Hollow-bearing trees on the Mid North Coast of NSW – Abundance and spatial distribution now, and a model for the future.

Background
This report is based on a work presented to the Australian Wildlife Management Conference by Justin Williams in Dubbo in December 2001. This report delivers on the RFA milestone Attachment 8, 1Q.

1. Summary

Method
1. Inventory data collected for yield modelling were used to identify the current distribution and abundance of hollow-bearing trees across an area of public forest on the Mid North Coast of New South Wales.
2. The forest was stratified based on a combination of forest yield association groups (YAGs) and growth stages mapped as part of CRA process (CRAFTI).
3. A matrix of likelihood of hollows trees was established based on the proportion of hollow-bearing trees were assessed by species and diameter class from the very large inventory dataset.
4. Forest stands were grown forward using yield simulation tools based on a no harvesting treatment and two harvesting treatments.
5. The hollow-tree matrix was applied to modelled future tree lists under different harvest scenarios to predict future hollow-abundance.
6. The spatial distribution of future hollows was mapped using an intersection of the forest strata and exclusion zone maps to show hollow-development in harvested and not-harvested stands.
7. Area weighted average future hollow abundance was calculated.

Results
1. Current abundance of hollow bearing trees in the forests assessed was 10 hollow-bearing trees per hectare with a range between strata of 2.6-15 trees/ha.
2. Likelihood of trees being hollow increases with tree diameter, but the proportions vary between species especially between 60-100 cm dbhob. Fast growing species are less likely to be hollow in those size classes than slow-growing species.
3. The modelling predicts an increase in the abundance of hollow-bearing trees in the future in this landscape.
4. Within harvested areas there is a modest increase from 10.1-12 trees/ha over 100 years whilst in the unharvested areas the increase is dramatic to 23.9 hollow trees/ha.

Discussion
1. There is expected to be significant increase in the number of hollow-bearing trees at the landscape scale over the next 100 years. This is largely a result of past harvesting reducing the existing hollow-bearing tree numbers and subsequent decisions to not harvest 60% of the study area allowing a significant recruitment of hollows as those protected areas mature.
2. The configuration of reserved and harvestable areas within the State forest estate means that in future hollow-bearing tree numbers will increase at both the harvest unit and landscape scale.
3. This increase in hollow-bearing tree numbers is likely to support increased populations of hollow-dependant species within State forests in future.

2. Methods and Study Area

The study area was 188,702 hectares of current and former State forests on the Mid North Coast from Nabiac in the south to Eungai in the North. The area includes 67,600 ha of State forests that were established as National Parks during the Comprehensive Regional Assessment (CRA) process in the late 1990s. The forests of the study area have a long history of timber harvesting and silvicultural practices such as Timber Stand Improvement (TSI) that have reduced the number of hollow-bearing trees in the forest landscape. In the study area, 76,000 hectares or 40% is available for harvesting.

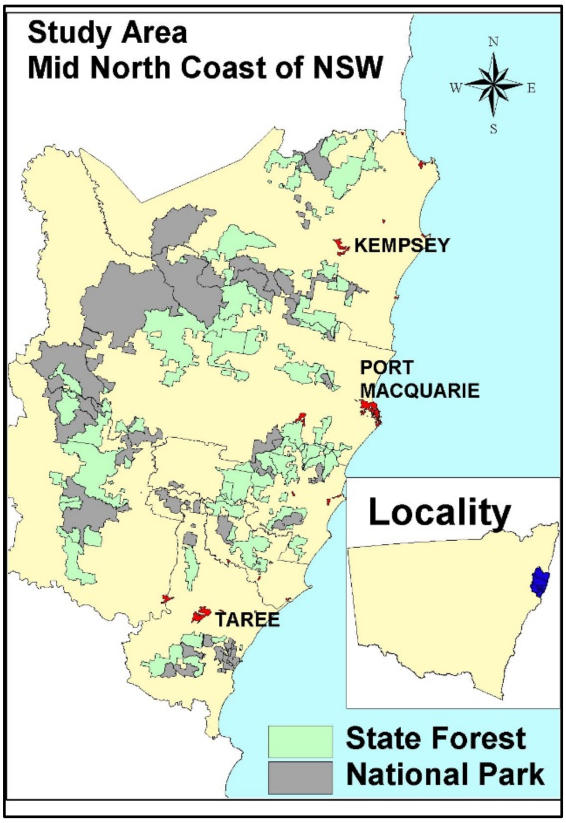


Figure 1 - Mid North Coast NSW Study Area

Stratification

The forests were stratified based on an amalgamation of forest types, called Yield Association Groups (YAGs) and forest structure categories based on the CRA Forest Type Inventory mapping project (CRAFTI).

Yield association groups were:

MCB – Moist Coastal Blackbutt
MCE – Moist Coastal Eucalypt/Moist Hardwood
TDE – Tall Dry Eucalypt/Mixed Hardwood
DBBT – Dry Blackbutt/Spotted Gum
DSF – Dry Sclerohpyll Forest

CRAFTI Growth Stage Groups were:

E – CRAFTI Codes E > 30% RCC regrowth
A – CRAFTI Code A - > 30% RCC Senescent
B – CRAFTI Code B – 10-30% RCC Senescent
C – CRAFTI Code C - < 10% RCC Senescent

The combined strata used are shown in Table 1.

Inventory

The North Coast inventory data was used. These were based on 0.1 ha circular plots that were located on a systematic random design. Every tree over 10 cm dbhob was measured in each plot for species, diameter, log product, canopy condition, dominance class and for presence of hollows. Hollows were scored on a 3-class system, 0 = not hollow, 1 = possible hollows and 2 = definite hollows. For this analysis, to be conservative, only trees scored as containing definite hollows. In addition, only trees larger than 40 cm diameter were considered in the analysis of current hollow abundance and when modelling future abundance. There were 539 plots in the study area which were used for the assessment of current hollow and modelling of future stands and future hollows.

Hollow Likelihood Matrix

The matrix of likelihood of hollow-bearing trees by species and size class was developed from the full North Coast inventory database (Upper and Lower North East CRA regions) available at the time of

2431 plots. These plots included a total 103,306 trees. Thirty-two (32) species which had greater than 200 trees measured and which were Eucalypts or Eucalypt like were selected to be assessed and these represented 67,189 of those trees. The hollow likelihood matrix is provided as Appendix 1 to this report for the 32 species.

Modelling Future Stands

Future stands were modelled using the FRAMES yield simulation tool. Simulations were run based on actual silviculture settings at the time (Actual – maximum of 30% basal area removal), heavy single tree selection silviculture (Heavy STS – maximum of 40% basal area removal) and no harvest. Stands were grown forward over a 200-year horizon and future tree lists for each plot were reported for the years 2000, 2025, 2050, 2100 and 2200. The FRAMES inventory and modelling environment used to model these stands is described in reports at 'NSW Comprehensive Regional Assessments – Project Number NA13/FRA'.

Modelling Future Hollow-bearing Trees

The Hollow Likelihood matrix was applied to the modelled future stands for each plot and each reporting period. A random number between 0 and 1 was assigned to each tree in excel. Where the random number assigned to the tree was less than the hollow likelihood for that tree size and species the tree was modelled as a hollow-bearing tree. The predicted abundance of hollows per hectare were then calculated for each forest strata for each reporting period.

To assess the landscape scale abundance and spatial distribution of future hollow-bearing trees from the model, the modelling strata were intersected with layers of harvest and non-harvest areas in a Geographic Information System (GIS). The predicted future hollow-bearing tree abundance for each strata and reporting period was tagged to the harvestable areas from each of the two harvesting scenarios run through the yield simulation. Similarly, the predicted hollow-bearing trees from the no harvest scenario were tagged to the non-harvest areas for each strata and reporting period. The future hollow-bearing tree abundance per hectare is reported by strata and at the landscape scale on an area weighted basis.

3. Results

Current Abundance

The area weighted mean current hollow-bearing tree abundance was 10.1 trees/ha, with a strata average ranging from 2.6-15 hollow-bearing trees per hectare (Table 1). When reviewed at the yield association group level it is evident that the hollow abundance is less in Blackbutt and Spotted/Gum Blackbutt stands than other yield association groups. At the growth stage level, the regrowth growth stages had fewer hollow-bearing trees per hectare than the mixed age forests and a higher proportion of plots without hollows. These results are not surprising as these forests have typically had much more active and intensive past harvesting history. It should be noted that 53% of the 0.1 ha plots did not contain a hollow-bearing tree. The high proportion of zero and one results at the plot level for hollow-bearing trees means there are large deviations around the means.

Table 1. Hollow-bearing Tree Abundance by Strata in the Year 2000

Strata Name	Strata Code	Area (ha)	N Plots	% of Plots with Hollows	Average Hollow-bearing trees/hectare
Regrowth Blackbutt	MCB_E	6,860	28	36%	6.7
Regrowth Moist Hardwood	MCE_E	6,453	14	36%	10
Regrowth Mixed Hardwood	TDE_E	6,621	26	38%	6.5
Regrowth Spotted Gum/ Blackbutt	DBBT_E	4,772	31	13%	2.6
Regrowth Dry Sclerophyll	DSF_E	1,467	6	33%	15
Mixed Age Blackbutt	MCB_AB	9,729	34	50%	8.5
Mixed Age Moist Hardwood	MCE_AB	31,656	79	63%	13.5
Mixed Age Mixed Hardwood	TDE_ABC	45,083	137	58%	12.8
Mixed Age Spotted Gum/ Blackbutt	DBBT_ABC	16,214	72	32%	5.7
Mixed Age Dry Sclerophyll	DSF_ABC	19,355	40	55%	10
Mature Regrowth Blackbutt	MBBT_C	17,451	32	34%	4.7
Mature Regrowth Moist Hardwood	MCE_C	8,243	18	50%	12.8
Rainforest with Emergent Euc's	RM/RE	14,800	22	59%	10.9
Total and area weighted mean		188,702	539	255	10.1
Yield Association group only results					
Blackbutt		34,040	94	40%	6.2
Moist Hardwood		46,352	111	58%	12.9
Mixed Hardwood		51,704	163	55%	12.0
Spotted Gum/Blackbutt		20,986	103	26%	5.0
Dry Sclerophyll		20,822	46	52%	10.4
Growth Stage only results					
Regrowth		26,173	105	30%	7.2
Mixed Aged		122,037	362	53%	11.3
Mature Regrowth		25,694	50	40%	7.3

Hollow Likelihood by species and size class

The assessment of the 103,000 tree database identified 32 species of trees which had more than 200 measurements for which the hollow likelihood matrix shown in Appendix 1 was developed. Of note is the variation in the rate at which hollows occur in different size classes between species. Subsequent statistical analysis has identified that a best-fit model is based on diameter and whole tree quality (high quality sawlog trees are less likely to contain hollows than lower quality trees) and has amalgamated species (Appendix 2). However, inspection at the species level was informative from an ecological and management perspective. Figure 2 shows an example of the variation in hollow likelihood amongst five common species, especially amongst the 60-80 cm size class. For these species, the likelihood of a tree being hollow ranges from 44% in Grey Gum trees to only 8% in Blackbutt trees. Although diameter is an important indicator of likelihood of hollows, information on the variation between species helps staff during forest mark-up to identify and protect trees with hollows, and importantly select recruitment trees that are more likely to develop hollows sooner. As trees in the 60-80 cm size class are nearly three times more common than trees between 80-100 cm diameter knowledge of the variation in hollow likelihood by size and species can better inform tree selection.

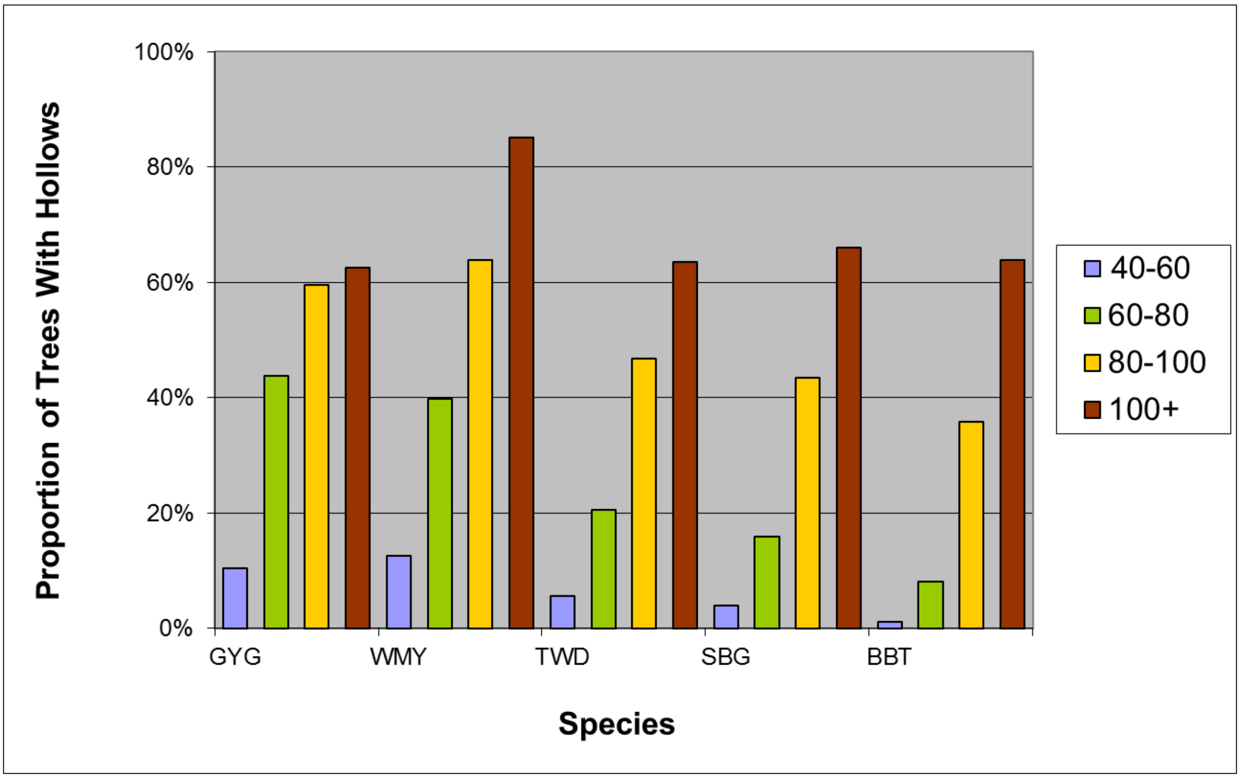


Figure 2. Proportions of trees with hollows for five common species in the 40-60, 60-80, 80-100 & 100+ cm diameter size classes.

Future Hollow Abundance

The models of future hollow-bearing tree abundance show, on average, a modest increase over 100 years within harvested stands, with the most marked increases in stands with current low hollow-bearing tree abundance (Table 2). In the absence of harvesting hollow-bearing tree abundance is predicted to more than double over the next 100 years.

Table 2. Predicted Hollow Abundance in 2100 by Strata in harvested and unharvested stands

Strata Name	Strata Code	Current Abundance	100-year Future Harvested Stands	100-year Future Unharvested Stands
Regrowth Blackbutt	MCB_E	6.8	12.0	21.8
Regrowth Moist Hardwood	MCE_E	10.0	7.4	24.8
Regrowth Mixed Hardwood	TDE_E	6.5	11.0	26.6
Regrowth Spotted Gum/ Blackbutt	DBBT_E	2.6	9.4	23.0
Regrowth Dry Sclerophyll	DSF_E	15.0	12.0	17.5
Mixed Age Blackbutt	MCB_AB	8.5	14.4	28.3
Mixed Age Moist Hardwood	MCE_AB	13.5	11.5	20.8
Mixed Age Mixed Hardwood	TDE_ABC	12.8	14.5	26.8
Mixed Age Spotted Gum/ Blackbutt	DBBT_ABC	5.7	12.9	25.9
Mixed Age Dry Sclerophyll	DSF_ABC	10.0	13.1	20.4
Mature Regrowth Blackbutt	MBBT_C	4.7	9.5	26.6
Mature Regrowth Moist Hardwood	MCE_C	12.8	12.5	25.5
Rainforest with Emergent Euc's	RM/RE	10.9	N/A	17.6
Area weighted mean		10.1	12.0	23.9

Figure 3 shows the modelled change in hollow-bearing tree numbers for each reporting period from for the two harvesting scenarios and in the unharvested stands. On average, there is a modest decrease in the first 25 years in harvested stands with recruitment occurring in subsequent periods replacing those lost as a result of harvesting and natural mortality.

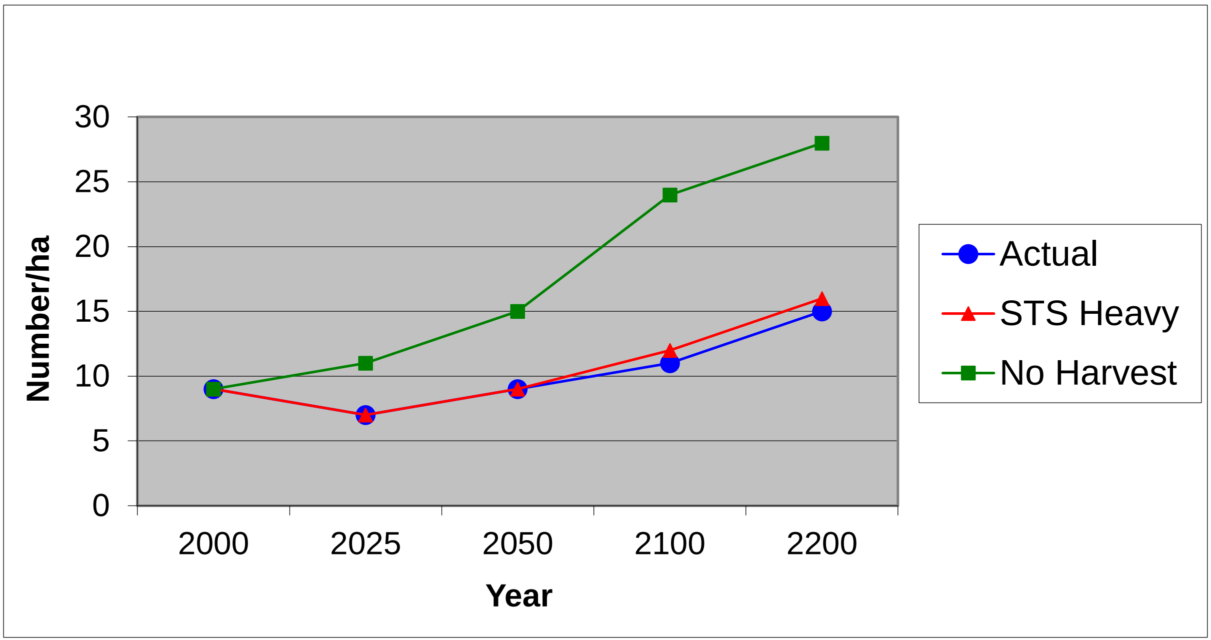


Figure 3. Model of the number of trees/ha with hollows for a 200-year period under three silvicultural scenarios.

Figure 4 shows the variation in those trends between some of the different strata under the actual silviculture harvesting scenario. The decline in the first 25 year period occurs in stands with higher numbers of hollow-bearing trees per hectare where harvesting conditions specify retention of 5 hollow-bearing trees per hectare whilst recruitment of hollow bearing trees begins to occur in the stands with fewer hollow-bearing trees in the earlier reporting periods through modelled tree retention.

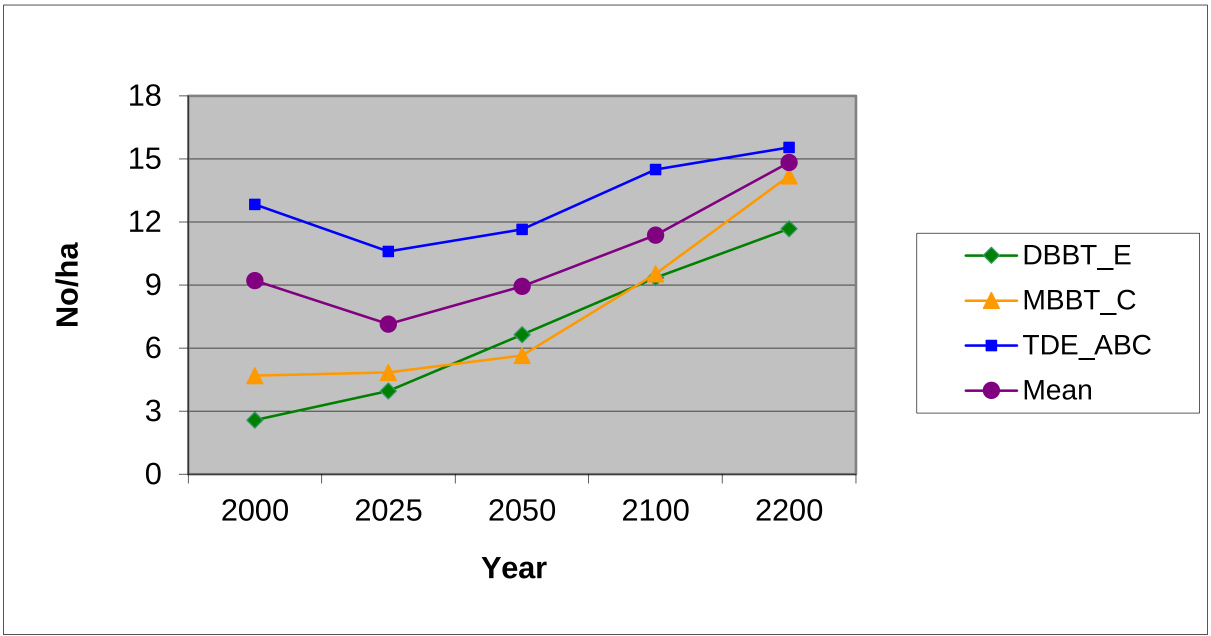


Figure 4. Model of Number of Hollow Trees/ha under Actual Silviculture scenario for three habitat strata.

At the landscape scale, when considering the mix of harvested and unharvested areas, total hollow bearing tree numbers are predicted to remain even for the first 25 years before increasing substantially over 100 years (Figure 5). This landscape scale increase results from current stands having reduced numbers of hollow-bearing trees due to past harvesting but the significant increase in hollows predicted to occur within now reserved areas. As these areas make up 60% of the study area and only 40% is available for harvesting the recruitment of hollow-bearing trees in these reserves as they mature has a dramatic effect on the numbers of hollow-bearing trees in the landscape.

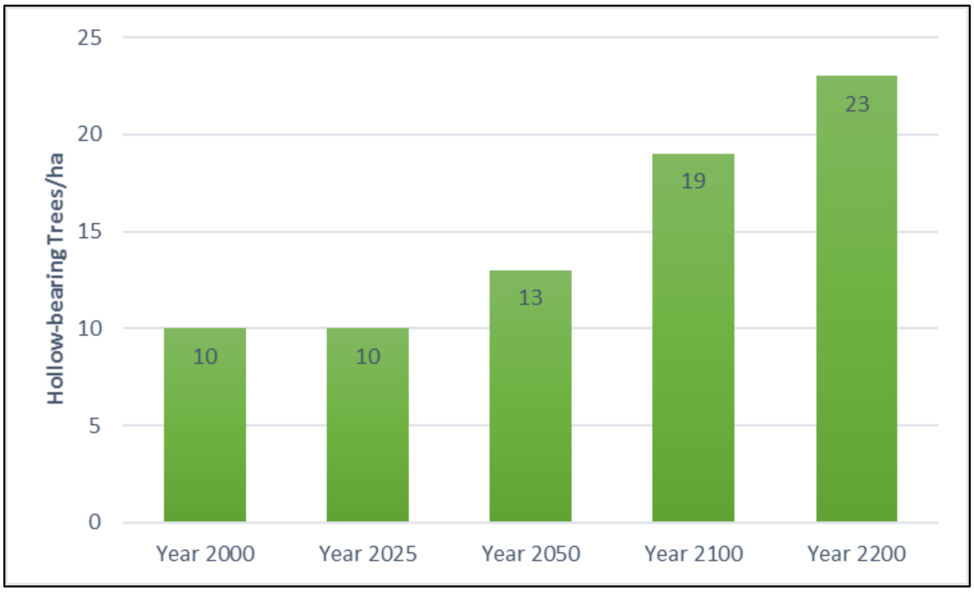


Figure 5. Average number of hollow-bearing trees/ha across the landscape over the next 200 years including harvested and reserved areas.

Spatial Distribution of Hollows

The change in spatial distribution of hollow-bearing trees is evident when maps of current and future distribution are assessed. Figures 6-8 show an example area within the study area where exclusion zones shown in figure 6 were intersected with the habitat strata developed for this study to show current (Figure7) and future (Figure 8) hollow-bearing tree abundance. The maps show the typical pattern of riparian corridors and old growth patches in forest in the study area. These progressively increase in the abundance of hollow-bearing trees over-time with the darker blue areas in Figure 8 showing the areas that are predicted to have high abundance of hollow-bearing trees in the future.

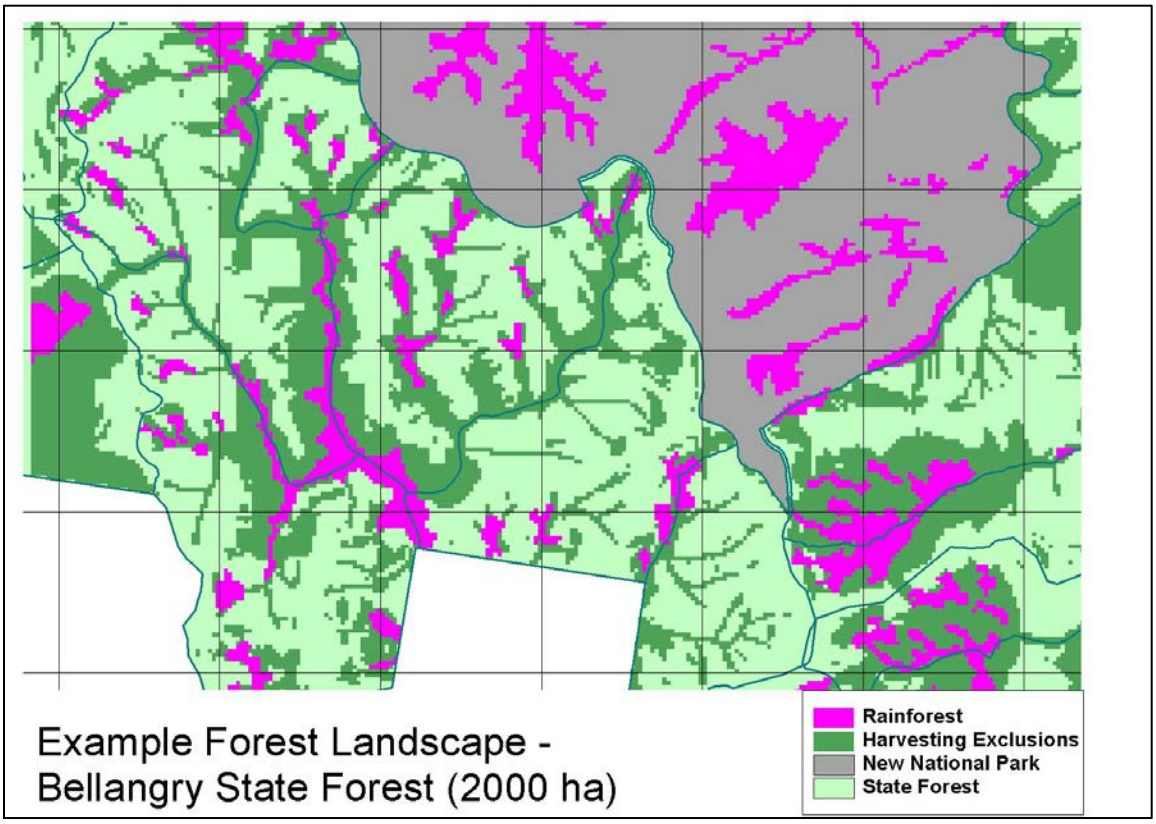


Figure 6. Example of Harvest Exclusions and new reserves in a local landscape in the study area.

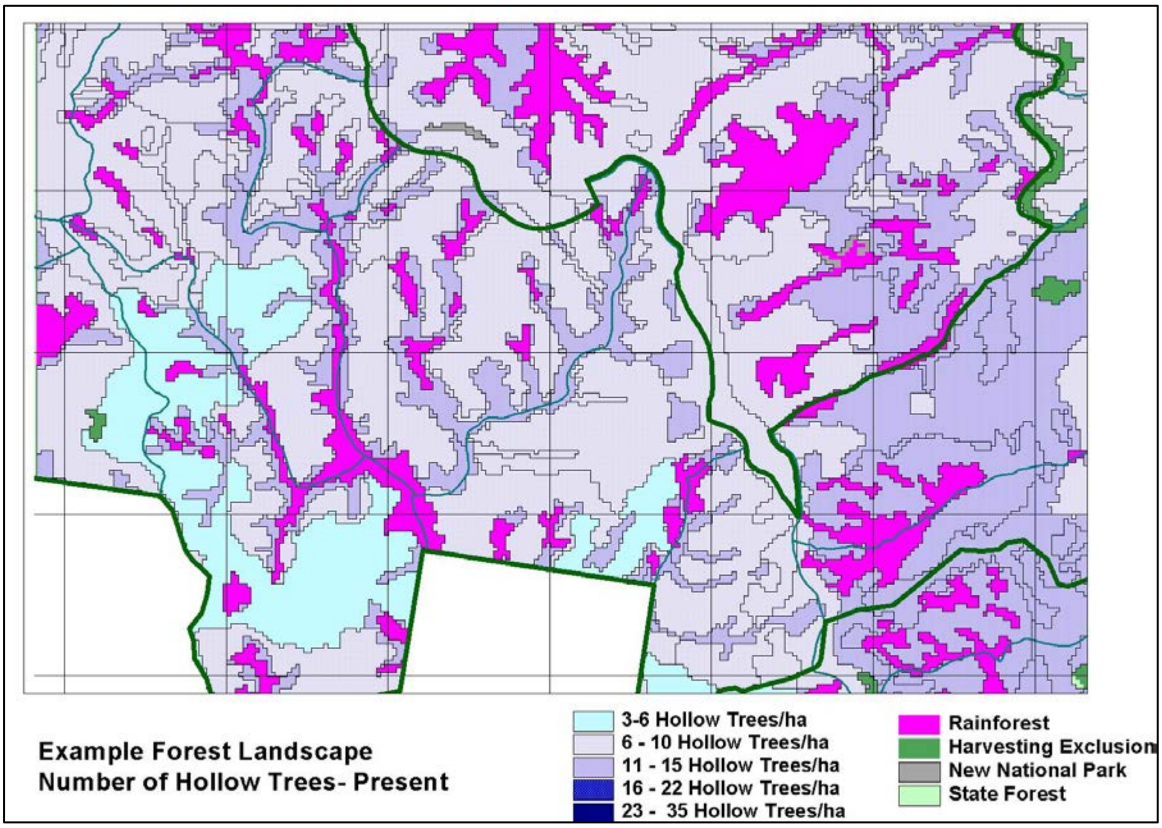


Figure 7. Average current number of hollow-bearing trees/ha by habitat strata in a local landscape in the study area.

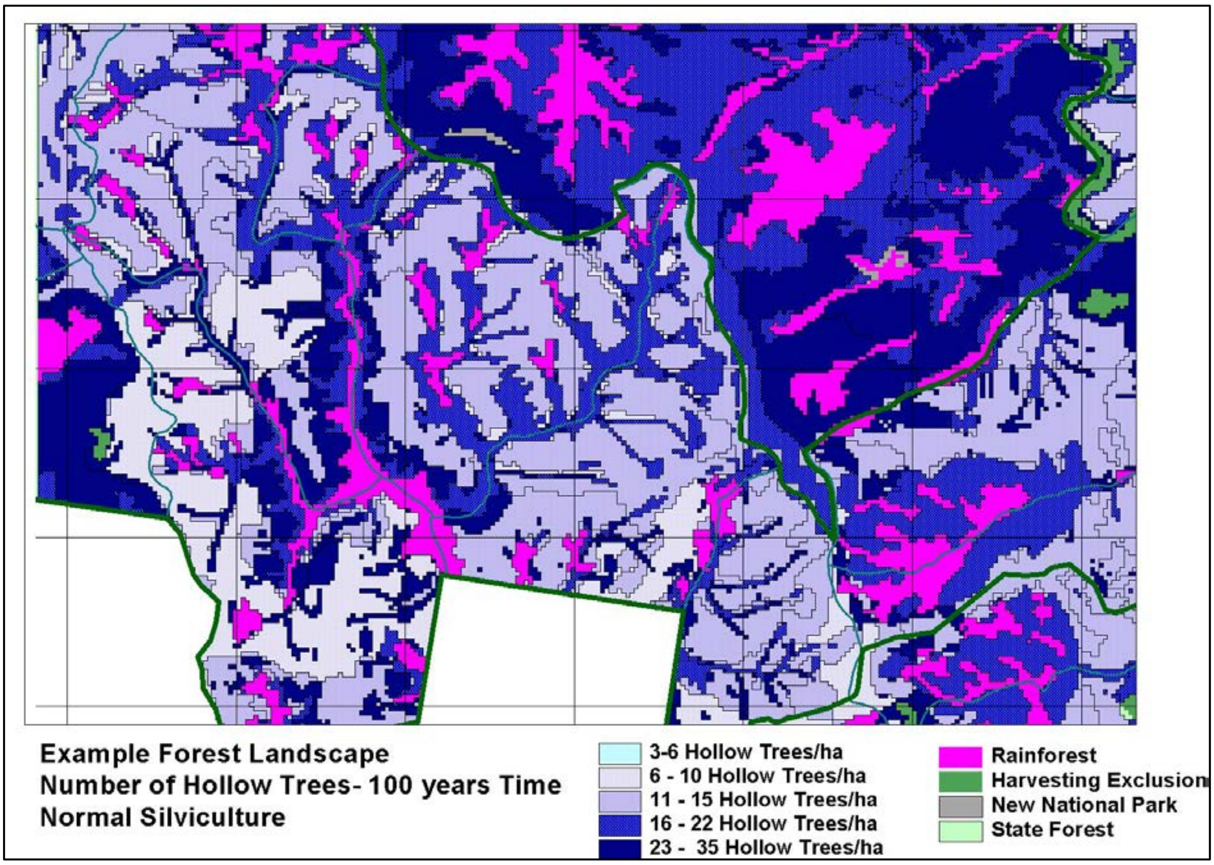


Figure 8. Average number of hollow-bearing trees/ha in 100 years time by habitat strata in a local landscape in the study area.

Whilst the model shows a large increase in the abundance of hollow-bearing trees in reserved areas within the State forest estate, to understand the potential benefits for wildlife populations it is useful to consider what the spatial arrangement of these reserves are. Figure 9 shows an example State forest landscape (ie not including national park estate) and shows the average distance from the harvest area to a mapped exclusion zone. This analysis, based on a 25m grid, identified the average distance to exclusion zones of 70 m and the median distance of only 50 m. The extensive corridor network established on State forests is predicted to increase the number of hollow-bearing trees both across the estate and within local landscapes. This is likely to have positive benefits for hollow-dependant species as the protected areas mature and hollow abundance increases.

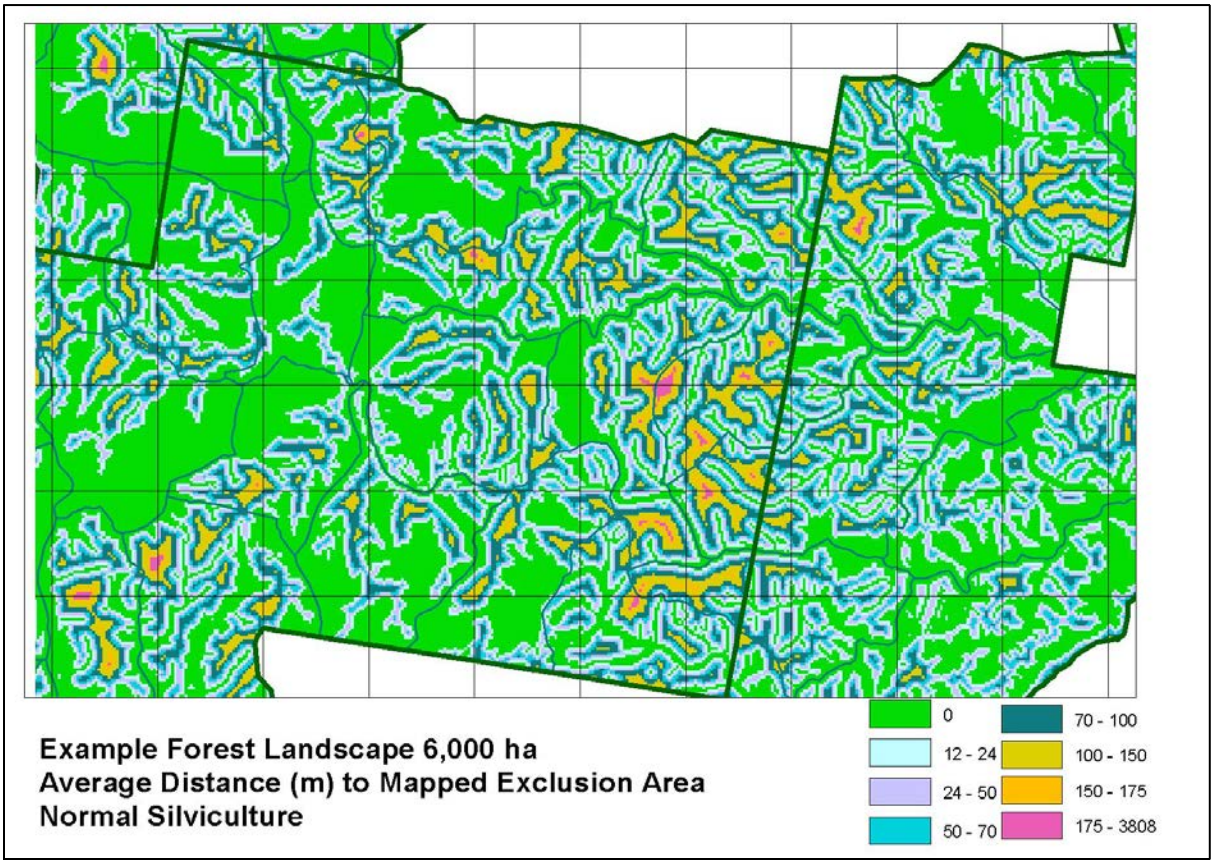


Figure 9. Average distance to exclusion area in an example 6,000 hectare State Forest landscape in the study area.

4. Conclusion

The State forest estate in New South Wales is dominated by forests with reduced numbers of hollow-bearing trees due to a long history of harvesting and silvicultural treatment. As many of these areas have since been reserved and will now be allowed to mature, models predict they will significantly increase in the abundance of hollow-bearing trees. The large reserve network established in public forests in New South Wales, and indeed Australia, will make a significant contribution to hollow-bearing tree abundance and wildlife habitat. Studies on potential impacts on hollow-dependant species in production forests need to consider likely hollow-bearing tree trajectories under proposed management conditions for both the harvested and reserved portions of the estate to fully understand likely impacts.

Appendix 1. Hollow-bearing tree Likelihood Matrix. Proportion of trees with hollows in four diameter size classes.

Species	40-60 cm	60-80 cm	80-100 cm	100+ cm	Count Total
ASB – Stringybark	5.5%	33.3%	60.0%	100.0%	393
BBT – Blackbutt	1.2%	8.2%	35.8%	63.8%	4703
BBX – Brushbox	8.3%	19.7%	39.0%	54.2%	3806
BLW – Bloodwood	12.3%	35.7%	53.8%	50.0%	3926
BWD –Brushwood	2.6%	0.0%	0.0%	0.0%	701
DSB - Diehard Stringybark	6.6%	16.7%	51.9%	70.0%	1701
FAS – Fastigata	6.3%	31.8%	62.5%	40.0%	452
FLG - Flooded Gum	0.8%	7.3%	0.0%	50.0%	447
FRG – Forest Red Gum	9.5%	17.6%	11.1%	50.0%	569
GBX – Grey Box	3.4%	16.7%	16.7%	16.7%	484
GIB – Grey Ironbark	1.8%	8.0%	0.0%	0.0%	740
GYG – Greygum	10.4%	43.8%	59.5%	62.5%	4406
IBK – Ironbark	4.0%	20.8%	54.5%	100.0%	3409
MAG – Manna Gum	10.5%	20.0%	28.6%	61.1%	665
MMT – Messmate	7.0%	18.3%	28.4%	63.2%	1942
NEB – New England Blackbutt	12.5%	30.7%	58.8%	74.3%	4826
NMY – Narrow-leaved White mahogany	36.8%	100.0%	100.0%	100.0%	326
NPM – Narrow-leaved Peppermint	27.9%	22.2%	33.3%	33.3%	629
PPM - Peppermint	10.3%	41.9%	53.8%	14.3%	334
RIB – Red Ironbark	11.1%	43.8%	50.0%	0.0%	447
RLG – Round-leaved Gum	6.3%	23.5%	66.7%	30.8%	498
RMY – Red Mahogany	11.8%	27.0%	71.4%	62.5%	1841
SAP – Smooth-bark Apple	30.9%	60.0%	60.0%	60.0%	916
SBG – Sydney Blue Gum	3.9%	15.8%	43.5%	66.1%	3395
SBK – Stringybark	5.1%	25.8%	70.0%	50.0%	921
SCG – Scribbly Gum	3.1%	0.0%	0.0%	33.3%	210
SPG – Spotted gum	10.0%	19.8%	61.1%	80.0%	5071
SSB – Silvertop Stringybark	4.3%	16.8%	34.7%	50.0%	1462
TRP – Turpentine	7.6%	15.7%	44.4%	50.0%	4850
TWD – Tallowwood	5.6%	20.6%	46.8%	63.5%	4973
WMY – White Mahogany	12.5%	39.7%	63.9%	85.2%	7545
WSB – White Stringybark	18.8%	42.9%	100.0%	100.0%	601
Grand Total	8.2%	23.3%	47.9%	63.0%	67189
> 40 cm Count Total	8073	2665	956	617	12312
H tree Total	662	621	458	389	2130

Note 1. Total count on right hand side is the total number of trees measured for each species.
Note 2. The > 40 cm totals at the bottom are the number of trees measured in each of the four size classes for all species in the model. H tree totals are the number of trees with visible hollows measured for all species in the model.

Appendix 2. Updated Statistical Models of Hollow-bearing Tree Likelihood.

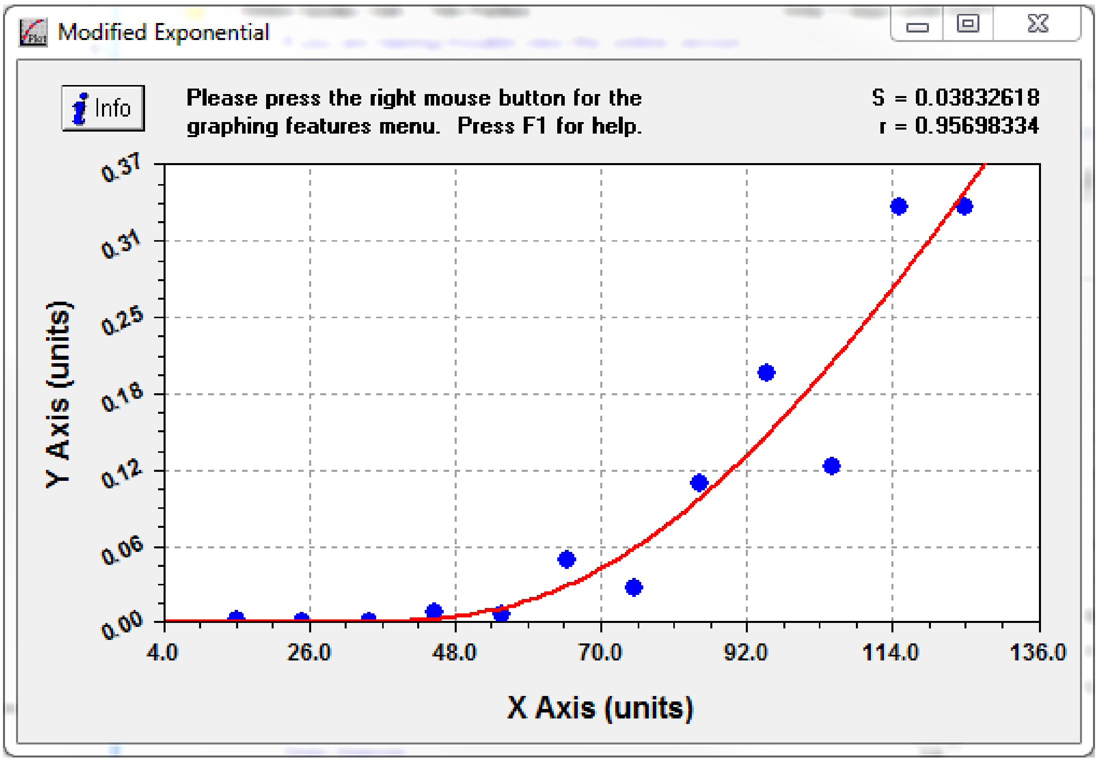
Background:

- Hollow-bearing tree likelihood models were updated in 2014 by Tim Parkes and Justin Williams using the RFA inventory datasets which include assessment of hollow-bearing tree status for each individual tree.
- This work review models using tree quality code (trees assessed as high quality sawlogs or not) for North Coast and South Coast.
- Developed separate models for fast growing species (Blackbutt and Flooded Gum) from other commercial species on the North Coast where data indicated hollow-development occurred at larger diameter in faster growing species.
- Undertook best-fit analysis of the proportion of hollow-bearing trees by diameter at breast-height over bark.
- Functions can be applied to inventory datasets and future modelled tree distributions under proposed silvicultural systems to assess likely hollow-bearing tree retention rates.

Results:

North Coast

4 models were developed, based on two species groups (Blackbutt and Flooded Gum or Fast Growing and Other species) and two whole tree quality groups (High Quality and Low Quality).
Model 1 : **Species Group 1** - Blackbutt and Flooded Gum: High Quality Sawlog Trees
Modified Exponential: y=a*e^(b/x)
Coefficient Data:
a = 4.82468358875E+000
b = -3.28497143733E+002



X Axis = Diameter at breast height over bark (cm)
Y Axis = Probability of tree containing hollows

Model 2 Spp Group 1 Flooded Gum and Blackbutt : Low Quality Trees

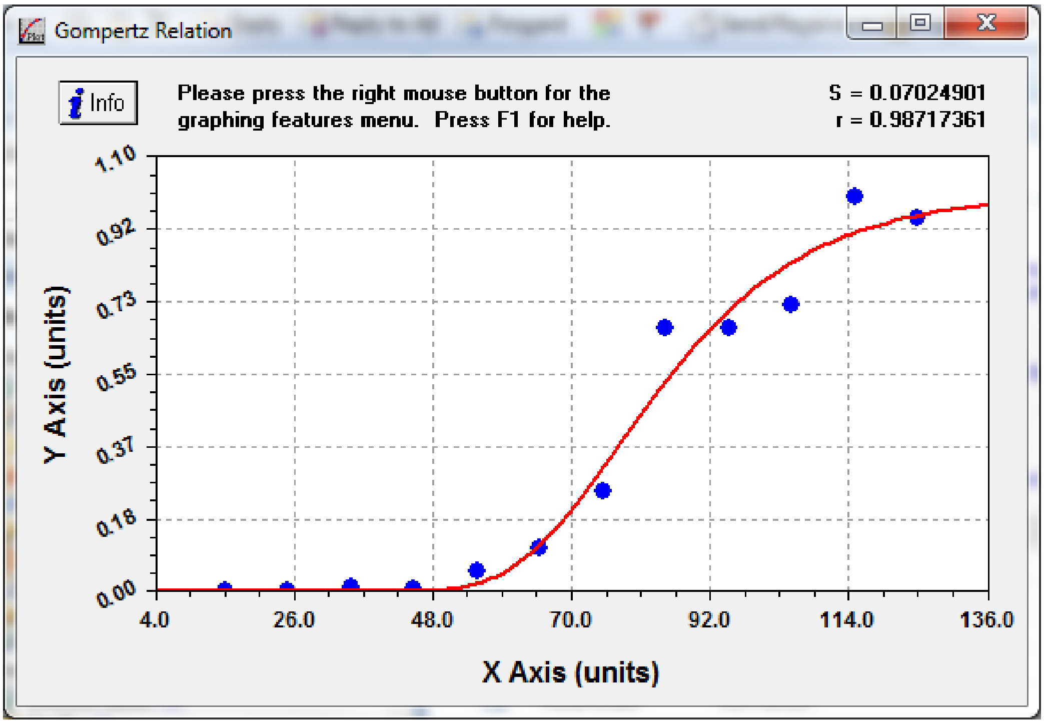
Gompertz Relation: y=a*exp(-exp(b-cx))

Coefficient Data:

a = 1.00732033912E+000

b = 4.69131517790E+000

c = 6.06091618862E-002

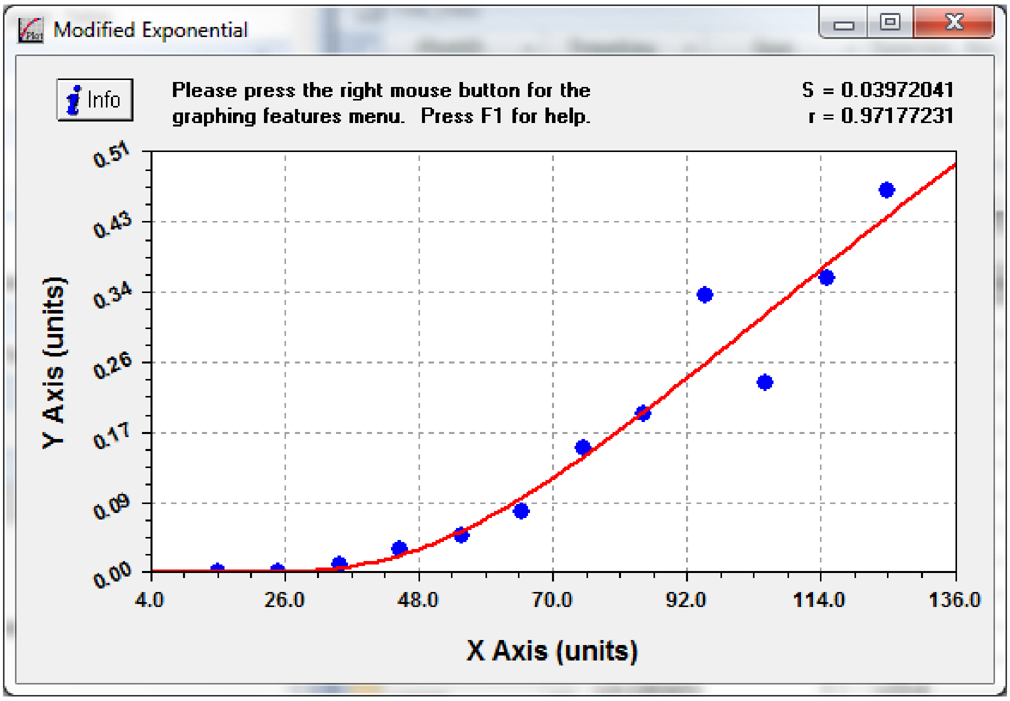


X Axis = Diameter at breast height over bark (cm)

Y Axis = Probability of tree containing hollows

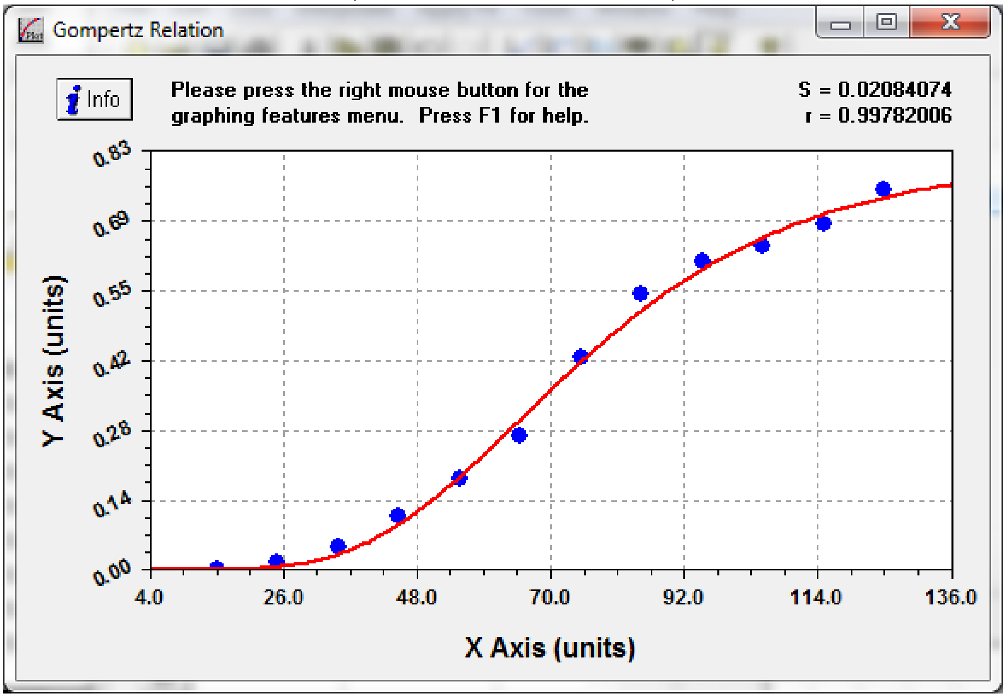
Model 3: Species Group 2 – Other Commercial Species: High Quality Trees

Modified Exponential: y=a*e^(b/x)
Coefficient Data: a = 2.34515389785E+000; b = -2.10213095064E+002

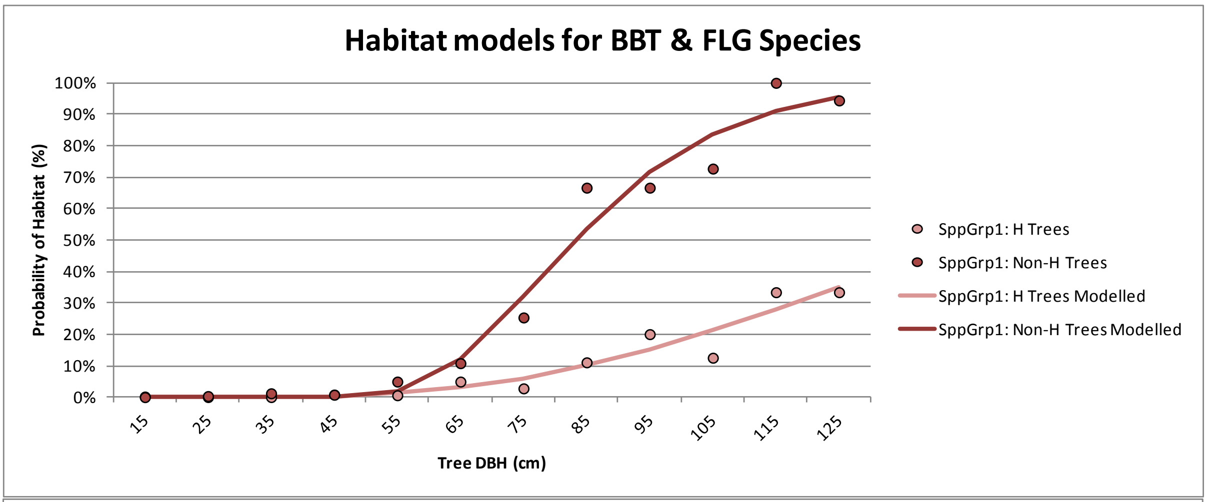


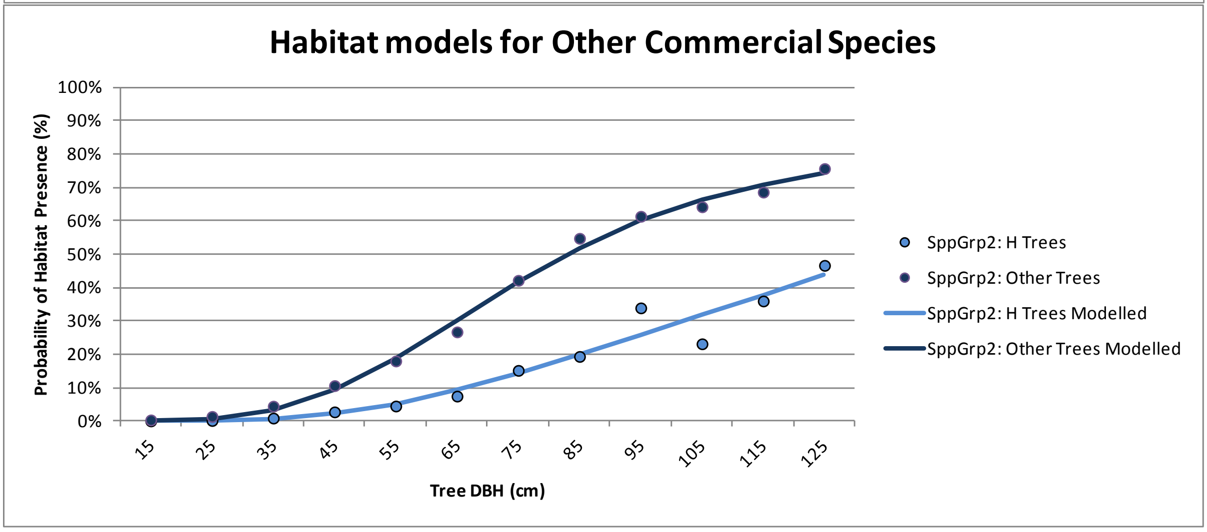
X Axis = Diameter at breast height over bark (cm)
Y Axis = Probability of tree containing hollows

Model 4: **Spp Group 2: Other Commercial Species: Non H Quality Trees**
Gompertz Relation: y=a*exp(-exp(b-cx))
Coefficient Data:
a = 8.14857860506E-001; b = 2.53957411790E+000; c = 3.91515821608E-002



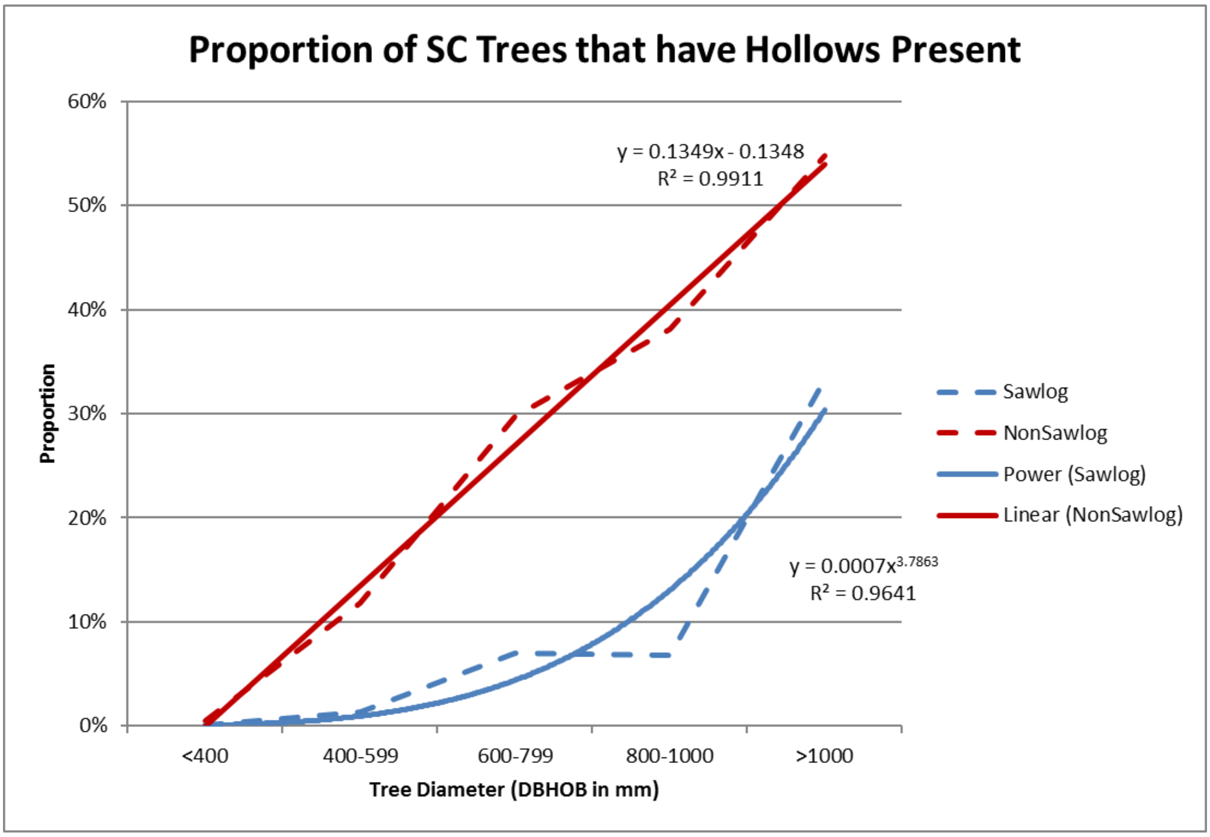
North Coast Models combined





South Coast

Two models were developed for the South Coast based on all commercial species combined and sawlog and non-sawlog tree quality categories.



Discussion

Best-fit statistical models applied to the hollow-bearing tree data for both the North Coast and South Coast show strong relationships to hollow likelihood and tree diameter. Increasing diameter is related to increasing likelihood of a tree containing hollows. This result is not surprising as hollow development is an age-related process and as trees grow older they typically grow larger. Within a stand of trees however the size and age of trees is not necessarily always closely related and the likelihood of the individual tree being hollow is typically a combination of age, size and damage. Dominant trees grow faster than sub-dominant trees so similar age trees in a stand can be vastly different in size. This is evident in the strongly different probability functions between trees assessed and high quality (sawlog) and low quality (non-sawlog) for both the North Coast and South Coast. High quality trees are typically straight and tall and faster growing than low quality trees. As a consequence high quality trees typically develop hollows at a larger diameter than lower quality trees that through age, damage, and growth position are often slower growing.