the mode of dispersal of seeds for those species is interrupted (e.g. if the animal that usually spreads the seed is missing or if seeds are spread by water and the remnant is downstream) [1]. Other factors affecting natural recruitment are site history (e.g. years of repeated clearing before regrowing began, years of regrowing before assisted natural regeneration began, years of assisted natural regeneration) and site-specific growing conditions (e.g. aspect, moisture, surrounding land use) [6]. Infill planting of species with limited potential to recruit naturally to a site can be used to accelerate the trajectory of the site towards a fully recovered state and may be desirable in any of the above situations [1][6].

Method

Density and diversity data were collected at 8 assisted natural regeneration sites (2 remnant and 6 regrowth) and 1 intact LSTRf reference site in north-east NSW in November 2022. The main factor limiting the amount of data collected was restricted project time. Size of the regeneration areas ranged from 0.5 to 15 ha and the LSTRf reference site is approximately 200 ha (See Appendix 2). Years of assisted natural regeneration ranged from <1 year to ~35 years.

Whether a regeneration area is likely to have originally been LSTRf or not was determined using NSW vegetation mapping [9]. For details regarding the methods, quality and limitations of this publicly available dataset please refer to [9].

For each regeneration site, the date and area where regeneration work occurred were determined from written records (regeneration reports, *Ecological Management and Restoration* journal articles) and the verbal account of bush regenerators and landholders. The application "BackCountry Navigator Pro" on Samsung J7-Pro smartphone (model number SM-J730F) running Android version 9 was used to record GPS data.

Species diversity data was collected by an individual with plant identification skills walking in the regeneration area and making a list of identified species. For large sites (>2 ha), where surveying the entire area was impractical with the time available, a species list was produced for a sample area from 0.5 to 1.5 ha in size. The individual making the list and size of area covered varied between sites.

Tree and shrub density data was collected in accordance with the *Monitoring Revegetation Projects for Biodiversity in Rainforest Landscapes Toolkit* (the *Toolkit*) produced by Griffith University [3]. The *Toolkit* describes a standardised method for monitoring and recording changes in a number of rainforest attributes including; tree and shrub density, canopy cover, canopy height, ground-cover, dead standing trees and fallen trees and branches [3]. It is designed for comparing data collected at the same site over a number of years (a longitudinal study) with data from a reference site, rather than comparing sites [3]. Due to the limited scope of this study only the method for monitoring and recording shrub and tree density was used and each site was surveyed once in November 2022. For clarity and completeness the relevant information from the *Toolkit* is included and slightly expanded upon here.

At each regeneration site native trees and shrubs were counted in six 5 m x 10 m quadrants arranged on two 50 m transects situated roughly in the middle of the regeneration area (See Appendix 3). At the reference site trees were counted in twelve quadrants on four transects.

There were some variations on the standard layout and situation of survey plots. Three sites each had a single non-standard plot. Two transects were bent, at 35 m and 40 m respectively, to avoid gullies. The GPS location of each bend was recorded. One quadrant was centred at 15 m on a transect instead of 25 m, to avoid a road through the regeneration area. Rotary Park and Stewarts Rd regeneration areas each sloped down to a gully with a stream roughly through the middle, so the transects were situated between the stream and an outer edge rather than in the middle.

Shrubs were classified as live free-standing woody-stemmed plants 1-2 m high (including the saplings of trees). Trees were classified as live free-standing woody-stemmed plants >2 m high and tallied by dbh (diameter at breast height = stem diameter at 1.3 m above the ground) into the following six classes: <2.5 cm, 2.5-10 cm, 10-20 cm, 20-50 cm, 50-100 cm, >100 cm. For trees with multiple trunks, each trunk >2 m high was counted separately (major stems only, not branches).

For this study the following two guidelines were added to those from the *Toolkit*; where 50% or more of the cross-sectional area of a stem at 1.3m above ground level was inside the quadrant, that stem was counted. Where a tree was growing horizontally with branches pointing upwards the trunk diameter was measured at 1.3 m from the base of the tree (and the branches were not counted).

For this study the method deviated from that described in the *Toolkit* in that only local native trees and shrubs (no exotic species) were counted.

Analysis was performed on an Acer Swift 7 laptop running Windows 10 using LibreOffice Calc version 7.3.7.2.

Results

Median stems per ha ranged from 600 (100 - 950) stems on a regrowth site <1 year after start of assisted regeneration to 14900 (11850 - 16000) stems on a remnant site ~35 years after start of assisted natural regeneration. The reference site had a median of 5600 (3500 - 7950) stems per ha. Figure 1. shows median stems per ha for each site and upper and lower quartiles.

Average (the mean of the means) stems per ha for LSTRf assisted natural regeneration sites based on the 8 sites surveyed is 68.2% certain to be between 2315 and 11685 stems per ha. Figure 2. shows average stems per ha for assisted natural regeneration sites.

Species diversity of trees and shrubs in surveyed areas ranged from 10 species on a regrowth site after <1 year of assisted natural regeneration to 75 species on a remnant site after ~35 years of assisted natural regeneration.

More large trees were counted at Nightcap (the reference site) and Elham (remnant, 30yrs) compared to other sites. Fig 3. shows the total number of large trees (>10 cm dbh) counted on each site, separated by dbh class.

Results are summarised in Table 1.

Fig 1. Median stem density on LSTRf sites, error bars show upper and lower quartiles

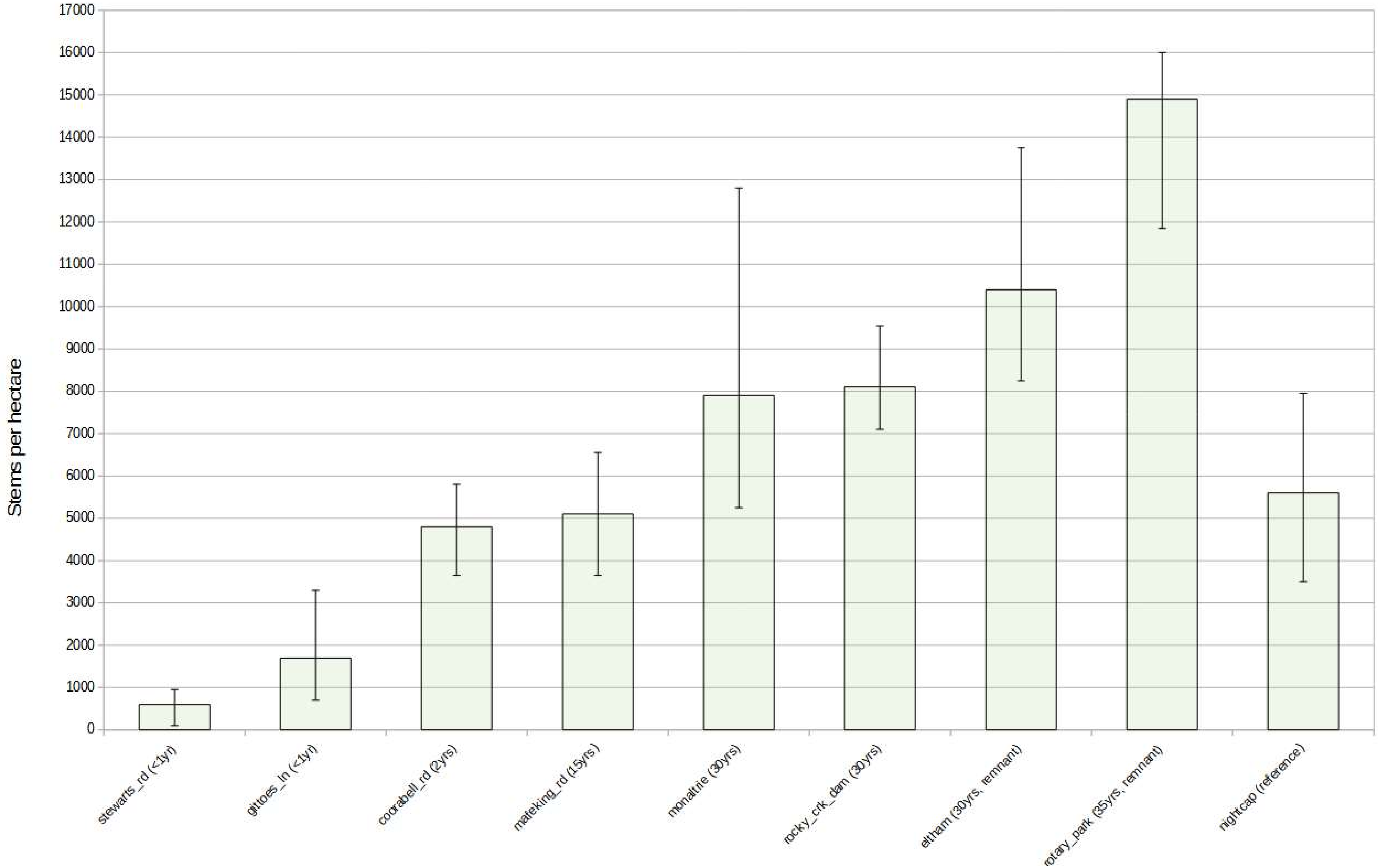

Fig 2. Mean stem density and standard deviation on LSTRf sites regeneration sites including remnants with average and standard error.

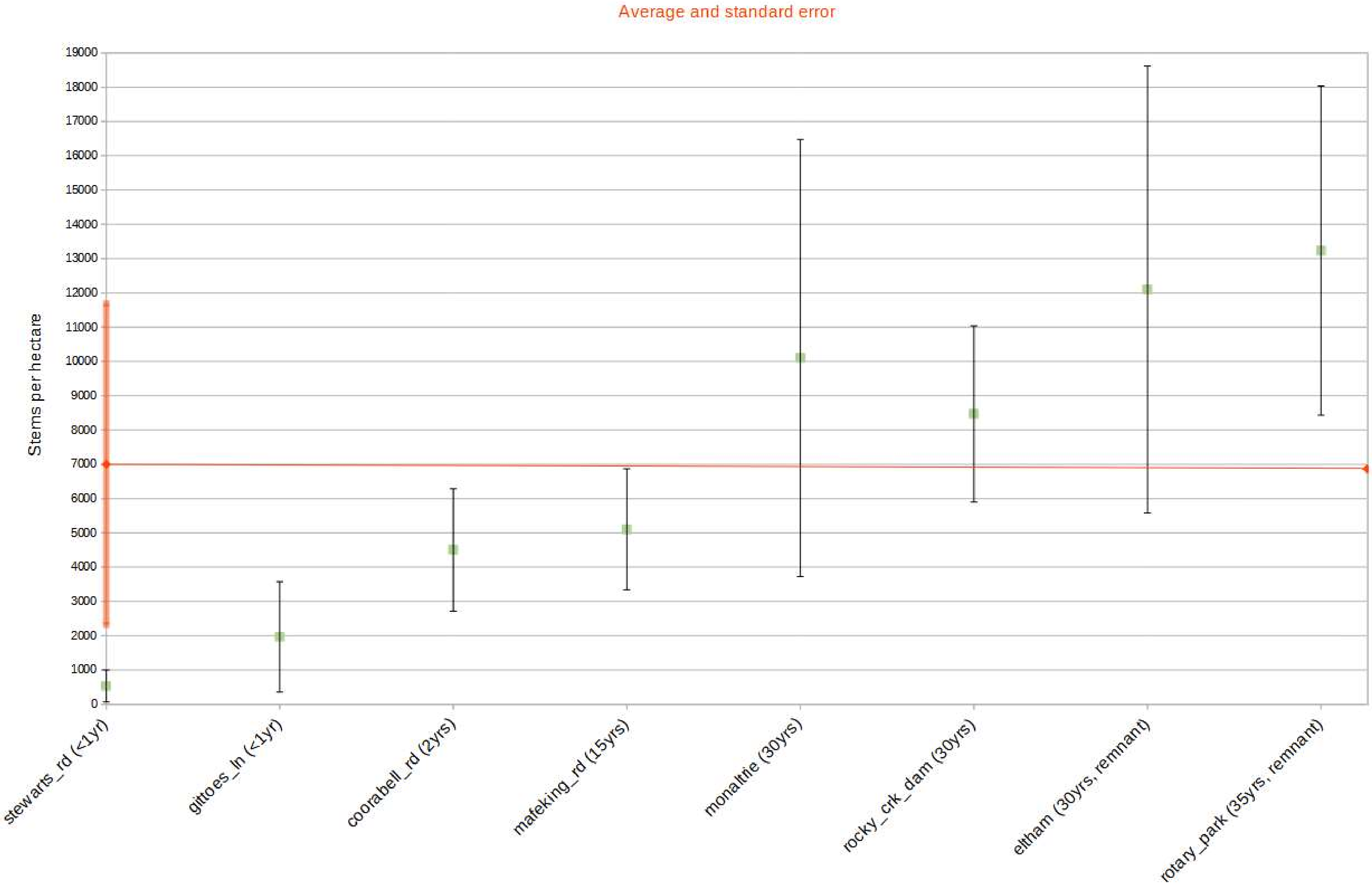

Fig 3. Large (>10 cm dbh) native trees counted on LSTRf sites in north-east NSW

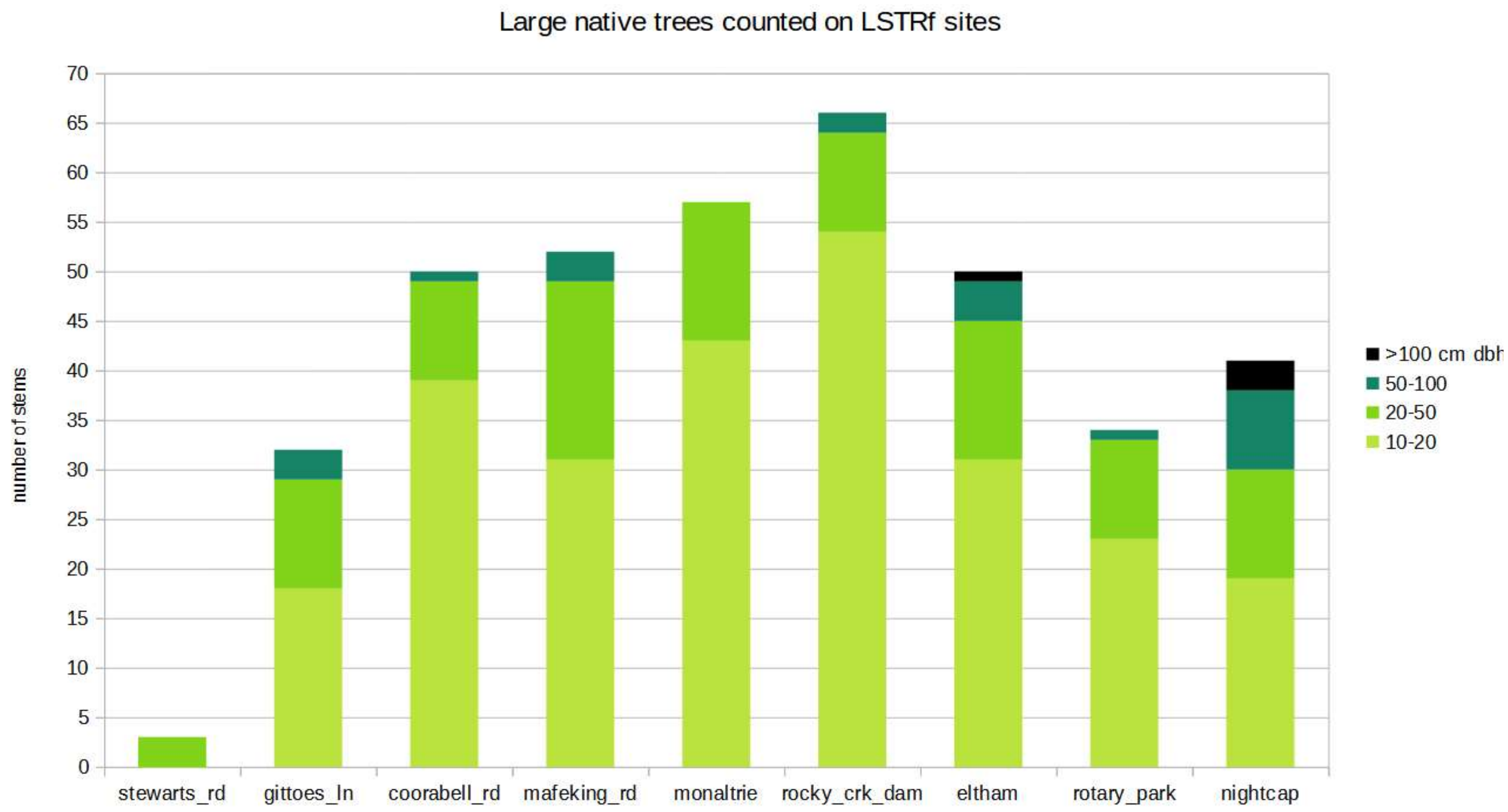

Table 1. Number of tree and shrub species, average stem density and standard deviation LSTRf sites in north-east NSW

Site Name (years of assisted regeneration work)	Stewarts Rd (<1yr)	Gittoes Ln (<1yr)	Coorabell Rd (2yrs)	Mafeking Rd (15yrs)	Monaltrie (30yrs)	Rocky Creek Dam (30yrs)	Eltham (30yrs, remnant)	Rotary Park (35yrs, remnant)	Nightcap (reference)
Type of site	-	-	-	-	-	-	Remnant	Remnant	Reference
Number of Species	10	27	33	48	39	69	43	75	46
Median stem / ha	**600**	**1700**	**4800**	**5100**	**7900**	**8100**	**10400**	**14900**	**5600**
Mean stem / ha	533	1967	4500	5100	10100	8467	12100	13233	5783
Standard deviation	468	1607	1788	1765	6376	2566	6520	4799	2842

Average (mean of means): **7000**
Standard error: **4685**

Discussion

Tree and shrub density for most sites was positively skewed (with the bulk of the data at the less-trees end and a tail in the more-trees direction). Therefore, when considering density on sites separately, the median represents the average stems better than the mean and the upper and lower quartile values represent variance better than the standard deviation.

Stems under 1m tall were not counted. This is not explained in the *Toolkit* [3] but likely has to do with survivorship (a type III survivorship curve) for subtropical rainforest seedlings [10].

Hight variance in stem density between 50m^2 quadrants (standard deviation) reflects the nature of the rainforest environment, both regenerating and intact. There were high density patches where saplings were growing under a parent tree and low density patches where there was a gap between parent trees, a fallen tree, rocky area or gully. Note that variance between 50m^2 quadrants of rainforest may not scale linearly to variance between hectares of rainforest.

High variance in stem density between sites (standard error) reflects how sites are different from each other. Key differences include the size and shape of a site, its position in the landscape (including proximity to remnant rainforest and surrounding land use), site history (e.g. years of repeated clearing before regrowing began, years of regrowing before assisted natural regeneration began, years of assisted natural regeneration) and site-specific growing conditions (e.g. aspect, rainfall, soil moisture).

Confidence in the mean could be increased (from 68.2%) by collecting data at more assisted natural regeneration sites in north-east NSW however variance is likely to remain similar even as sample size increases. High variance between LSTRf assisted natural regeneration sites means the average may not be a useful way to describe the population.

Stem density was low on the reference site (Nightcap, median 5600 stems/ha) compared to the average for regeneration sites (7000 stems/ha). This is related to tree size. More large trees 50 – 100 cm dbh and >100 cm dbh were counted at Nightcap and Elham compared to other sites. Large trees take up more space and grow further apart resulting in lower stem density. As mentioned in the introduction, it may take decades or centuries for a regenerating LSTRf ecological community to fully recover with human assistance [1]. Over this time tree and shrub density in a regenerating area will usually increase then decrease. Small trees grow at higher density sharing abundant light, water and nutrients. As the trees get larger they compete with each other and density decreases until it resembles that of the reference community. Therefore, unless size is accounted for, stem density is unsuitable as an indicator of progress of the LSTRf ecological community towards recovery.

Size-adjusted stems per ha, produced using dbh as a multiplier (smaller trees would result in a lower size-adjusted stems per ha value and larger trees would have a higher value) still would not account for whether the trees are a good match for the reference community in terms of species and relative density of species.

The *National Restoration Standards* [8] describes a five-star system for evaluating the progress of an ecosystem towards recovery. A regenerating ecosystem can be described as having one to five stars in six key ecosystem attributes (absence of threats, physical conditions, species composition, structural diversity and ecosystem function) relative to the reference ecosystem [8]. The reference ecosystem would have 5 stars in all six attributes [8]. The five-star system is a thorough and standardised option for evaluating the progress towards recovery of any Australian ecosystem.

Alternatively, relative density of mature phase species is considered to be a good indicator of progress towards recovery for LSTRf [1][5][6]. It is likely to be an effective and efficient option for evaluating the progress towards recovery of the LSTRf ecological community specifically.

Unfortunately, the species diversity lists produced for study are not suitable for comparison because of variation in the way they were compiled (by different people, covering different areas).

Conclusion

Stem density alone is unsuitable for describing regenerating LSTRf in north-east NSW. Alternative methods recommended to measure the progress towards recovery of regenerating LSTRf are the five-star system in the *National Restoration Standards* [8] or the relative density of mature phase species [1][5][6].

A more consistent methodology is recommended when collecting species diversity data.

Glossary of terms

Composition (of an ecosystem): the set and relative proportion of species within an ecosystem [8].

Damage (to an ecosystem): a substantial impact generally from a single event such as a bulldozing or flood event [8].

Degradation (of an ecosystem): a persistent decline in the structure, composition and function of an ecosystem compared to its former (dynamic) state, generally from frequent or ongoing impacts [8].

Destruction (of an ecosystem): reduction to a simple homogeneous state relative to the reference ecosystem (e.g. removal of practically all native flora and fauna, depletion of the native soil seed bank, loss of modems for native seed dispersal, changes to soil biology and hydrology).

Ecological community: the flora and fauna components of an ecosystem [11].

Ecosystem: an assemblage of abiotic (e.g. sunlight, moisture, non-living components of soil) and biotic (e.g. flora, fauna, living components of soil) elements which occur together, interact with, and depend on each other [8].

Functions (of an ecosystem): processes arising from interactions between abiotic and biotic elements (e.g. nutrient cycling and sequestration, food production, herbivory, predation and decomposition, water filtration, soil formation, provision of habitat, pollination, succession, disturbance and regeneration) [8].

Full recovery (of an ecosystem): a state in which all ecosystem attributes closely resemble those of the reference ecosystem [8].

Natural recruitment (of trees and shrubs) : phenomenon by which trees and shrubs grow from propagules that originate on a site or arrived by non-human means such as dispersal from nearby mature rainforest by wind, water or non-human animals especially flying frugivores.

Recovery (of an ecosystem) the *outcome* of an ecosystem having regained a structure, composition and function similar to that of the reference ecosystem [8]. Recovery can be partial or full [8].

Reference ecosystem can be a conceptual model based on information from numerous reference sites [8]. For example, the reference ecosystem for LSTRf may contain 370 tree, shrub and vine species whereas the maximum number of tree, shrub and vine species recorded on any one **reference site** is 222 [1].

Regeneration (of an ecosystem) the *process* of an ecosystem changing from a damaged/degraded/destroyed state to a recovered state. Regeneration can occur with or without human assistance (**assisted natural regeneration** and **natural regeneration** respectively) [1][5].

Structure (of an ecosystem) the physical arrangement of abiotic and biotic elements that make up an ecosystem (e.g. canopy layers, habitat size and complexity, species density and distribution) [8].

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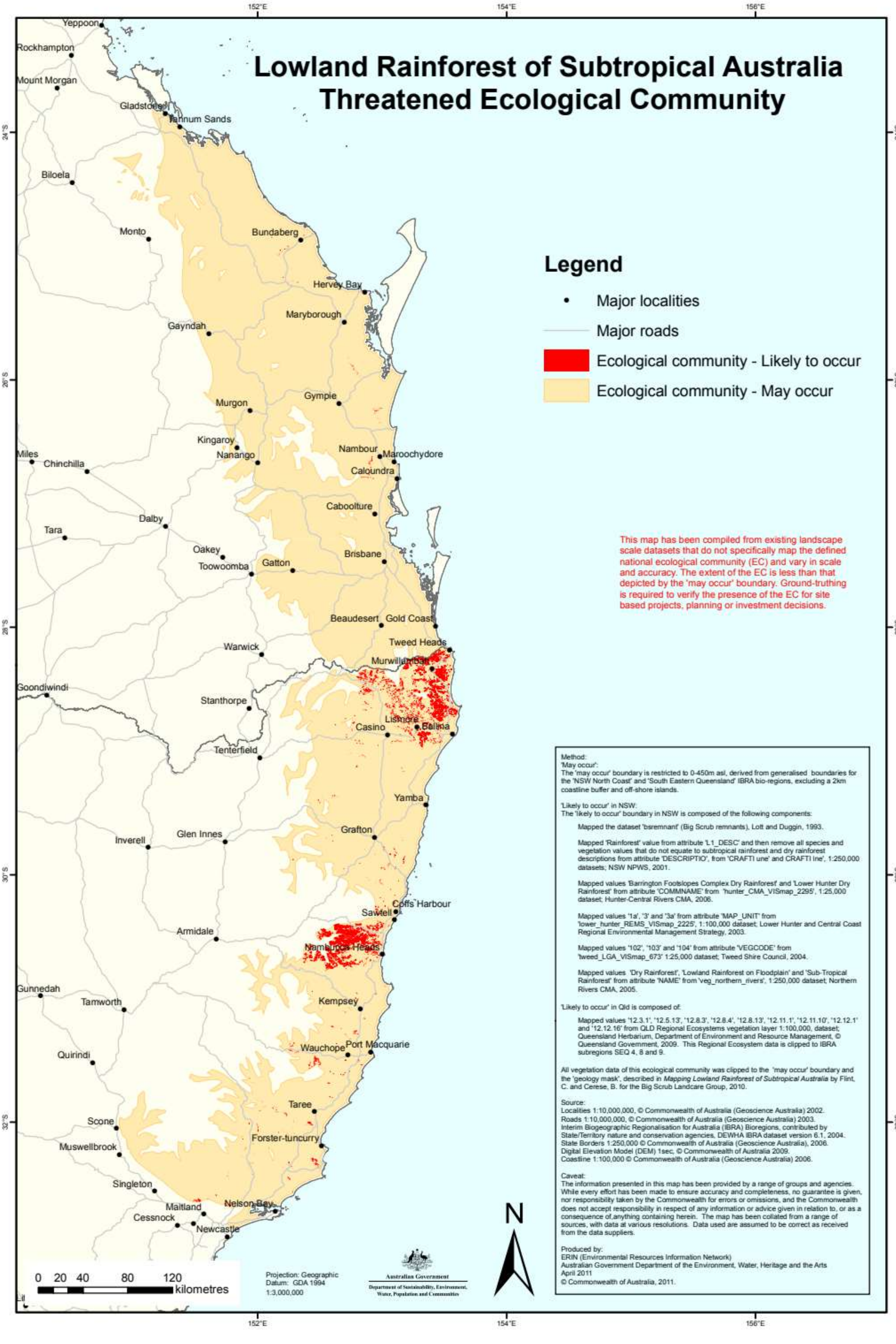
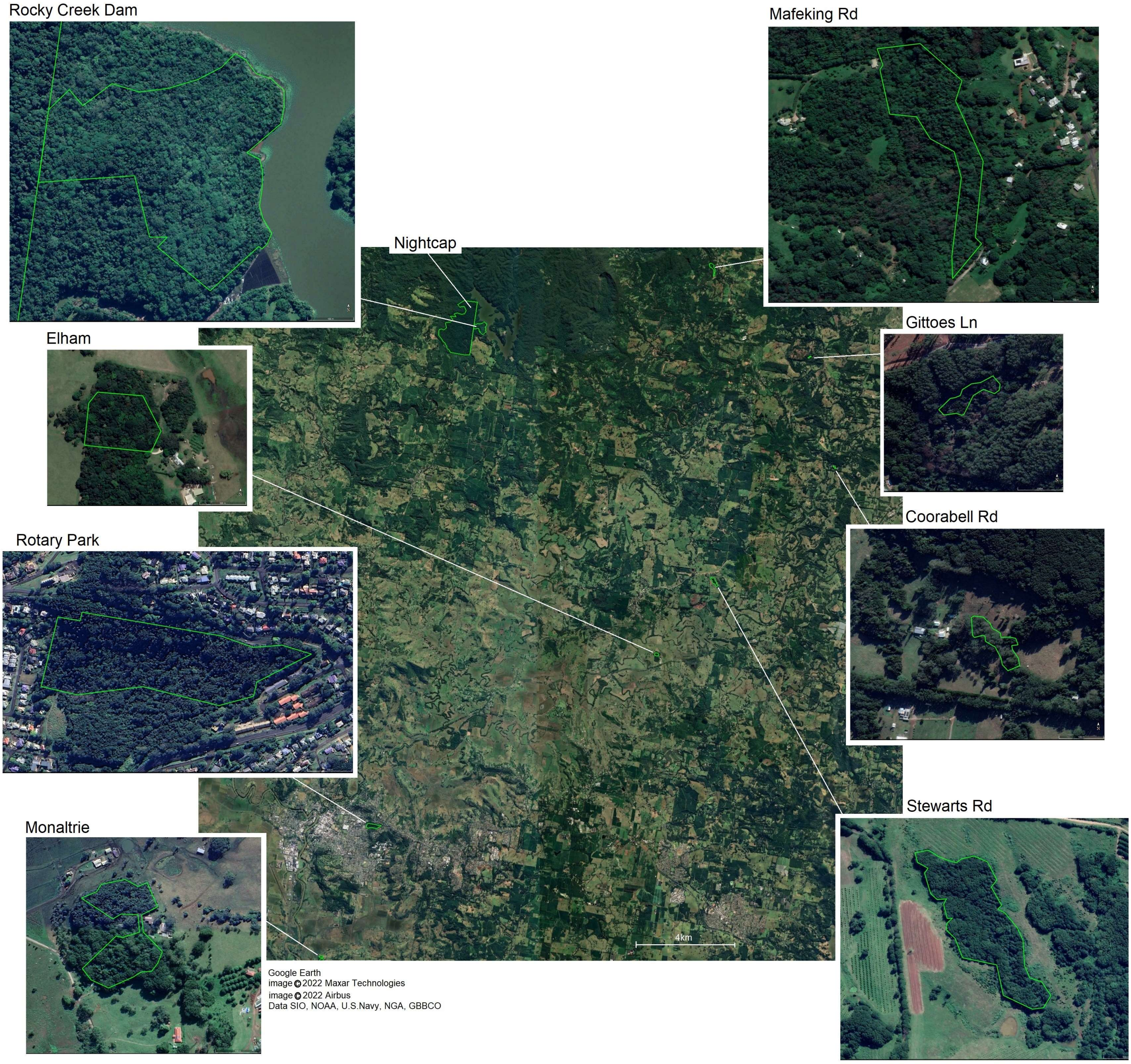
Appendix 1 Likely distribution of LSTRf in NSW



Source: Australian Government Department of Environment Water Heritage and the Arts, April 2011

Appendix 2 Data collection sites

Centre image shows the position of sites in the landscape. Inset images show the relative size of sites. Due to its overwhelming size relative to the regeneration sites, the reference site (Nightcap) is shown only in the centre image.



Appendix 3 Survey plot layout

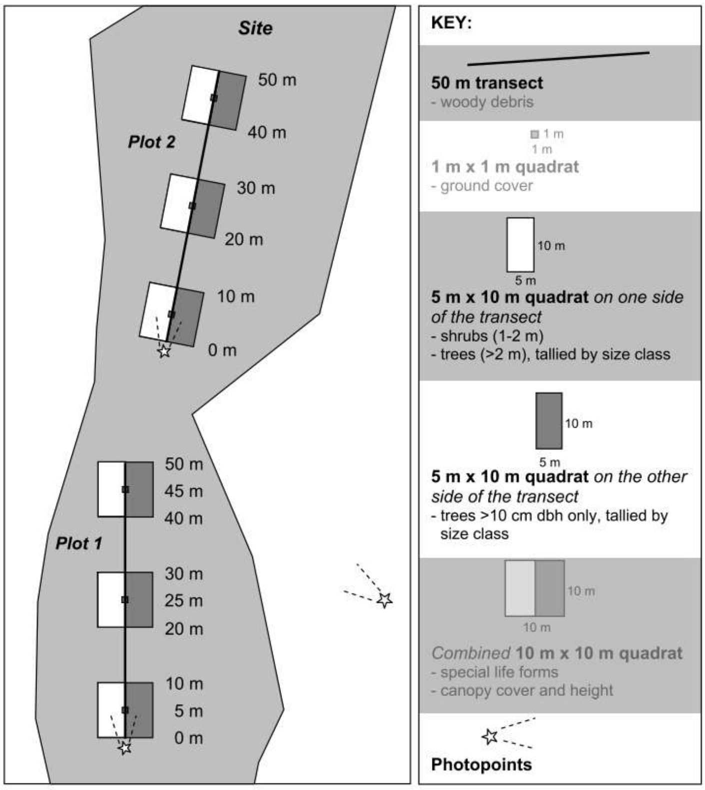
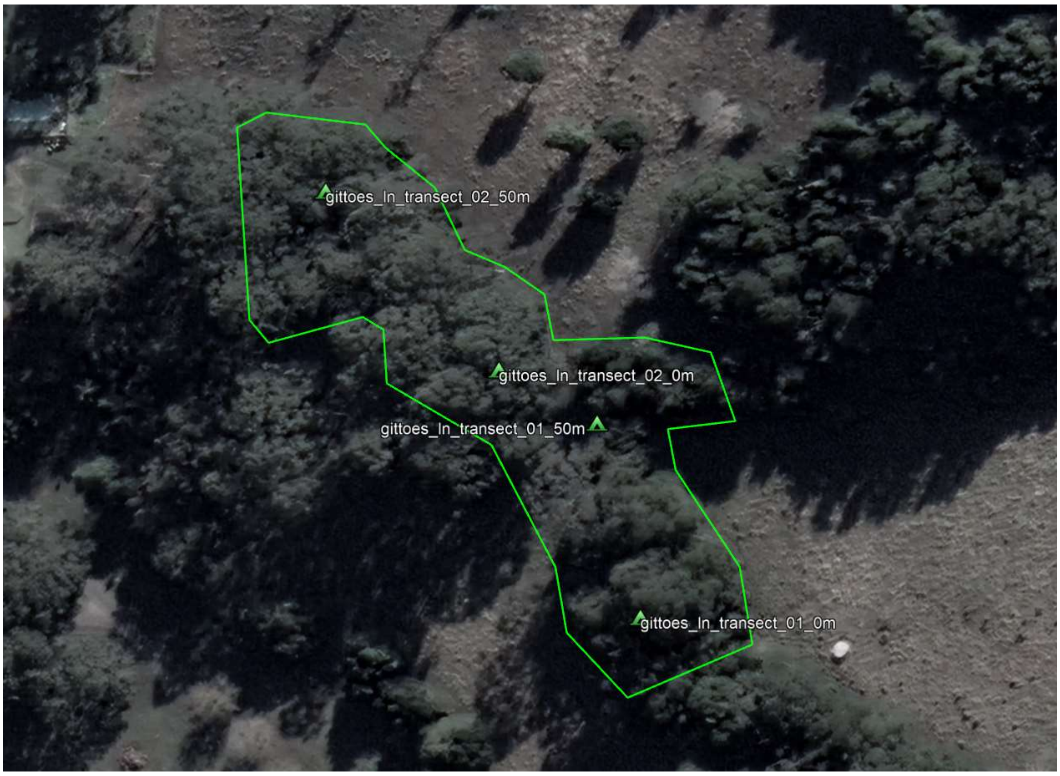


Figure 3: Standard layout of survey plots for monitoring basic indicators.

Source: *Monitoring Revegetation Projects for Biodiversity in Rainforest Landscapes Toolkit* [3]



Satellite image of regeneration area and transect endpoints

Source: Google Earth Pro