Biodiversity Assessment Project
for the

Western Newfoundland
Model Forest

MODEL FOREST NETWORK
RÉSEAU DE FORÊTS MODÈLES

Biodiversity assessment of four forest management scenarios in District 15, Western Newfoundland (Revised version)

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February 2006

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Summary

Indicator models related to forest landscape conditions have been applied to four different forest management scenarios in District 15 of Western Newfoundland Model Forest to assess biodiversity sustainability over a 200 years horizon. Biodiversity indicators were developed to express landscape structure (fragmentation), ecosystem diversity and wildlife habitat quality of three species, being the pine marten, the woodland caribou and the boreal owl. Forest management scenarios were developed according to contrasting planning rules in the spatio-temporal layout of the harvest blocks in terms of block size, block dispersion and compartment accessibility. Among them, a scenario was specifically developed for providing more pine marten high quality habitat. Analyses were performed on the several indicators in order to detect a) difference among the scenarios, b) linear temporal trends over the 200 years of the horizon, and c) departure from initial forest conditions using ANOVA, linear regression and comparison to a theoretical mean. Multivariate analysis using principal component analysis was also used to look after global ecosystem and adjacency composition difference among scenarios and switch over time. Trade-offs analysis was conducted between harvest level and biodiversity indictors using linear regression techniques.

Results show that the four scenarios differed for many dimensions of biodiversity. Among the most discriminating ones, mention forest age, landscape composition and diversity, landscape fragmentation and wildlife habitat quality. Old age classes were more abundant in the Pine Marten Friendly scenario (PMFR). This scenario was the only one sustaining such landscape element over the course of the horizon at a level similar to the initial conditions. However, even in this scenario, the oldest age classes are reducing with time.

Landscapes are on average globally not different in composition across the scenarios. However, I observed a lost of habitat diversity in all scenarios over the course of the simulation due to a drastic loss of the hardwood component and an unmixing of softwood mixed habitat types mostly at the expense of pure fir stands. The PFMR scenario is switching a little bit slower in composition because, I think, of the reserve effect of the Pine Marten Management Units (PMMUs), delaying composition switch in these “frozen” landscape portions.

Fragmentation was greater in the FRAG than in the BAU and the PFMR than in the AGGR. However, core area, in general, was not different among scenarios. When considering softwood over-mature habitat, mean patch size and patch size percentiles get the biggest in the PMFR scenario, probably do to the reserve effect of the use of the PMMUs. As the amount

of core area do not change for over-mature with time for any scenario, I believe that the fragmentation effect is not too strong in any scenario for biodiversity important values.

All scenarios allowed maintaining pine marten male populations and habitats of high quality at a level at least equal to what it is actually. The PMFR, the pine marten specifically designed forest management scenario, generated landscape allowing to support 18% more than the Business-As-Usual (BAU) scenario. However, this difference is mainly due to a harvest level reduction rather than the use of the PMMUs as floating reserves.

For the woodland caribou, the calving habitat did not seem to be sensitive to the forest management. No difference was detected for the calving habitat among the scenarios. Moreover, the calving habitat suitability is increasing with time in all scenarios. The wildlife model that was discriminating the most among the scenario was the woodland caribou wintering habitat. PMFR and FRAG scenarios were providing landscapes with better suitability index value for the wintering habitat. All scenarios were showing a rapid decline in wintering habitat at a lower level than the starting conditions. The boreal owl habitat suitability index did not differ among the scenarios for the entire horizon, although we were observing greater variation in the PMFR scenario with very low value in the first century and higher value in the last century of the simulation.

In conclusion, I identify six critical biodiversity issues that will need to be addressed by the next forest management plan. These are:1-Forest age structure, 2-Forest composition, 3-Over-mature habitat patch size, 4-Pine marten population, 5-Woodland caribou wintering habitat, 6-Boreal owl habitat. Each biodiversity issue is summarized and recommendations for addressing the issue are proposed.

Acknowledgements

First of all, I would like to thanks the Western Newfoundland Model Forest and its partners (Kruger CBPP, Abitibi-Consolidated, Department of Natural Resources, Department of Tourism, Culture and Recreation - Inland Fish and Wildlife Division, Gros Morne - Parks Canada, Canadian Forest Service - Natural Resources Canada) for their support in this project. We have learned a great deal of knowledge all through that journey, applying daily the principle of continuous learning that is at the very center of adaptive management. As this project has been ongoing for many years, many people have contributed to it, from close to far collaborations. I would like to thank the BAP working group (Stephen Balsom, Carl marks, Christine Doucet, Mathew Churchill, Dave Poole, Don Brain, Jana Fenske, Jason pond, Jim Taylor, Len Moores, Reg Parsons, Scott Taylor, Sean Dolter, George VanDusen, Xinbiao Zhu), and particularly its coordinator, Tim Moulton, for all the support and the clear direction they have been giving to this project from the very start. Sean Dolter from the Western Newfoundland Model Forest has taken in charge in a very professional way of all the management aspects of this project that involves many partnerships, making sure that all the players together will contribute and get to a same understanding of the biodiversity issues in the WNMF. I am also thankful of Jason Pond, from the Forest Ecosystem Management Division of the Newfoundland Forest Service at the ministry of Forest Resources and Agrifoods, who has been in charge of preparing the forest management scenarios and to produce the simulation of these scenarios with the harvest scheduler model; his work was crucial to this project. Many other people in Newfoundland and Labrador have put their own ingredients in this project and I would like to acknowledge all their participation:

- Len Moores, Jim Taylor and George VanDusen for their interest to see this project happenning;
- Christine Doucet, Neal Simon, Jana Fenske in regards of the HSMs;
- Darren Jennings for his work with Woodstock-Stanley;
- Glenda Garnier for helping with the administrative aspects of the project;
- Doug Piercy, Carl Marks, Scott Taylor, Jason Pond and Tim Moulton for having run the BAP tool box on the forest projections.

Thanks are also expressed to Arnold Rudy, from KBM Consultants in Thunder Bay, who was in charge of adjusting the BAP Toolbox codes in order to make it working for the WNMF and also for his translation of the vector Pine Marten population/habitat model into a raster environment.

Finally, I would like to thank to persons working with me at the IQAFF: Benoit Lafleur has really helped me in analyzing the results of the BAP indicators and Régis Pouliot was indispensable for his GIS, database and programming support.

This project has been funded through the Model Forest Program of the Canadian Forest Service.

Introduction

Biodiversity conservation in managed forests has been recognised by scientists as a cornerstone for ensuring forest sustainability (Burton *et al.* 1992, Gustafsson and Weslien 1999). Nowadays in forestry, maintaining biodiversity while using the forest for human uses, like timber, has become the major challenge of applying the paradigm of ecosystem management (Grumbine 1994). As humans better understand ecosystem functioning and the numerous relationships among its elements, which interact at different scales, we, at the same time, just start to measure the challenge of managing such complexity. The tools traditionally used are now outdated by the complexity of the overall system. Forest managers are thus in need of strategic planning analytical tools for assessing alternative management strategies in terms of biodiversity values.

In order to help forest managers to include biodiversity in their forest management value assessment, we developed an analytical procedure and a strategic planning toolbox (Biodiversity Assessment Project, BAP) (Doyon and Duinker 2003). The Biodiversity Assessment Project (BAP) has first been applied for a publicly owned forest managed by Millar Western Forest Products in Alberta (Doyon and Duinker 2003, Van Damme *et al.* 2003). In the BAP approach, potential responses of the forest to forecasted actions are simulated using projection tools and relevant indicator models are applied to the projections to track changes in abundance or quality of valuable forest conditions. The analysis of the indicator model outcomes leads to a reformulation and retesting of the management strategies until an acceptable management strategy is achieved (forecasting loop). Such a portrayal is consistent with well-established frameworks for adaptive management (Walters 1986).

The Western Newfoundland Model Forest is a partnership of diverse stakeholders dedicated to sustaining Newfoundland and Labrador's natural forest resources for the benefit and use of all residents, both now and in the future. Its vision is to promote the use of Newfoundland and Labrador's forests to sustain biodiversity, provide employment and opportunities for recreation, and ensure a healthy environment for years to come. As biodiversity is at the very center of all aspects of forest sustainability, the WNMF has developed a project that uses the BAP technology specifically parameterized for the District 15 of Newfoundland and Labrador aiming at defining a forest management strategy that would actualize the strategic vision of the province. Since 2002, efforts have been made to transfer the BAP technology to Western Newfoundland by the Western Newfoundland Model Forest (WNMF) (Dolter 2004).

The objectives of this project were:

? To develop models of bioindicators appropriate to Western Newfoundland conditions for evaluating landscape patterns, ecosystems distribution, and habitat quality of selected vertebrate species;

? To develop forest management scenarios different enough to provide insightful information when being compared in order to detect trade-offs among values;

? To analyze and compare bioindicator model performances over the long term according to forest projections obtained under the forest management scenarios;

? To provide guidance, based on the results, for silvicultural practices and forest management strategies that will help to maintain biodiversity.

Methodology

BAP Structure

As biodiversity covers multiple aspects, we developed indicator models for landscape patterns, ecosystem diversity, and habitat supply of selected vertebrate species (Table 1). Such a strategy was inspired by the coarse- and fine-filter approach in conservation biology (Hunter 1990) where landscape pattern and ecosystem diversity indicators serve as coarse filters while the habitat supply models (HSMs) as fine filters. Each of these three levels of biodiversity forms an independent analytical module of a suite of bioindicator models linked to forest projection tools (Doyon and Duinker 2003, Rudy 2000).

In choosing indicators of forest sustainability in terms of spatial configuration, we wanted to be capable of detecting unnatural conditions of spatial arrangement of habitats and levels of fragmentation. According to Riitters *et al*. (1995), many of the landscape metrics are redundant, so we followed their recommendation in selecting our landscape configuration indicators (Table 1).

For the last level of biodiversity, we used HSMs of certain wildlife species considered important in the region. The HSMs were based on the most up-to-date literature on the wildlife species and we used the envirogram technique (Andrewartha and Birch 1984) as proposed by Van Horne and Wiens (1991) to conceptualize the models. As spatial arrangement and scale of suitable habitat patches is an important consideration in the model interpretation, special attention was put on spatial components in the models. To indicate the potential value of each pixel as the center of the home range, we carried out a process known as home-range smoothing (Daust and Sutherland 1997), which averages the suitability index (SI) values inside a circular area comparable in extent to the home range of the species. The species modelled were the pine marten (need a reference here!), woodland caribou (Doyon and Côté 2003), and boreal owl (Doyon, Côté and Bergeron 2003) (Table 1).

Table 1. Indicators modelled in the BAP toolbox for Western Newfoundland Model Forest

LANDSCAPE PATTERN	ECOSYSTEM DIVERSITY	WILDLIFE HABITAT SUPPLY
Patch area	Are-weighted stand age	**Birds**
Patch shape	Habitat type proportion	Boreal Owl
Mean edge contrast index	Habitat diversity	**Mammals**
Contrast-weighted edge length		Pine Marten
Core area by habitat type		Woodland Caribou
Length of different adjacency		
Mean-nearest neighbour*		
Contagion*		

* Although available in the BAP tool box, they were not use for this round of analysis

Habitat types: the building blocks for BAP

To apply the BAP approach to Western Newfoundland, landscape and ecosystem parameters have been adjusted to reflect forest conditions encountered the territory of District 15, which encompasses most of the WNMF (Doyon 2003). As forestry has a major impact on biodiversity by changing within habitat-structure as well as the proportion and the spatial distribution of habitats in the landscape (Hunter 1990, Thompson *et al.* 1993), we developed a habitat classification procedure proper to Western Newfoundland conditions. In the Biodiversity Assessment Project, habitats are the units used for the ecosystem and the landscape biodiversity assessment and allow to track changes in environmental conditions in the landscape under a disturbance regime (forest management or any other disturbance regime) (Doyon 2000). Classification of meaningful habitat units is a critical step, particularly when spatial considerations are taken in account (MacGarigal and Whitcomb 1995).

As forest management activities alter mainly terrestrial forested habitats, emphasis was placed on these habitats. Terrestrial habitats were split first by separating forestable and non-forestable habitats. Non-forestable habitats have been organised into woody and non-woody habitats. These habitats were: scrubs & stand remnants, bogs, and bare lands. Although recent results using past aerial photographs shows that over long run (century), scrubs are slowly changing to forests and vice-versa, all these three non-forestable habitats were considered static when the forest was projected in the future.

Forestable habitats were firstly separated based on the composition, and then according to their structure (Doyon 2000). To do so, a two-level hierarchical classification procedure has been developed. For composition, we defined a broad level, which expresses more the vegetation type, and the specific level, which described the tree species association. For the structure, a first level (strucstage) discriminates developing and forested stands, while the second level (standstage) describes more finely the silvicultural stage of the stand. Since, the number of habitat types is also a critical issue as the complexity of analysis grows exponentially with the number of habitat types, we tried to limit the number. The ecological classification of Newfoundland forest has also served as a basis for identifying major habitat types (Meades and Moores 1994).

Three broad composition types have been defined (Doyon 2003). These are hardwood, mixedwood and softwood (Table 2). Specific composition classes were defined according to the representativeness of a species association in the landscape. Pure balsam fir habitat was very dominant at the starting landscape and we decided to split this habitat into two classes having different site productivity (Table 2). As this level of classification is hierarchically embedded in the broad habitat type, it had to be consistent with it (Table 2).

Table 2. Forestable habitat types according to the composition and structure at the two levels. Numbers give the habitat type code.

		Strucstage	Developing (1)		Forest (2)		Over-mature (3)
Broad	**Specific**	**Standstage**	Regenerating (11)	Sapling (12)	Immature (23)	Mature (24)	Over-mature (35)
Hardwood (1)	Hardwood (11)		1111	1112	1123	1124	1135
Mixedwood (2)	Hardwood / Mixedwood (21)		2111	2112	2123	2124	2135
	Softwood / Mixedwood (22)		2211	2212	2223	2224	2235
Softwood (3)	Fir on poor soil (31)		3111	3112	3123	3124	3135
	Fir on medium&good soil (32)		3211	3212	3223	3224	3235
	Fir / Spruce (33)		3311	3312	3323	3324	3335
	Spruce / Fir (34)		3411	3412	3423	3424	3435
	Spruce (35)		3511	3512	3523	3524	3535

For each specific composition type, we broke them down into five stand development stages (standstage, table 2). Developmental stages are periods within which habitat structure is considered maintaining similar attributes while it ages. They are: *regenerating*, *sapling*, *immature*, *mature* and *over-mature* stages (Doyon 2000). *Regenerating* and *sapling* developmental stages make up the *developing* structural stage, *immature* and *mature* developmental stages make up the *forest* structural stage.

The age breakdowns separating the developmental stage have been adjusted according to the specific composition types (Table 3).

Table 3. Age (years) of developmental stages for each specific composition.

	Developmental stages				
Specific composition	Regenerating	Sapling	Immature	Mature	Over-mature
Hardwood	0-10	11-20	21-40	41-100	101+
HWD / Mixedwood	0-10	11-20	21-40	41-100	101+
SWD / Mixedwood	0-10	11-20	21-40	41-100	101+
Fir on poor soil	0-10	11-20	21-40	41-100	101+
Fir on med.&good soil	0-10	11-20	21-40	41-100	101+
Fir / Spruce	0-10	11-20	21-45	46-130	131+
Spruce / Fir	0-10	11-20	21-50	51-145	146+
Spruce	0-15	16-25	26-55	56-150	151+

Habitat similarity analysis

Many indicators (adjacency analysis, diversity index, core area, mean edge contrast index, contrast-weighted edge length) use a weighting factor that aims at reflecting the difference in habitat structure between two habitat types (Rudy 2000). To provide such weighting factor, we used the results from a similarity analysis previously performed (Doyon 2000). Such analysis was conducted using the temporary sample plots (TSPs) and the permanent sample plots (PSPs) collected in District 15. Internal habitat features were derived from the data collected in these plots. After having classified each plot in one of the 40 habitat types according to its stand age and composition, similarity between two different habitat types were computed by averaging the similarities between all combinations of two plots from in each of the two habitats respectively. Similarities (or contrasts) between forested and non-forested habitats were assigned subjectively, based on the difference in habitat structure. A height/age curve was also derived from this analysis and was used in determining stand height for the Pine Marten Habitat Supply Model (Doyon 2002).

Forest projections

Forest management scenarios were designed to explore contrasted conditions of the forest management feasible space bounded by changes in silviculture practices and its spatial layout. Four forest management scenarios were developed for comparing outcomes of the biodiversity indicators. These scenarios are BUSINESS-AS-USAL (BAU), AGGREGATED (AGGR), FRAGMENTED (FRAG), and PINE-MARTEN FRIENDLY (PMFR) and they differ mostly in the spatial distribution of clearcutting cutblocks and harvest level. These scenarios were modelled using Woodstock-Stanley Version X.X (Remsoft Inc.), providing forest projections for a horizon of 200 years, with 5 year steps. In this model, succession was stochastic and the transition probabilities between strata curves had been defined according to the origin disturbance (clearcut in most cases) (Doyon 2002). These transitions were based on stand dynamics described in Meades and Moores (1994) and local expert judgements. Details of the parameters used in the Woodstock-Stanley model for each scenario are provided in Pond (2004).

Applying the BAP TOOLBOX on the forest projections

Forest projections were translated for being used by the BAP toolbox in the Arc-GIS environment. All coarse filter (landscape and ecosystem) indicators were run except mean-nearest neighbour and contagion indicators. For the indicators that are computed by habitat type (patch size, patch shape, core area and age class distribution), only the combination of broad composition and structural stages was used (nine broad habitat types). These indicators were also computed for all the forest, regardless of the habitat type. For the pine marten HSM, population density was derived using 10 resampling of random male territory (Pine Marten HSM document?).

Data analysis

I used one-way ANOVA (type III sums of squares) to test for differences in the mean of the biodiversity indicators between forest management scenarios. Duncan's mean range tests were conducted when the ANOVAs were significant (P ? 0.05) to identify which scenarios differed.

The analysis of variance model used was written as:

$$y_{ij} = \mu_i + \text{forest management scenario effect} + ?_{ij}$$

where

y_{ij} = *j*th observed sample value from the *i*th population;
μ_i = mean of the *i*th population; and
$?_{ij}$ = deviation of the *j*th observed value from its respective population mean.

Then, for each scenario, I used linear regression analysis to test for changes in biodiversity indicators over the 200 years projection. This was done in order to detect a temporal trend in the value for an indicator. I calculated the R^2 to determine the percentage of variation in the indicators explained by time, and the slope to determine the change in an indicator corresponding to a unit of change in time. I used the following linear regression model:

$$y_{ij} = ?_0 + ?_1(\text{Time}) + ?_{ij}$$

where

y_{ij} = *j*th observed sample value from the *i*th population;

$?_0$ = the intercept, i.e., the value of the line when *Time* = 0, and

$?_1$ = the slope of the regression line, i.e., the change in *y* corresponding to a unit of change in *Time*, and

$?_{ij}$ = deviation of the *j*th observed value from its respective population mean.

I used principal component analysis (PCA) to synthesize the change over time and the difference between forest management scenarios in habitat types and adjacency types (Legendre and Legendre 1983). In order to reduce the PCA matrix for adjacency types, I decided to include in the analysis the indicators corresponding to 97% of the information available. Therefore, of the 72 adjacency types found in the study area, 60 were used in the PCA, excluding the 12 adjacencies involving hardwood habitat types.

Statistical analyses were carried out using SPSS-Win 10.0 package (SPSS Inc. 1988, 2000).

Results

Harvest volume

1.1 Harvest level

Mean harvested volume differed among scenario (*F* = 56.956, *P*<0.001), each scenario being different from the others (Table 4). The BAU scenario had the highest mean harvest level while the PMFR scenario had lowest harvest level (BAU>AGGR>FRAG>PMFR).

Table 4. Mean harvest level (m^3/year) comparison between scenario and linear regression statistics of the temporal trend over the 200 years horizon.

Scenario	Anova				Regression			
	Mean	F	P	Duncan's	R2	Slope	F	P
BAU	422616	56.96	<0.001	a	0.02	39.80	0.315	0.582
FRAG	380732			c	0.79	243.47	29.206	0.000
AGGR	394686			b	0.56	223.85	8.020	0.011
PMFR	342895			d	0.13	-39.07	0.308	0.586

1.2 Even-flow

The harvest level is fluctuating along the course of the simulation (Figure 1). This is more obvious for the AGGR scenario, which had more wide amplitude variation with time, as expressed by higher standard deviation of harvest level (23 854 m^3/yr) than the three others (around 18 000 m^3/yr). The harvest level in BAU and PMFR scenarios does not significantly change linearly whereas it increases at a rate of more than 200 m^3/yr in the FRAG and AGGR scenarios (Table 4, Figure 1).

Coarse filter biodiversity indicators

2.1 Age indicators

2.1.1 Age class structure

Whatever the scenario, the forest age class structure is much similar, with two distinct groups of age classes, one between 0 and 65 years, and one between 65 and 165 years (Figure 2). Such structure is not the uniform one of a normalized forest. Although there was no significant difference between each scenario for each 10 years-classes, there was a tendency of seeing older forests under the PMFR scenario while younger forests are detected under the BAU scenario (Figure 2).

2.1.2 Area-weighted age

Area-weighted age significantly differed (F = 11.097; P <0.0001) among scenarios (Table 5). The PMFR scenario maintains the oldest forest and the BAU the youngest. AGRR and FRAG were not significantly different (Table 5).

Table 5. Age indicator ANOVA and regression statistics

Indicator	Scenario	Anova				Regression			
		Mean	F	P	Duncan's	R2	Slope	F	P
Area-weighted mean age	BAU	52.41	11.21	<0.001	c	0.30	-0.022	8.05	0.011
	FRAG	55.09			b	0.34	-0.024	10.11	0.005
	AGGR	54.63			b	0.42	-0.025	13.79	0.001
	PMFR	56.93			a	0.09	0.002	2.01	0.173
25th percentile	BAU	21.43	7.95	<0.001	b	0.00	-0.001	0.02	0.881
	FRAG	24.05			a	0.00	-0.002	0.07	0.796
	AGGR	23.57			a	0.00	-0.002	0.05	0.822
	PMFR	24.29			a	0.18	0.012	4.24	0.053
50th percentile	BAU	43.57	2.80	0.045	b	0.08	-0.021	1.69	0.209
	FRAG	46.43			a	0.37	-0.038	11.06	0.004
	AGGR	45.71			ab	0.24	-0.029	5.93	0.025
	PMFR	46.90			a	0.10	-0.021	2.17	0.157
75th percentile	BAU	71.66	7.33	<0.001	c	0.34	-0.072	9.91	0.005
	FRAG	77.86			b	0.29	-0.064	7.73	0.012
	AGGR	77.62			b	0.33	-0.070	9.57	0.006
	PMFR	82.86			a	0.16	-0.056	3.84	0.065

When we look at the temporal trend in forest age, all scenarios but PMFR showed a linear trend of getting slightly younger with time at the pace of 1 year of age every 50 years of the simulation.

2.1.3 Age percentile

Age percentiles were significantly different among the scenarios for the three age percentile indicators (P<=0.05). However, percentile indicators show that the difference between the four scenarios get stronger as we are considering older age classes (Table 5 and Figure 3). In fact, the differences were much more marked with the 75th age percentile where more then 10 years separated the BAU and PMFR scenarios while only 3 years differed between these two same scenarios for the 25th and the 50th age percentiles.

The age of the youngest first quarter of the forest did change over the long run, as the 25th age percentile indicator did not show a significant temporal trend over the 200 years of the horizon (Table 5 and Figure 4). However, the decrease was significant for the 50 percentile for the FRAG and AGGR scenarios, and for the 75 percentile for the BAU, FRA and AGGR scenarios. This result shows that not only the forest age is reducing with time but this reduction is mostly due to loss in the last percentile at a pace of 1 year of age every 15 years of simulation. However, the reduction in the oldest age class is all observed in the first 100, after what it stabilizes (Figure 4), showing that this effect is particularly severe in the fist half of the simulation.

2.1.4 Developmental stages

Development stages basically reflect the age class structure, as it is practically the same age breakdown scheme for any specific composition classes (except for the ones involving spruces, Table 3). In every scenario, about 37% of forests were classified as mature stands and 13 % as old stands (Table 6, Figure 5). Old habitats were greater in the PMFR scenario than in the BAU by approximately 3%, and greater than FRAG and AGGR by 1.5% (Table 6). The only significant temporal trend observed with the developmental stage was with mature forest in FRAG and AGGR scenarios (Table 6).

Table 6. Developmental stage proportion. ANOVA and regression statistics

Indicator	Scenario	Anova				Regression			
		Mean	F	P	Duncan's	R2	Slope	F	P
Regenerating	BAU	13.77	3.39	0.023	a	0.01	-0.002	0.27	0.609
	FRAG	12.87			ab	0.00	0.001	0.05	0.822
	AGGR	13.22			ab	0.00	0.001	0.05	0.823
	PMFR	12.45			b	0.08	-0.007	1.60	0.221
Sapling	BAU	12.40	2.13	0.103		0.01	0.003	0.27	0.607
	FRAG	11.56				0.03	0.004	0.51	0.486
	AGGR	11.85				0.04	0.004	0.71	0.409
	PMFR	11.42				0.00	-0.001	0.48	0.830
Immature	BAU	25.69	3.49	0.019	a	0.10	0.015	2.01	0.172
	FRAG	24.23			ab	0.14	0.016	3.15	0.092
	AGGR	24.79			ab	0.17	0.017	3.85	0.065
	PMFR	23.11			b	0.00	0.002	0.03	0.867
Mature	BAU	36.66	1.95	0.127		0.10	-0.018	2.17	0.157
	FRAG	38.56				0.30	-0.025	8.28	0.010
	AGGR	37.31				0.24	-0.026	6.02	0.023
	PMFR	38.75				0.00	0.002	0.01	0.907
Over-mature	BAU	11.48	5.19	0.003	b	0.01	0.003	0.14	0.710
	FRAG	12.77			b	0.03	0.005	0.49	0.492
	AGGR	12.83			b	0.01	0.004	0.27	0.606
	PMFR	14.27			a	0.01	0.005	0.22	0.643

2.2 Habitat diversity indicators

2.2.1 Diversity index

The four scenarios generated very similar habitat diversity values (Figure 6). The PMFR scenario had the highest average habitat diversity (0.1924), while the BAU and FRAG scenarios had the lowest average habitat diversity (0.1849). Although close to be, the difference was not significant (P=0.0547).

Over the course of the simulation, however, the habitat diversity values varied widely within scenarios (Figure 7). Every scenario had their highest habitat diversity after 40 to 50 years, and their lowest diversity value after 120 to 130 years. Between 150 to 200 years the diversity value increased for the four scenarios. By the end of the simulation, each scenario went back to their starting habitat diversity value. Over the simulation horizon, however, each scenario showed a significant decrease of its habitat diversity (Table 7). Indeed, we observed, after a slight increase in the diversity index for the first 50 years, a strong diversity reduction for the following 70 years (Figure 7).

Table 7. Diversity index regression statistics

Indicator	Scenario	Regression			
		R2	Slope	F	P
Diversity index	BAU	0.32	-1.0E-04	8.96	0.007
	FRAG	0.33	-1.0E-04	9.50	0.006
	AGGR	0.19	-1.0E-04	4.52	0.046
	PMFR	0.22	-1.0E-04	5.24	0.034

2.3 Habitat type distribution

2.3.1 Specific habitat type distribution

The study area is largely dominated by softwood stands (86.44%). Mixedwood covered 12.72% while hardwood stands occurred marginally, covering only 0.83% of the study area. Among the habitat types, significant difference among scenarios where detected only for the softwood habitat types (Appendix 1). The hardwood component disappears with time (Figure 8), generating significant regression for all but regenerating and over-mature developmental stages (Appendix 1). As no recruitment in hardwood stands is seen in years 10 and on, I believe it is an artifact of model formulation in Woodstock. It seems that no process (deterministic or stochastic) in Woodstock have allowed the generation of hardwood stands. Consequently, because of that artifact and because of it low presence in the landscape, the following analyses will not consider the hardwood habitat type specifically.

For softwood habitats, we detected difference in importance among scenarios for 7 specific habitat types (Table 8). Over-mature pure fir on poor soil were more abundant in the PMFR scenario than all the others. Pure fir stands on medium and good soils were more important in the PMFR scenario for the mature forest stand stage and more abundant in the FRAG and the PMFR scenarios for the over-mature stand stage. However, the PMFR scenario had much less of the four youngest pure spruce stand stages than the three others scenarios.

In the hardwood-dominated mixedwood habitat types, significant temporal reductions were detected for regenerating (BAU, AGGR, PMFR) and over-mature stages (all scenarios) (Table 8). In the softwood-dominated mixedwood habitats, significant increase was detected for the over-mature habitat in the BAU scenario (Table 9).

Table 8. Significant difference in area (ha) of stand stage for softwood specific habitat types.

Specific composition	Stand stage	Scenario	Anova			
			Mean	F	P	Duncan's
Fir/poor soil	Over-mature	BAU	14190.20	6.65	<0.001	b
		FRAG	16057.35			b
		AGGR	16386.01			b
		PMFR	18851.36			a
Fir/good&med soil	Mature forest	BAU	19381.65	2.85	0.043	b
		FRAG	20955.63			ab
		AGGR	19532.43			b
		PMFR	21201.85			a
Fir/good&med soil	Over-mature	BAU	4799.64	5.04	0.003	b
		FRAG	6245.68			a
		AGGR	5526.96			ab
		PMFR	5726.96			a
Spruce	Regenerating	BAU	3348.65	46.23	<0.001	a
		FRAG	3256.11			a
		AGGR	3267.50			a
		PMFR	1172.77			b
Spruce	Sapling	BAU	2283.14	20.52	<0.001	a
		FRAG	2260.31			a
		AGGR	2233.57			a
		PMFR	881.58			b
Spruce	Immature forest	BAU	7888.74	30.27	<0.001	a
		FRAG	8060.56			a
		AGGR	7965.23			a
		PMFR	2916.36			b
Spruce	Mature forest	BAU	4880.34	25.62	<0.001	b
		FRAG	5994.73			a
		AGGR	5834.68			a
		PMFR	3961.01			c

Many temporal trends in softwood habitat were detected. Generally speaking, mixed softwood habitat type (fir/spruce and spruce/fir) were rapidly declining for almost all the stand stage and the scenarios, at the expense of the pure softwood habitat (fir and spruce) (Table 9). The only exception to this general rule was the spruce habitats in the PMFR scenario which was rather declining. The rate of decrease for the mixed softwood habitats is very fast (up to 100 ha/yr for the mature fir/spruce habitat), leading to almost the disappearance of the habitat type along the simulation horizon.

Table 9. Significant linear temporal area change (ha) of specific softwood habitat types.

Specific composition	Stand Stage	Scenario			
		AGGR	BAU	FRAG	PMFR
Hw-Mw	Regenerating	-7.67	-9.31		-11.04
Hw-Mw	Sapling				
Hw-Mw	Immature				
Hw-Mw	Mature				
Hw-Mw	Over-mature	-11.30	-11.30	-11.31	-11.30
Sw-Mw	Regenerating				
Sw-Mw	Sapling				
Sw-Mw	Immature				
Sw-Mw	Mature				
Sw-Mw	Over-mature		16.65		
Fir/poor soil	Regenerating				
Fir/poor soil	Sapling				
Fir/poor soil	Immature	40.53		34.56	
Fir/poor soil	Mature	80.32	90.91	88.82	124.15
Fir/poor soil	Over-mature	43.67	39.31	40.18	46.79
Fir/mediumj&good soils	Regenerating				
Fir/mediumj&good soils	Sapling				
Fir/mediumj&good soils	Immature		20.17	16.43	
Fir/mediumj&good soils	Mature				37.62
Fir/mediumj&good soils	Over-mature			9.25	
Fir/Spruce	Regenerating	-13.09	-14.47	-12.65	-12.48
Fir/Spruce	Sapling	-12.01	-12.44	-10.93	-10.91
Fir/Spruce	Immature	-33.74	-34.31	-31.47	-31.93
Fir/Spruce	Mature	-95.82	-92.57	-100.21	-101.54
Fir/Spruce	Over-mature				
Spruce/Fir	Regenerating				
Spruce/Fir	Sapling				
Spruce/Fir	Immature	-7.17	-7.70	-6.91	-6.40
Spruce/Fir	Mature	-51.91	-48.60	-50.81	-49.74
Spruce/Fir	Over-mature	-10.82	-9.87	-10.59	-11.09
Spruce	Regenerating	6.38	6.92		-7.29
Spruce	Sapling	6.05	5.84		-3.74
Spruce	Immature	29.50	25.09	29.03	
Spruce	Mature			7.80	-7.64
Spruce	Over-mature				

2.3.2 Habitat type ordination

Running the principal component analysis (PCA) has allowed to detect at least two significant components. The first PCA axis (PC 1) of the habitat type distribution explains 46.9% of the variance, and is positively correlated developing stands (hardwood, hardwood-dominated mixedwood, and fir/spruce (1112, 2111, 3311)), and with mature fir/spruce stands (3324, Figure 9). This axis is also negatively correlated with immature pure fir stands growing on poor soil (3123). The second axis (PC 2) explains 13.1% of the variance and is positively correlated with hardwood over-mature (1135), and with hardwood, fir/spruce, and spruce/fir immature stands (1123, 3323, 3423), and negatively correlated with pure fir mature stands growing on poor soil (3124).

The analysis of variance performed on the scores along PC 1 and PC 2 detected no difference between the four scenarios (PC 1: F = 0.425, P = 0.735; PC 2: F = 1.161 P = 0.330). Such result suggests that globally, over the long run, the forest composition was not different among scenarios.

To detect a temporal trend composition change, I plotted a transition vector by joining each simulation step in their step order (from year 0 to year 200, Figure 10). As there was no difference among the scenarios, I put the four points for all the scenario of a time step together. Such procedure has allowed us to show an overall tendency to move from the upper right quadrant to the lower left quadrant of the ordination space, particularly rapidly in the first 100 years (Figure 10). Such trend confirm the switch of composition change from softwood mixed types (3323, 3324, 3424) to pure fir/poor soil type (3123 and 3124) detected in the individual specific habitat analysis (Section 1.3.1), whatever the scenario is.

2.4 Adjacency analysis

2.4.1 Adjacency distribution

As District 15 is highly covered by non-forest habitat types, in the 10 most important adjacencies encountered in the study area almost all involved one non-forest habitat type (particularly “scrubs”) (Table 10). These first 10 adjacency types represent approximately 78% of the total edge length computed along the 200 years of the horizon. Forest habitats in these most important adjacencies involved mainly mature softwood forest.

2.4.2 Adjacency type ordination

Principal component analysis was also used to analyze the difference in the assemblages of adjacencies among scenarios. The first (PC 1) and second (PC 2) axes of the adjacency type distribution explain respectively 41.3% and 28.4% of the variance. PC 1 is positively correlated with scrub/softwood developing, bog/softwood developing, bare land/softwood developing and water/softwood developing adjacencies, and negatively correlated with scrub/softwood old, mixedwood forest/mixedwood old, softwood forest/softwood old adjacencies. PC 2 is positively correlated with scrub/softwood old, bog/mixedwood old, mixedwood old/softwood developing and mixedwood old/softwood forest adjacencies, and negatively correlated with scrub/softwood forest and mixedwood forest/softwood old (Figure 11) adjacencies.

Table 10. The 10 most important adjacencies in District 15 of Western Newfoundland overall all scenarios and the 200 years of the horizon.

Adjacency	Length (m)	%	% cumulative
Scrubs / SW mature	953080.45	27.00	27.00
SW developing / SW mature	396581.79	11.23	38.23
Scrubs / SW developing	367177.77	10.40	48.63
Bogs / SW mature	203169.54	5.75	54.39
SW mature / SW over- mature	196791.06	5.57	59.96
Scrubs / SW over- mature	172636.41	4.89	64.85
MW mature / SW mature	148994.27	4.22	69.07
Bare lands / SW mature	119 726.44	3.39	72.46
Water / SW mature	119 464.13	3.38	75.85
Bogs / SW developing	81052.45	2.30	78.14

An analysis of variance performed on PC 1 and PC 2 detected a significant difference between the scores of the scenarios along PC 1 ($F = 7.405$, $P < 0.001$) only. Along that component axis, the AGGR and PMFR scenarios had lower scores than the BAU and FRAG scenarios. The crosses in Figure 12 show these differences in scores on the first axis; AGGR and PMFR scenarios have more adjacencies involving old and forest habitats than BAU and FRAG that are more characterized by adjacencies involving developing softwood. Temporal transition vector of the scores of individual steps along the first two PC axes showed no clear temporal trends (Figure 12).

2.5 Patch size and core area

2.5.1 Overall patch size

When we perform the patch size analysis with habitat type not being distinguished, we find that patch size differs among the four scenarios (Table 11, Figure 13). The AGGR scenario had a significantly higher patch size (12.99 ha) than the three other scenarios while FRAG scenario had a significantly lower patch size (11.86 ha) than the three other scenarios ($F = 31.91$; $P < 0.001$). In two scenarios (BAU and AGGR), we observe a significant increase in patch size over the course of the simulation. However, only the AGGR scenario ended the simulation with a higher mean overall patch size area than at the start of the simulation (Figure 14).

Table 11. Mean patch size (ha) by scenario, regardless of habitat type, in District 15 of Western Newfoundland. ANOVA statistics of comparison among scenario and temporal linear regression statistics for each scenario are presented.

Patch size	**Scenario**	**Anova**				**Regression**			
		Mean	**F**	**P**	**Duncan's**	**R2**	**Slope**	**F**	**P**
Overall	BAU	12.24			b	0.21	0.003	5.05	0.037
	FRAG	11.87	31.91	<0.001	c	0.01	-0.001	0.16	0.694
	AGGR	12.99			a	0.74	0.006	54.63	<0.001
	PMFR	12.17			b	0.06	0.001	1.20	0.287
25th percentile	BAU	11.28			b	0.47	0.006	17.04	<0.001
	FRAG	10.99	25.18	<0.001	b	0.16	0.002	3.52	0.076
	AGGR	12.26			a	0.86	0.011	120.42	<0.001
	PMFR	11.22			b	0.29	0.004	7.59	0.013
50th percentile	BAU	35.73			b	0.58	0.031	26.66	<0.001
	FRAG	31.23	51.07	<0.001	c	0.02	-0.005	0.49	0.490
	AGGR	41.58			a	0.90	0.067	166.92	<0.001
	PMFR	34.03			b	0.11	0.009	2.30	0.146
75th percentile	BAU	103.20			b	0.01	0.015	0.25	0.625
	FRAG	76.50	79.11	<0.001	c	0.28	-0.110	7.34	0.014
	AGGR	131.35			a	0.73	0.217	50.95	<0.001
	PMFR	97.33			b	0.05	-0.028	1.05	0.318

2.5.2 Patch size by habitat type

I detailed at the different habitat classification levels the patch size analysis. By broad habitat, there is no difference among scenarios for hardwood and mixedwood habitat types (Appendix 1). For softwood, results are expressing the same results as the overall patch size analysis (Appendix 1). When looked at broad habitat type (combination of broad composition type and developmental stage), patch size differed among scenarios and temporal trends of change were significant only for softwood developmental stages (Appendix 1). Patch size was the biggest for the forest and the smallest for the over-mature developmental stages (Table 12). AGGR scenario allows obtaining the biggest patches of developing and forest habitat. Patch size was the biggest for over-mature in the PMFR scenario. Mean patch size of the developing stage was quite smaller than the target block size that was put in the Woodstock Stanley model (BAU:250 ha, FRAG:50, AGGR:300 and PMFR:free, Pond 2004). Except of the developing softwood habitat in the AGGR scenario, all significant temporal trends changes are showing a reduction in patch size (Table 12). This particularly through for the softwood forest habitat type in the FRAG scenario, at the pace of 2 ha for every 100 years. In all scenarios, patch size in softwood over-mature is reducing at the pace of 1 ha for every 100 years.

Table 12. Patch size (ha) statistics for softwood by developmental stage habitats

Developmental stage	Scenario	Anova				Regression			
		Mean	F	P	Duncan's	R2	Slope	F	P
Developing	BAU	21.829	52.280	<0,001	b	0.063	0.008	1.287	0.271
	FRAG	19.271			c	0.127	0.007	2.762	0.113
	AGGR	26.647			a	0.245	0.027	6.173	0.022
	PMFR	19.023			c	0.281	-0.015	7.414	0.014
Forest	BAU	40.561	9.540	<0,001	b	0.117	-0.013	2.507	0.130
	FRAG	41.982			ab	0.240	-0.021	5.985	0.024
	AGGR	42.526			a	0.053	-0.009	1.072	0.313
	PMFR	38.725			c	0.222	-0.019	5.410	0.031
Over-mature	BAU	9.993	3.320	0.024	b	0.224	-0.009	5.489	0.030
	FRAG	10.487			ab	0.288	-0.010	7.699	0.012
	AGGR	10.261			b	0.388	-0.012	12.033	0.003
	PMFR	11.096			a	0.335	-0.011	9.577	0.006

2.5.3 Patch size percentile

With the patch size percentile analysis, we are interested not be the average patch size but rather by the patch size distribution, particularly the largest percentile quarter (75th). Overall, regardless of habitat type, the patch size distribution among scenarios reflects the average patch size (Table 11). In general, the largest patch size class was separated (between the 50th and the 75th percentile) in the AGGR scenario by a size value (147 ha) almost twice as large as what it is in the FRAG scenario (80 ha) (Figure 15).

When looked at the broad composition level (HW, MW, SW), significant differences in patch size distribution among scenario were detected only for the softwood habitat type, except for the patch size 75th percentile of the developing mixedwood, which reflected the usual order (AGGR>BAU and PMFR>FRAG) (Appendix 1). Analyzed by softwood developmental stages (developing, forest, olg-growth), patch size distribution shows different results than the general trend as presented in Figure 15. For the developing stage, the PMFR scenario had a patch size distribution similar to the FRAG scenario, generating a different order (AGGR>BAU>PMFR and FRAG) (Figure 16). For the forest and the over-mature developmental stage, the difference among scenario was significant only for the 25th and the 50th percentile (Figure 17 and 18). Patch size distribution of the softwood forest developmental stage shows a different order among scenarios (AGGR>BAU and FRAG>PMFR) (Figure 17). Inversely, for the over-mature stage, the PMFR provided the biggest patches, followed by the FRAG scenario, followed by the AGGR and the BAU scenario (Figure 18). Interestingly, the last patch size class (75th percentile) for over-mature did not differ among the scenarios (Figure 18).

Over the course of the simulation, change in patch size distribution, when significant, for mixedwood broad composition habitats were all an increase in patch size, whatever the percentile (25th, 50th, or 75th) or the developmental stage (Table 13). However, the increase rate (slope) was rather low. Regardless of the developmental stage, when the patch size distribution was significantly changing over time, softwood habitats were increasing in size, except for the FRAG scenario at the 75th percentile with a rate of change that was rather small (Table 13). However, when distinguished at the developmental stage, the pattern over time and its magnitude was different, the percentile and the scenario (Table 13). At the developing stage, patch size percentile increases with time the AGGR scenario while decreases in the PMFR scenario. At the forest stage, the patch size percentile decreased for the significant combinations of scenario/percentile; the FRAG scenario had a significant relationship for the three percentiles indicator (Table 13). Finally, for the over-mature developmental stage, all significant temporal trends were showing a reduction in patch size distribution, even in the AGGR scenario, although none of the scenarios significantly changed for the 75 percentile indicator.

2.5.4 Core area

Area of core habitat differed among scenario when all habitat are considered, for general mixedwood and softwood habitats, and for softwood developing, and softwood over-mature habitats (Table 14). For the overall, the softwood and the softwood developing habitat, core area was the smallest in the PMFR and FRAG scenarios. However, the picture was inversed when considering softwood over-mature and mixedwood habitats.

Temporal trends that were significant all show an increase in core area over the course of the horizon at a pace of around 20 ha/year (Table 14). The AGGR scenario was the scenario the most often significant for the different habitats type and levels.

2.5.5 Core area patch size

Core area patch size behaves like patch size for most of it (Table 15). When looked overall, regardless of habitat type, scenarios ranked the same way as for patch size (Figure 19). The AGGR scenario had the highest average core area patch size (5.78), and the FRAG scenario the lowest area patch size (5.42) ($F = 15.748$; $P < 0.001$). On average, the AGGR scenario had a core area patch size 5% higher than the other scenarios. Over the course of the horizon, all scenarios show a significant increase in the overall core area patch size (Table 15) while it was not the case for patch size alone (Table 11).

When detailed at sub-level habitat types, many scenarios showed significant temporal linear increase in the core area patch size of over the projection (Table 16). Among core area-changing forest types, every scenario showed a significant increase for mixedwood and over-mature mixedwood habitats. The FRAG scenario showed a significant increase in core area patch size for developing softwood, and the AGGR scenario showed significant increases for developing mixedwood, developing softwood, and softwood.

2.5.6 Core area patch size percentile

Because of the accentuated effect of edge on size in the core area indicator, core area size distribution is different than patch size. Overall, the AGGR scenario had significantly larger core areas for the 25 and 50 percentiles, while the PMFR scenario had significantly larger core areas for the 75 percentile. Indeed, for the 75th percentile of core area, the order of core area is PMFR>FRAG>AGGR and BAU (Table 15).

Over the 200 years projection, the four scenarios showed a significant increase for the 25 percentile. A significant increase was also detected for the BAU and AGGR scenarios for the 50 percentile, while a significant decrease was detected for the FRAG scenario (Table 15). Although patch size 75th percentile was decreasing in the FRAG scenario and increasing in the AGGR scenario with time (Table 11), the largest percentile quarter of core area patch size was not significantly changing with time in any scenario.

Table 13. Significant linear regression statistics of the temporal trend for patch size percentiles by developmental stage habitats under four forest management scenarios in District 15 of Western Newfoundland over the course of the 200 years of the simulation horizon.

Composition	Dev. Stage	Scenario	Percentile	R^2	Slope	F	P
SW	Overall	AGGR	75	0.72	0.192	48.007	0.000
MW	Overall	BAU	75	0.77	0.150	62.962	0.000
MW	Overall	AGGR	75	0.69	0.143	42.486	0.000
MW	Overall	PMFR	75	0.62	0.098	30.334	0.000
MW	Overall	FRAG	75	0.64	0.096	33.512	0.000
SW	Overall	FRAG	75	0.36	-0.160	10.695	0.004
SW	Overall	AGGR	50	0.91	0.074	181.897	0.000
MW	Overall	AGGR	50	0.73	0.045	52.345	0.000
MW	Overall	BAU	50	0.64	0.043	33.313	0.000
MW	Overall	FRAG	50	0.62	0.029	31.469	0.000
SW	Overall	BAU	50	0.40	0.024	12.481	0.002
MW	Overall	PMFR	50	0.56	0.024	23.971	0.000
MW	Overall	AGGR	25	0.78	0.014	65.867	0.000
MW	Overall	BAU	25	0.68	0.011	39.474	0.000
SW	Overall	AGGR	25	0.87	0.010	125.223	0.000
MW	Overall	FRAG	25	0.60	0.008	28.630	0.000
MW	Overall	PMFR	25	0.55	0.007	23.558	0.000
SW	Overall	BAU	25	0.36	0.004	10.751	0.004
SW	Overall	PMFR	25	0.23	0.003	5.614	0.029
MW	Over-mature	FRAG	75	0.34	0.567	9.953	0.005
MW	Over-mature	AGGR	75	0.33	0.560	9.136	0.007
MW	Over-mature	BAU	75	0.30	0.531	8.134	0.010
MW	Over-mature	PMFR	75	0.22	0.361	5.389	0.032
MW	Over-mature	BAU	50	0.30	0.161	8.038	0.011
MW	Over-mature	AGGR	50	0.31	0.159	8.541	0.009
MW	Over-mature	FRAG	50	0.27	0.145	7.102	0.015
SW	Over-mature	AGGR	50	0.19	-0.042	4.497	0.047
SW	Over-mature	BAU	25	0.21	-0.011	4.938	0.039
SW	Over-mature	FRAG	25	0.31	-0.014	8.377	0.009
SW	Over-mature	PMFR	25	0.26	-0.014	6.611	0.019
SW	Over-mature	AGGR	25	0.37	-0.015	10.977	0.004
SW	Forest	AGGR	75	0.27	-19.005	6.901	0.017
SW	Forest	FRAG	75	0.42	-23.895	13.487	0.002
SW	Forest	FRAG	50	0.40	-5.504	12.691	0.002
SW	Forest	BAU	25	0.28	-0.256	7.448	0.013
SW	Forest	PMFR	25	0.40	-0.334	12.402	0.002
SW	Forest	FRAG	25	0.31	-0.425	8.550	0.009
SW	Developing	PMFR	75	0.56	-1.055	23.814	0.000
SW	Developing	AGGR	50	0.28	0.234	7.526	0.013
MW	Developing	AGGR	50	0.19	0.044	4.403	0.049
SW	Developing	PMFR	50	0.59	-0.243	27.153	0.000
SW	Developing	AGGR	25	0.37	0.108	10.940	0.004
MW	Developing	AGGR	25	0.20	0.016	4.613	0.045
SW	Developing	PMFR	25	0.47	-0.036	16.486	0.001

Table 14. Corea area by scenario, by habitat type, in District 15 of Western Newfoundland. ANOVA statistics of comparison among scenarios and temporal linear regression statistics for each scenario are presented.

Habitat	**Scenario**	**Anova**				**Regression**			
		Mean	**F**	**P**	**Duncan's**	**R2**	**Slope**	**F**	**P**
Overall	BAU	215172	11.9	<0.001	a	0.094	15.399	1.969	0.177
	FRAG	212450			b	0.126	15.407	2.733	0.115
	AGGR	215488			a	0.328	22.391	9.285	0.007
	PMFR	211382			b	0.001	-1.412	0.025	0.877
MW	BAU	35161	7.77	<0.001	b	0.142	11.381	3.152	0.092
	FRAG	35141			b	0.123	11.937	2.654	0.12
	AGGR	35742			b	0.357	19.06	10.554	0.004
	PMFR	37679			a	0.477	21.172	17.321	0.001
MW developing	BAU	4679	1.05	0.365		0.021	-2.507	0.398	0.536
	FRAG	4280				0.003	-0.891	0.051	0.824
	AGGR	4795				0	0.297	0.007	0.932
	PMFR	4400				0.082	-5.212	1.7	0.208
MW Forest	BAU	8595	0.43	0.732		0.012	4.221	0.224	0.641
	FRAG	8571				0.003	2.34	0.064	0.804
	AGGR	8647				0.026	6.331	0.508	0.485
	PMFR	9332				0.034	8.323	0.659	0.427
MW over-mature	BAU	3470	0.26	0.852		0.053	5.603	1.063	0.315
	FRAG	3507				0.047	5.387	0.944	0.343
	AGGR	3602				0.044	5.332	0.883	0.359
	PMFR	3869				0.046	6.19	0.914	0.351
SW	BAU	244454	7.46	<0.001	a	0.55	26.497	23.221	<0.001
	FRAG	244416			a	0.504	25.848	19.328	<0.001
	AGGR	243817			a	0.38	18.714	11.667	0.003
	PMFR	241938			b	0.491	16.676	18.323	<0.001
SW developing	BAU	36698	20.7	<0.001	a	0.171	14.892	3.906	0.063
	FRAG	32873			b	0.203	19.033	4.826	0.041
	AGGR	35949			a	0.359	23.705	10.622	0.004
	PMFR	31991			b	0.05	-6.705	0.991	0.332
SW Forest	BAU	56306	1.92	0.133		0.008	3.531	0.15	0.703
	FRAG	56945				0.02	-5.655	0.396	0.537
	AGGR	56074				0.045	-7.355	0.895	0.356
	PMFR	55253				0.053	7.983	1.072	0.314
SW over-mature	BAU	7127	4.88	0.04	b	0.115	7.175	2.458	0.133
	FRAG	8620			a	0.169	12.406	3.871	0.064
	AGGR	8143			ab	0.113	8.179	2.422	0.136
	PMFR	9007			a	0.073	8.531	1.491	0.237

Table 15. Mean core area patch size (ha), by habitat type, in District 15 of Western Newfoundland. ANOVA statistics of comparison among scenarios and temporal linear regression statistics for each scenario are presented.

	Scenario	Anova				Regression			
		Mean	**F**	**P**	**Duncan's**	**R2**	**Slope**	**F**	**P**
Overall	BAU	5.58	15.74	<0.001	b	0.58	0.002	25.99	**<0.001**
	FRAG	5.42			c	0.38	0.001	11.78	**0.003**
	AGGR	5.78			a	0.63	0.003	31.70	**<0.001**
	PMFR	5.54			b	0.28	0.001	7.36	**0.014**
25th percentile	BAU	10.52	15.75	<0.001	b	0.80	0.007	75.53	**<0.001**
	FRAG	9.87			c	0.42	0.003	13.90	**0.001**
	AGGR	11.33			a	0.82	0.011	85.83	**<0.001**
	PMFR	10.34			b	0.33	0.003	9.17	**0.007**
50th percentile	BAU	48.74	31.84	<0.001	b	0.23	0.015	5.72	**0.027**
	FRAG	41.21			c	0.29	-0.025	7.82	**0.011**
	AGGR	54.10			a	0.66	0.043	37.21	**<0.001**
	PMFR	47.81			b	0.03	0.005	0.55	0.469
75th percentile	BAU	6168.86	89.64	<0.001	b	0.02	-0.821	0.47	0.502
	FRAG	6313.52			ab	0.13	-3.187	2.96	0.102
	AGGR	6097.03			b	0.03	-0.037	0.632	0.437
	PMFR	6527.42			a	1.0E-03	0.356	0.02	0.892

Table 16. Core area patch size temporal trends by habitat type, in District 15 of Western Newfoundland as expressed by linear regression statistics for each scenario.

	BAU			FRAG			AGGR			PMFR		
	Slope	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value
MW	0.009	0.60	**<0.001**	0.007	0.56	**<0.001**	0.012	0.74	**<0.001**	0.006	0.50	**<0.001**
Dev.	0.004	0.15	0.082	0.003	0.10	0.163	0.007	0.29	**0.012**	0.001	0.01	0.669
Forest	0.001	0.01	0.679	0.000	0.00	0.961	0.002	0.01	0.609	0.000	0.00	0.978
Overmat.	0.010	0.46	**0.001**	0.009	0.44	**0.001**	0.009	0.42	**0.001**	0.006	0.20	**0.043**
SW	0.001	0.06	0.302	-0.002	0.09	0.198	0.005	0.64	**<0.001**	0.000	0.00	0.804
Dev.	0.004	0.15	0.083	0.003	0.21	**0.036**	0.008	0.27	**0.017**	-0.002	0.05	0.316
Forest	0.000	0.00	0.963	-0.003	0.08	0.209	0.001	0.01	0.716	-0.001	0.03	0.482
Overmat.	-0.001	0.01	0.629	0.000	0.01	0.724	0.000	0.01	0.670	0.000	0.01	0.753

2.6 Patch shape

2.6.1 Overall shape index

The average patch shape index significantly differed among scenarios (Figure 20). The AGGR scenario had the highest average shape index (1.1319), and the PMFR scenario the lowest average index (1.1309), this difference being significant ($F = 6.472$; $P < 0.001$). Over the course of the simulation, the patch shape index significantly increased for all scenarios (Table 17). This was particularly important in the first 50 years (Figure 21).

Table 17. Mean shape index, by habitat type, in District 15 of Western Newfoundland. ANOVA statistics of comparison among scenarios and temporal linear regression statistics for each scenario are presented.

Habitat	Scenario	Anova				Regression			
		Mean	F	P	Duncan's	R2	Slope	F	P
Overall	BAU	1.13	6.47	0.001	b	0.68	9.9E-06	39.96	<0.001
	FRAG	1.13			bc	0.71	9.7E-06	48.19	<0.001
	AGGR	1.13			a	0.75	1.3E-05	56.15	<0.001
	PMFR	1.13			c	0.63	7.4E-06	32.13	<0.001
Mixedwood	BAU	1.12	1.87	0.141		0.72	1.6E-05	48.39	<0.001
	FRAG	1.12				0.57	1.3E-05	25.11	<0.001
	AGGR	1.12				0.86	2.2E-05	117.60	<0.001
	PMFR	1.12				0.35	1.1E-05	10.08	0.005
developing	BAU	1.12	0.81	0.495		0.01	3.5E-06	0.09	0.762
	FRAG	1.12				0.00	-2.5E-06	0.04	0.830
	AGGR	1.12				0.05	1.3E-05	0.93	0.346
	PMFR	1.12				0.00	-2.3E-06	0.02	0.877
forest	BAU	1.12	0.26	0.853		0.02	8.7E-06	0.34	0.566
	FRAG	1.12				0.01	6.3E-06	0.17	0.683
	AGGR	1.13				0.07	1.9E-05	1.47	0.240
	PMFR	1.12				0.01	6.7E-06	0.16	0.689
over-mature	BAU	1.13	0.22	0.883		0.03	1.9E-05	0.59	0.453
	FRAG	1.13				0.01	1.3E-05	0.28	0.604
	AGGR	1.13				0.02	1.4E-05	0.37	0.550
	PMFR	1.13				0.00	2.3E-06	0.01	0.921
Softwood	BAU	1.13	9.27	<0.001	b	0.43	6.7E-06	14.23	0.001
	FRAG	1.13			bc	0.48	6.8E-06	17.62	<0.001
	AGGR	1.13			a	0.51	9.7E-06	19.90	<0.001
	PMFR	1.13			c	0.43	5.1E-06	14.37	0.001
developing	BAU	1.13	3.59	0.017	bc	0.09	1.4E-05	1.86	0.189
	FRAG	1.14			ab	0.07	1.5E-05	1.47	0.241
	AGGR	1.14			ab	0.03	1.1E-05	0.67	0.425
	PMFR	1.13			c	0.09	1.3E-05	1.92	0.182
forest	BAU	1.13	0.50	0.682		0.00	8.6E-07	0.02	0.885
	FRAG	1.13				0.21	1.3E-05	4.92	0.039
	AGGR	1.13				0.12	9.5E-06	2.58	0.125
	PMFR	1.13				0.03	3.3E-06	0.55	0.467
over-mature	BAU	1.14	3.35	0.017	a	0.11	-1.3E-05	2.40	0.138
	FRAG	1.14			b	0.23	-2.1E-05	5.62	0.029

	AGGR	1.14	b	0.13	-1.7E-05	2.89	0.106
	PMFR	1.14	b	0.15	-1.4E-05	3.26	0.087

2.6.2 Shape index by habitat types

Mixedwood habitats (shape index=1.12) had simpler shapes than softwood habitats (shape index=1.13) (Table 17). Shape index was not different among scenarios for any mixedwood habitats (Table 17). Differences among scenarios were detected for developing and over-mature softwood habitats. The developing habitat had its most complex shape in AGGR and FRAG, while its simplest one was in the PMFR. In the FRAG, AGGR and PMFR scenarios, the softwood over-mature habitat had its most complex shape and its simplest one in the BAU.

Increase in shape complexity of habitat was also detected in the mixedwood and the softwood habitat (Table 17). At the developmental stage level, change in patch shape index was detectable only in the FRAG scenario, for the forest and over-mature stages; at the forest stage patch shape increases while it decreases for the over-mature stage.

2.7 Edge

2.7.1 Contrast-weighted edge length

Contrast-weighted edge length (CWEL) was at the starting point at 53.457 km. CWEL was significantly higher ($F = 4.98$, $p = 0.0032$) for the PMFR scenario (54.533 km) than the AGGR (53.275 km) and BAU (53.357 km) scenarios, and the FRAG scenario (53.979 km) had a higher CWEL than AGGR (Figure 22). Over the 200 years span of the simulation, no scenario showed a significant linear temporal trend in CWEL. However, PMFR had a mean CWEL significantly higher than the starting conditions.

2.7.2 Mean edge contrast index

Mean edge contrast index (MECI) was at 0.54 at the start of the simulation. The AGGR scenario (0.545) had a significantly higher ($F = 2.90$, $P = 0.04$) MECI than the FRAG (0.538) and the BAU scenarios (0.537) (Figure 23). Over the 200 years span of the simulation, no scenario showed significant linear temporal trend in MECI. However, AGGR had mean a MECI significantly higher than the starting conditions.

2.7.3 Edge length

Dividing the contrast weighted edge length by the mean edge contrast index, it possible to obtain the total edge length. The most edge-producing scenario was PMFR while the least edge-producing scenario was AGGR (BAU=99.3 km, AGGR=97.8 km, FRAG=100.3 km and PMFR=100.6 km).

Fine filter biodiversity indicators

3.1 Pine Marten

3.1.1 Male Pine Marten population number

Average male Pine Marten populations range between 150 and 200 males over the simulation (Figure 24). The PMFR scenario allowed to support on average 194 male pine marten, the FRAG scenario 182, while the BAU and AGGR scenarios had significantly the lowest populations, being 162 and 169 males ($F = 612.66$, $P < 0.001$).

Scenarios showed changes in the number of male pine marten over the course of the simulation (Figure 25). All scenarios experienced a rapid decrease in pine marten numbers immediately after the start of the simulation, from 160 males to as low as 121 males for the BAU scenario at year 20. After this early reduction in population, all scenarios showed a rapid recovery in marten numbers, up to a level even higher than the starting conditions. However, this increase only generates a statistically significant linear progression of number of males pine marten with time over the length of the simulation for the PMFR scenario (approx. 18 per century, $R^2 = 0.41$, $P = 0.002$).

3.1.2 Pine marten habitat

The four scenarios have generated results in regard to total suitable habitat area, contiguous habitat area, and proximate habitat similar to the ones on the pine marten population. In fact, male pine marten population numbers were all highly correlated (Pearson $r > 0.95$) with high and total habitat area, contiguous habitat and proximate habitats. Ranging from 2214 to 2816 km^2, the total suitable habitat area available for the pine marten was significantly higher ($F = 13.957$, $P < 0.0001$) for the PMFR scenario than the suitable habitat areas in the AGGR and the FRAG, which were themselves greater than the one in the BAU scenario. Covering approximately 80% of the total habitat area for every scenario, high quality habitats (ranging from 1844 to 2246 km^2) were also more important in the PMFR scenario than in the three other scenarios ($F = 16.42$, $P < 0.0001$).

Total habitat area, contiguous, and proximate habitats changed during the 200 years of the simulation according to a pattern similar to what was observed for male pine marten population. However, suitable habitat area distinguishes the scenarios among themselves differently than male pine marten population; PMFR scenario was more distinctly suitable while the FRAG and the AGGR scenarios where much more similar (Figure 26). All scenarios reached a plateau after 50 years at a level higher than the starting conditions. However, the PMFR scenario was the only one showing any significant increase of area, contiguous and proximate habitat and over the course of the simulation (Table 18).

Table 18. Temporal trend statistics for pine marten habitat.

	BAU			FRAG			AGGR			PMFR		
	Slope*	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value	Slope	R^2	P-value
Area High	1.580	0.10	0.165	1.138	0.05	0.314	1.104	0.04	0.367	4.606	0.37	0.003
Area Total	2.340	0.10	0.156	1.815	0.07	0.232	1.742	0.06	0.287	5.671	0.36	0.004
Cont. High	1.992	0.12	0.116	1.544	0.08	0.220	1.339	0.05	0.334	5.055	0.37	0.003
Cont. Total	2.905	0.13	0.112	2.353	0.10	0.165	1.985	0.06	0.284	6.323	0.36	0.004
Prox. High	1.794	0.12	0.127	1.292	0.06	0.267	1.148	0.04	0.363	4.649	0.36	0.004
Prox. Total	2.637	0.12	0.122	2.031	0.09	0.194	1.792	0.06	0.287	5.767	0.35	0.005

* Slope is expressed in km^2/year.

3.2 Woodland caribou

3.2.1 Wintering habitat

PMFR and the FRAG scenarios have generated higher area of wintering habitat than the other two scenarios ($F = 14.17$, $P < 0.0001$) (Figure 27). The PMFR scenario had on average a SI value of 0.2853 for wintering habitat, 0.2840 for the FRAG, 0.2801 for the AGGR and 0.2745 for the BAU.

Over the course of the simulation, all scenarios experienced a series of ups and downs in the suitability value of wintering habitat (Figure 28). Although none of the scenarios showed any significant temporal trend of woodland caribou wintering habitat SI value, it is clear that most of the time generated landscapes will be less suitable than starting conditions, whatever the scenarios. Such results is important as the starting SI value is rather low.

3.2.2 Calving habitat

Woodland caribou calving habitat suitability is in average high for all scenarios. The average SI value of calving habitat was not different between the four scenarios, SI values ranging from 0.6319 to 0.6510 ($F = 0.404$, $P = 0.750$) although we could detect a tendency of seeing improvement in SI average values from the BAU to FRAG, to AGGR, to PMFR scenarios (Figure 29).

During the course of the simulation, the calving habitat SI value behaved very similarly across scenarios (Figure 30). It all started at 0.48 and ended up around to 0.70 after 200 years. Every scenario showed a rapid increase in calving habitat quality for the first 70 years and then levelled off for the rest of the horizon. Such pattern translates in a significant temporal trend, as detected by the linear regression analysis, for all scenarios with R^2 ranging from 0.63 to 0.70.

3.3 Boreal owl

The average habitat SI value for the boreal owl did not differ among the four scenarios ($F = 1.848$, $P < 0.145$). We see a little tendency of getting better boreal owl habitat suitability index mean value in the FRAG and the PMFR scenarios (Figure 31). In all scenarios along the 200 years of the horizon, habitat suitability index is lower than the starting conditions (Figure 32). Although over the course of the simulation, no scenario showed significant linear trend in habitat suitability, we can observe a period of lower values in the first century compared to the second century where SI gets better, particularly for the PMFR scenario (Figure 32).

Discussion

Biodiversity indicators responded differently to the different scenarios analyzed in this study. This section will discuss which aspects are biodiversity-sensitive, which biodiversity values seem to be sustained over the simulation, how they differ between forest management scenarios and, if possible, why.

Forest age

Probably the most important effect of forest management on biodiversity is the residual forest age structure of the managed landscape. All the scenarios maintain an age class structure similar to each other generally speaking. This happens because the initial age structure footprint has a strong constraining effect on the ability of changing the age structure lately when harvesting is subject to an even-flow constraint. They all start with an over-representation of very young stands, creating a mode in age structure that is slightly sliding with time in all scenarios (see Figure 33 for an example of the BAU scenario). Such behavior of the age class structure with time is highly structuring for many biodiversity indicator models. For example, for the woodland caribou calving habitat, the amount of young stands in the landscape determines the risk of calf predation by bear and lynx. Therefore, the SI increases as the mode slide toward older stand ages and levels off at age 60, when most of the mode has been reduced to a comparable level of young age stands (Figure 30 and Figure 33).

Even if globally they are similar, when we look at specific age class component, especially the oldest age classes, we found that all the scenarios but the PMFR one will not be sustainable in terms of that age component. Such aspect is expressed in BAP mainly by the over-mature habitat classes and the 75th percentile of age. The 75th age percentile indicator shows that the oldest age classes are drastically declining with time (at a pace of 1 year of age every 15 years of simulation) in all scenarios (even in the PMFR the decrease is almost significant). This result shows that not only the forest age is reducing with time but also that this reduction is mostly due to a loss in the last percentile. Interestingly, over-mature proportion was not reducing although the 75th age percentile was drastically reducing. This suggests that the age-breakdown used for defining over-mature habitat type is under the age of the stands that disappeared with time in the simulation. Moreover, as discussed in the following section, there is a strong shift from spruce-dominated stands to fir-dominated stands, making the average threshold age for defining over-mature forest in the landscape lower.

Landscape composition and diversity

We observed a loss of habitat diversity in all scenarios over the course of the simulation. It results in landscapes being globally not different in composition across the scenarios. In fact, they all follow the same trajectory of compositional change conjointly, as expressed by the no difference result on the first and second principal components of the PCA analysis. Such general reduction in diversity is mainly due to two effects. Firstly, we observed a drastic loss of the hardwood component of the landscape, probably due to a mechanistic problem in the projection tool. However, such a strong decline trend for hardwood and hardwood-dominated mixedwood stands in the landscape has been observed in the last 70 years using past aerial photographs (Doyon *et al.*, in prep.) and might not be too far from reality. The second diversity reduction effect comes from the unmixing of softwood mixed habitat types mostly at the expense of pure fir and, to some degree, pure spruce habitats. Doyon *et al.* (in prep.) are showing that the forest harvesting of the last 30 years have tremendously changed the forest composition toward a more fir-dominated landscape (twice as what was observed in 1934 and 1968). The projections of the four scenarios analyzed here show that forestry will keep increasing the amount of fir in the landscape at an important rate. We see the PFMR scenario is switching a little bit slower in composition because, I think, of the reserve effect of PMMUs, delaying composition switch in these “frozen” landscape portions.

Landscape fragmentation

Until now, District 15 has not been artificially fragmented like other landscapes managed under forestry in Canada. Past historical cleacrcut blocks were big enough with a aggregated layout to maintain a grain perceptible at a higher scale than in other managed landscape under dispersed cutblocks strategy as often seen in the rest of Canada (Figure 34 and 35). Indeed, in D15, the patch grain is mostly driven by natural distribution of non-“forestable” sites like water bodies, rock barrens, bogs and scrubs.

Applying the different forest management scenarios did change the landscape configuration and its fragmentation level. In fact, the most important distinctions among the scenarios were in regard of the spatial layout of the cut blocks (size and dispersion) in the forest simulation rules (Figure 36, 37, 38, and 39). The observation of the spatial layout of the cut blocks allows us to see that fragmentation was greater in the FRAG than in the BAU and the PFMR than in the AGGR.

Most of the spatial configuration indices are statistically supporting that observation (overall patch size and patch size percentiles, overall core area patch size and core area patch size percentiles). However, when considering softwood over-mature habitat, mean patch size and patch size percentiles get the biggest in the PMFR scenario, probably do to the reserve effect of the use of the PMMUs.

In regard of the amount of core area, however, the story is a little bit different: AGGR and BAU provide more interior conditions than the other two scenarios, regardless of the habitat type. However, considering softwood over-mature habitat, the BAU scenario is the one providing the least interior forest conditions. PMFR contributes for more mixedwood interior habitat conditions just because it allows for maintaining more of this habitat during the simulation.

Contrast-weighted edge length and the mean edge contrast index are showing landscape fragmentation is not significantly following a linear trend over the 200 years of the simulation. Interior forest conditions were sustained for all the scenarios for the major habitat types, even over-mature habitat. Even more, for many other habitat types, the amount of core area is increasing with time.

However, when we look at some patch size indices (patch size, core area patch size), we are generally finding that patch-size is reducing with time. This is particularly true for over-mature patches that reduce in size in all the scenarios at the pace of one ha by 100 years. However, if we focused on the large tracts (75^{th} percentile) of over-mature, no scenario showed a significant linear temporal trend. As the amount of core area do not change for over-mature with time for any scenario, I believe that the fragmentation effect is not too strong in any scenario for biodiversity important values.

This assumption is supported by the fact that over the course of the simulation, the patch shape index significantly increased for all scenarios. Usually, shape complexity follow patch size as increasing size allowed a more circumvoluated configuration of the patch. Considering that the structural grain of the District 15 landscape is conditioned by natural “non-forestable” sites in the initial forest cover map, the only way of getting more complex shape is by having bigger patch size. That is why the AGGR scenario had the highest average shape index.

As a result of the compositional change, we observed more adjacencies involving old and forest habitats with non-forest openings contributing to an increase in the mean edge contrast index in the AGGR and PMFR scenarios and while more adjacencies involving developing softwood in the BAU and FRAG scenarios produce more subtle edges. Randomly dispersing more and smaller cutblocks in the landscape "softens" the mean edge contrast as the probability of a polygon being aside another polygon more similar increases.

Male Pine Marten populations

All scenarios seem to be able to sustain a pine marten male population at a level at least as large as what the level is right now. Consequently, if all assumptions in our modeling exercise are right, maintaining the pine marten population is not a critical biodiversity issue under the realm of the forest management strategies compared in this study. However, the most critical period will occur in the coming two decades when male pine marten population gets to its lowest levels for all scenarios. The conservation question that arises is: will the population recover at the same pace as the increase of the suitability of its habitat after that critical period? Population dynamics are driven by many processes that are often density threshold sensitive (like pairing). It is unknown if lowering down the population level as low as 121 males (year 20 in BAU) is not going to jeopardize population resilience. Consequently, I advocate that the most important effort for maintaining the pine marten population will occur in the next 20 years. Special attention to maintain the pine marten habitat at a high level of suitability has to be considered in the tactical and operational plans.

The results also show that we have been successful in increasing the density of pine marten with a scenario specifically designed for that value (PMFR scenario). Indeed, the PMFR produces landscapes being able to support 19.8% more males pine marten then the BAU. However, the very question comes when we ask if such increase in the PMFR scenario is due to the floating reserve constraint using the PMMUs that we imposed or strictly due to a harvest level reduction of 18.9% when compared to BAU. When I analyze the relationship between male pine marten population level and harvest level, I find a significant negative relationship for all scenarios except FRAG (Figure 40). Hence, to be sure to detect a landscape engineering effect other than the harvest level reduction, the slope of the relationship for the PMFR scenario would have to be different and less pronounced then the one of the other scenarios. However, when we look at the regression lines of each scenario, we observe that the negative slope of the PMFR scenario is the most pronounced, inversely to what we expected. Therefore, at first glance, it seems that the beneficial aspects to the pine marten in the PMFR scenario are mainly due to a harvest level reduction.

Putting all scenarios together, we detect a significant trade-off function ($R^2=0.57$, $p<0.001$) between harvest level and male pine marten population levels. Under such trade-off function, we observe that we loose 4 pine marten males for every 10 000 m^3/year increase in harvest level. Such ratio expresses a strong tension between two values competing for the same resources (forestry fetching old stands with volume and pine marten trying to make up a territory in landscape section of old and mature forests). As demonstrated in the previous paragraph, the floating reserve strategy alone has not proved to be enough for reducing such tension between the two values. Other strategies will have to be implemented to allow reduction of the tension in the trade-off function. I suggest that including partial cutting systems and variable retention would probably contribute to this goal of tension reduction in the trade-off function if one wants to increase the AAC while maintaining the pine marten in the landscape at a level.

Woodland caribou habitat

Woodland caribou habitat suitability results showed that the wintering habitat is the most discriminating among the scenarios. No difference was detected among the scenarios in terms of calving habitat suitability. For the wintering habitat, the PFMR scenario with the FRAG scenario had the highest level of suitability while the BAU had the lowest suitability values. Although no significant difference is detectable between PMFR and FRAG scenario for the entire horizon of the simulation, it appears clearly that PMFR gets better suitability values then FRAG in the second century of the simulation.

Although none of the scenarios showed any significant temporal trend of woodland caribou wintering habitat SI value, it is clear that most of the time generated landscapes will be less suitable than starting conditions, whatever the scenarios. Two periods with the lowest values are detectable as more critical: a first one at the end of the first century of the simulation and a second one at year 150 for all scenarios. Although the decreases observed might appear very limited on an absolute scale (a difference of 0.015 in the SI value), as the SI is a relative evaluation, one has to consider that it can reflect a biologically significant response, particularly since it reflects the whole landscape average.

Woodland caribou wintering habitat is also a competitive value with harvest level. In fact, when we plot all scenarios together the wintering habitat with the harvest level, a clear negative trend is detectable. Running a linear regression analysis confirm such trend by a very significant relationship ($F=27.74$, $n=20$, $p<0.0001$) where suitability index for the wintering habitat is reduced by 0.001 for every 10 000 m^3/year increase (Figure 41).

Looking at the relationship between woodland caribou wintering habitat and harvest level specifically by scenario, I found two significant regression lines, one with the PMFR scenario and one with all the other scenario together (Figure 41). One can easily observe that the slope for the PMFR scenario is the inverse of the general trend with the three others (Figure 41); wintering SI value increases by 0.016 from 310 000 m^3/year to 375 000 m^3/year. Such result shows that under the PMMU floating reserve strategy of the PMFR scenario, increasing the harvest level up to 375 000 m^3/year has been beneficial for the woodland caribou. I can not state how much the harvest level can still be raised over that level without starting to see a decrease in the wintering habitat SI. However, it seems to be a promising path for reducing the tension between these two values in the trade-off function.

It has been very surprising to see that the woodland caribou calving habitat was not discriminating the scenarios we compared as this SI model is highly dependent on spatial arrangement of cutblocks (predator's foraging habitat), which mostly distinguishes our four scenarios. It seems that the SI value based on the predator foraging habitat was not sensitive to the differences in landscape structure generated by our scenarios. I also looked at the trade-off function between harvest level and calving habitat and also did not detect any significant relationship. Such result confirms the insensitivity of this SI to the predator foraging habitat. One possible explanation can be the relative difference between the structural grain under the different scenario and the size of the window when the home-range smoothing procedure is performed. We used for this SI a radius of 1500m (225 ha) which is much greater than the average cutblock size for the openings (around 20 ha), whatever is the scenario (see patch size distribution of the developing stage). At this stage, without a detailed analysis of the intermediary outputs that are “killed” during the running of the model (the link between bear and lynx habitats and the predator SI for example), it is difficult to explain this behavior of the model.

Boreal owl habitat

The boreal owl habitat suitability model assesses the nesting and the foraging habitats conjointly using spatially explicit relationships (Coté *et al.* 2004). The nesting component looks at the amount of large live and dead trees potentially providing nesting cavities, while the foraging habitat SI gets high value for good hunting grounds represented by openings at close distance to a forest edge. Our results showed that the boreal owl habitat suitability model was not sensitive to the differences in forest management strategies we compared when we look at the entire simulation horizon. We were expecting seeing the FRAG scenario generating greater

SI values for the foraging SI of the boreal owl HSM because of the greater juxtaposition of openings and forest cover and the PMFR generating higher SI values of the nesting SI of the boreal owl HSM because of higher importance of old forest; the FRAG and the PMFR scenarios obtained the highest mean habitat suitability index but were not significantly different from the others. We also observed higher variation in SI values in the PMFR than in the other scenarios. High variation in SI values may not be a desired outcome as it may lead to some density threshold where non-linear population dynamic processes generate a population crash, even if the overall the simulation horizon mean SI value is the highest.

All scenarios showed a significant reduction in the SI values just after the start of the simulation. This is particularly true for the PMFR that lost 0.035 in mean SI value after 50 years (Figure 32). This reduction is not strictly related to the harvest level *per se*; I did not detect any significant relationship between harvest level and boreal owl habitat suitability index, neither globally nor when looked for scenario individually. I believe that this reduction is due to the loss of nesting habitat related to the diminishing of mature and old forests that we observed in the beginning of the simulation as shown by the age percentile drop for the 50th percentile (Figure 4). Here also, a detailed analysis of the intermediary outputs that are “killed” during the running of the model would allow confirming this hypothesis.

Conclusions and recommendations

Applying the biodiversity indicator models on the forest projections of the four different forest management scenarios we compared has allowed to identify critical forest conditions that could jeopardize some biodiversity values and the ecosystem integrity. Based on the interpretation of the results, I identify six biodiversity elements that need to be specifically addressed, although some of them are interrelated, in the forest management plan with particular measures. These are:

1. Forest age structure
2. Forest composition
3. Over-mature habitat patch size
4. Pine marten population
5. Woodland caribou wintering habitat
6. Boreal owl habitat

The following paragraphs summarize the critical issues identified for each of these five elements and propose some recommendations on how to tackle them in the forest management plan.

Forest age structure

Issues: Our results show a strong tendency of truncating the forest age structure with time. All scenarios but PMFR are not sustaining the over-mature age component of the forest landscape.

Recommendations: As many biodiversity values reside in over-mature forest conditions, it is important to consider options to maintain that value. As the area-weighted average age of the forest is inversely correlated with the harvest level ($r=-0.521$, $P<0.001$), lowering down the harvest level will help reaching sustainability, to some extent. From our results it is clear that the sustainable harvest level reside between the level used in the PMFR and the FRAG. However, such relationship with harvest level would express only 0.27% (-0.521 squared) of the explanation of forest age, it is believed that other parameters condition forest age structure, leaving space for landscape expressly designed for managing that value without impacting too much on the AAC. Specifically addressing that issue by constraining the model to maintain a minimum level of over-mature would probably be the most appropriate way of optimizing the trade-off between maintaining over-mature and the AAC. Without any Natural Disturbance Regime (NDR) baseline, I suggest that the actual level should, at least be maintained. Such recommendations would translate in maintaining 25% of the landscape at an age greater than 85 years old.

Forest composition

Issues: Forest harvesting generates a compositional drift in favor of the balsam fir at the expense of the hardwood component, mainly, and of the spruce (black and white) component, to a lesser degree. Past aerial photographs analysis are showing a strong reduction in mixedwood since 1968 (Doyon *et al.*, in prep.). This trend is at least maintained if not exacerbated by the forest management strategies compared in this study. Reducing the forest composition diversity brings also other issues like risk to pest outbreak (monoculture effect).

Recommendations: Comparing the actual forest composition to what it was at the beginning of the century shows that the WNMF would have to undertake serious landscape restoration actions if ecosystem management is at the very heart of its forest management philosophy. To develop a restoration strategy, one will have to answer the question if forest harvesting alone is responsible of that compositional drift or if other phenomena like the late-century arrival of a spruce-budworm outbreak or the increase of the moose browsing could share the load of such response. Maintaining the mixture of mixedwood stands (bF with HW and bF with other SW) in the landscape has to be set as a target. In absence of paleo-ecological studies, I suggest to use the proportion described by the forest at the beginning of the 20th century as a guideline (bF: 14%, bFbS: 21%, bS: 10%, bSbF: 19%, SWwB: 17%, wB: 2%, wBbF: 4%, Non-Forest & Scrub: 13%) (Doyon et Jardon, in preparation)

Over-mature habitat patch size

Issues: Unless specifically constrained in the harvest scheduling model by cutblock minimum size, patch size is more than likely to be reduced over the strategic planning horizon. Such effect is particularly detectable for over-mature habitat that need to maintain their patch integrity for a long time to make up a forest tract offering interesting interior forest conditions.

Recommendations: Even with the AGGR that had a elevated cutblock minimum size constraint, over-mature patch size is diminishing with time along the course of the simulation. Even if patch coalescence might partly have counteracted such effect, over-mature patch erosion with time is observed in all scenarios. To avoid patch size erosion subsequently to the patch formation after harvesting, the integrity of some forest tracts has to be preserved by some kind of mechanisms in order to sustain that biodiversity value. I am not aware of any way of putting directly an over-mature patch size constraint in the harvest scheduling model Woodstock-Stanley. However, I believe that such forcing can be achieved by freezing landscape portion (like we have done in the PMFR with the floating PMMU reserves) combined with some cutblock minimum size constraint (like in the AGGR).

Pine marten population

Issues: In general, pine marten population is maintained or increased under all forest management scenarios when compared to the starting conditions. However, an important population reduction is forecast to occur in the next 20 years.

Recommendations: Since the critical period for the pine marten population is in the coming next two decades, specific planning has to be made for the pine marten. As the model identifies high quality habitat every stands with height class greater than height class 3 (>=6.6 m), specific height constraints could be directly included in the formulation of the harvest scheduling model using height/age curves by strata for the first rollover (30 years). This is particularly true as the correlation between pine marten population and pine marten high quality habitat was very high (r>0.95), suggesting no need for spatialisation in order to report on a proxy of pine marten population level. If such a constraint lowers the AAC to an unacceptable level, some silviculture specifically designed to retain pine marten habitat features at the stand level could be implemented. Such a strategy would allow to harvest up to 75% of the volume and still maintain good pine marten habitat (Fischer and Wilkinson 2005, Tews *et al*. 2004; Sullivan *et al*. 2001, Sullivan and Sullivan 2001). I suggest that including partial cutting systems and variable retention would probably contribute to this goal while allowing some harvesting.

Woodland caribou wintering habitat

Issues: Woodland caribou wintering habitat suitability is showing a systematic and general reduction over all scenarios when compared to starting conditions.

Recommendations: The woodland caribou wintering habitat suitability model uses three suitability index functions which involve stand age, stand cover type (composition), and stand cover density (Côté and Doyon 2003). For stand age, maximum suitability is achieved in stands older than 60 years. The cover type suitability index gives better value to higher proportion of softwood in the cover. The density SI is optimal for stand with mid-density. As the cover type changes toward more softwood (and consequently improves the wintering SI), and as the density of each stand is maintain all through the simulation, the only other component that could adversely affect the wintering SI is the stand age SI. Looking at the age class distribution (Figure 2), we clearly see that PMFR and FRAG scenarios support a greater proportion of forest older than 60 years and the pattern with time of the 75th age percentile (Figure 4) is very close to what is observed in the wintering habitat suitability (Figure 28). Therefore, the wintering suitability is mostly reducing with time because of a constant loss of stand older than 60 years old. Consequently, in order to minimize the impact of forest management on woodland caribou wintering habitat suitability, I suggest to maintain the proportion of forest older than 60 years at a level at least equal to what we have now, being 50%.

Boreal owl habitat

Issues: Boreal owl habitat suitability is showing a systematic and general reduction over all scenarios when compared to starting conditions. A significant drop in the habitat suitability is expected to occur in the next 50 years.

Recommendations: I hypothesized that the observed drop was mainly due to the reduction in nesting habitat suitability because of a loss of stands old enough to support an interesting population of cavity nesting trees. When we looked at the boreal owl nesting suitability index model, we observed that the AGE variable class modifier gives the highest density of cavity nesting trees at age 60 and on (Côté *et al*. 2004, table 2). Consequently, in order to minimize the impact of forest management on boreal owl habitat suitability, I suggest to maintain the proportion of forest older than 60 years at a level at least equal to what we have now, being 50% in order to avoid the decrease in habitat suitability.

Although not directly assessed by the BAP, I would like to stress the importance of stand structure distribution in the landscape. Even if no multi-storied stands is identified in the forest inventory (there is no age class 9), work conducted by Jardon and Doyon (2003) has clearly shown that the age structure and the tree size structure in many of the balsam fir stands exhibit an uneven or an irregular structure. Such a pattern in stand structure is common for landscapes under a disturbance regime driven by insect outbreaks generating many partial disturbances, particularly in landscape dominated by a shade-tolerant species like the balsam fir. This issue has not been addressed specifically by our study but is probably as important as the others identified previously in this section. Better knowledge on stand structure distribution in the landscape is very important in order to tighten the coarse filter used to ensure biological conservation in the WNMF forest.

Habitat suitability model validation will very improve the use of the model for future work. Validation will be useful in two ways. First, model validation will provide the relative importance of the habitat features for determining habitat suitability. For example, at which distance from a shelter habitat foraging grounds stop to be interesting for the boreal owl? Such results will refine the relationship between the suitability and feature deemed important. Second, it will also help in putting in relation SI values with population responses. For example, the habitat mean SI values for the boreal owl is rather low (smaller than 0.2) for all the scenarios. Because habitat suitability models are only relative, one can not say if it is an indication of the poor value in general for the D15 forest landscape (absolute) or it is within the variation observed that we can derive habitat suitability (relative, the way it has been used in this study). Moreover, model validation will also allow identifying non-linear response to SI value. We expect that population density will not respond linearly to habitat suitability. Identifying the zones that are linearly and non-linearly related is important for conservation issues while modeling species/habitat relationships.

Finally, I also want to mention that BAP has been developed under the idea of using the natural disturbance regime as a template for a) identifying critical biodiversity issues after comparing the performance of a biodiversity indicator when applied to a forest management strategy with its natural range of variation (NRV) envelope and b) for designing biodiversity-specific forest management strategies that forces the indicator to stay within the natural range of variation envelope. For example, the suggestion of maintaining 50% and more of forest older than 60 years for maintaining woodland caribou wintering habitat and boreal owl nesting habitat has been stated based on the actual distribution of forest age, not the NRV envelope. The critical biodiversity issues identified here in this conclusion and the recommendations proposed to address them will be very improved when we will be able to compare the behaviour of the indicators with their natural range of variation. Such work is now under progress using LANDIS model (He and Mladenoff) and new insights or changes in valuing important issues will emerge of the comparison with the NRV envelope.

Literature cited

Andrewartha, H.G. and L.C. Birch. 1984. *The Ecological Web. More on the distribution and the Abundance of Animals*. University of Chicago Press, Chicago, IL. 506pp.

Burton, P.J., A.C. Balinsky, L.P. Coward, S.G. Cumming, and D.D. Kneeshaw. 1992. The Value of managing for biodiversity. The Forestry Chronicle 68:225-237.

Coté, M. and F. Doyon. 2004. Spatially explicit habitat sustainability indices for the woodland caribou (Rangifer tarandus caribou) in Western Newfoundland. Technical Report of the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) for the Western Newfoundland Model Forest. 25 p. + appendices.

Coté, M., F. Doyon and N. Bergeron. 2004. Spatially explicit habitat suitability index model for the boreal owl (*Aegolius funereus*) in Western Newfoundland. Technical Report of the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) for the Western Newfoundland Model Forest. 27 p. + appendices.

Daust, D.K. and G.D. Sutherland. 1997. SIMFOR: software for simulating forest management and assessing effects on biodiversity. In: The Status of Forestry/Wildlife Decision Support Systems in Canada (I.D. Thompson, compiler), pp. 15-29. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, Ontario.

Dolter, S. 2004. Using Biodiversity Indicators to Assess the Success of Forecasting Adaptive Ecosystem Management: The Newfoundland and Labrador Experience. URL: http://www.eman-rese.ca/eman/reports/publications/2005/camesa/page7.html.

Doyon, F. 2000. WNMF BAP project. Phase I: Coarse-filter analysis. Mid-Project report. Technical Report of the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) for the Western Newfoundland Model Forest. 32 p.

Doyon, F. 2002. WNMF BAP project. Phase II: Analysis of biodiversity-friendly alternatives using coarse-filter and pine marten habitat supply model. Mid-Project report. Technical Report of the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) for the Western Newfoundland Model Forest. 32 p.

Doyon, F. et P. N. Duinker. 2003 Assessing forest-management strategies through the lens of biodiversity: A practical case from Central-West Alberta. *Pages* 207-224 *In* Systems Analysis in Forest Resources, Arthaud, G. J. et T. M. Barrett (éds.). Proceedings of the Eighth Symposium, Sept. 27-30, 2000, Snowmass Village, Colorado, U.S.A. Kluwer Academic Publishers, Dordretch. Série: Managing Forest Ecosystems Vol (7).

Duinker, P. N., F. Doyon, R. Morash, L. Van Damme, H. MacLeod et A. Rudy. 2000. Background and Structure. Biodiversity Assessment Project. BAP Report 1. Millar Western Forest Products Ltd, Edmonton, Alberta. 20 pp.

Duinker, P.N., F. Doyon, R. Morash, L. Van Damme, H.L. MacLeod, and A.Rudy. 2000. Background and structure. Biodiversity Assessment Project for Millar Western Forest Products. BAP Report 1. Millar Western Forest Products Ltd., Whitecourt, AB. 20 pp.

Fischer, J. T., and Wilkinson, L. The response of mammals to forest fire and timber harvest in the North American boreal forest. Mammal Review 35(1): 51-60.

Grumbine, R.E. 1994. What is ecosystem management? Conservation Biology 8:27-39.

Gustafsson, L. and J. Weslien. 1999. Special Issue: Biodiversity in Managed Forests - Concepts and Solutions. Forest Ecology and Management 115(2-3).

He, H. S. and D. J. Mladenoff. 1999. Spatially explicit and stochastic simulation of forest landscape fire disturbance and succession. Ecology **80**: 81-99.

Hunter, M. L. 1990. Wildlife, Forests, and Forestry. Principles of Managing Forests for Biological Diversity. Prentice Hall, Englewood Cliffs, New Jersey. 370pp.

Jardon, Y. and F. Doyon. 2003. Stand Dynamics of the Balsam Fir Forest of Western Newfoundland Under a Two Co-Occuring Insect Outbreak Disturbance Regime. Technical Report of the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) for the Western Newfoundland Model Forest. 35 p.

Legendre, P. and Legendre, L. 1983. Numerical Ecology. Elsevier Scientific Publishing Company, Amsterdam.

McGarigal, K., and W. C. McComb 1995. Relationships between landscape structure and breeding birds in the Oregon coast range. Ecological Monographs 65 :235-260.

Meades W. J. and L. Moores. 1994. Forest Site Classification Manual. A Field Guide to the Damman Forest Types of Newfoundland. Second edition. Western Newfoundland Model Forest, Department of Forestry and Agriculture, and Natural Resources Canada, Canadian Forest Service. FRDA Report 003.

Messier, C., M.-J. Fortin, F. Smiegelow, F. Doyon, S. G. Cumming, J. P. Kimmins, B. Seely, C. Whelam, et J. Nelson. 2003. Modelling tolls to assess the sustainability of forest management scenarios. *Pages* 531-580 *in* Towards sustainable management of the boreal forest, P. J. Burton, C. Messier, D. W. Smith and W. L. Adamoviicz. NRC Research Press, Ottawa Ontario, Canada.

Noss, R.F. 1993. Sustainable forestry or sustainable forest? *In* Defining Sustainable Forestry. *Edited by* G. Aplet, N. Johnson, J. Olson, and A. Sample. Island Press, Covelo, Calif.

Pond, J. 2004. A Summary of the Forest Management Scenarios used in the Western Newfoundland Model Forest Biodiversity Assessment Project. Prepared for the Western Newfoundland Model Forest. 17.p

Riitters, K.H., R.V. O'Neill, C.T. Hunsaker, J.D. Wickham, D.H. Yankee, S.P. Timmins, K.B. Jones, and B.L. Jackson. 1995. A factor analysis of landscape pattern and structure metrics. Landscape Ecology 10:23-39.

Rudy, A. 2000. BAP Report 8. BAP PROGRAM DOCUMENTATION. Prepared for Millar Western Forest Products'. Biodiversity Assessment Project. KBM Forestry Consultants Inc., Thunder Bay, Ontario. 38p. + 1 Appendice.

Rudy, A. and Doyon, F. 2002. Western Newfoundland Pine Marten Habitat Model in raster analysis environment. Technical Report of the Institut Québécois d'Aménagement de la Forêt Feuillue (IQAFF) for the Western Newfoundland Model Forest. 10 p.

SPSS Inc.. 1988. SPSS-X User's Guide, third ed. SPSS Inc.,Chicago, IL, 1072 pp.

SPSS Inc.. 2000. SPSS for Windows 10.0.5 Package. Software.

Sullivan, T. P., Sullivan, D. S. and Lindgren, P. M.F. 2001. Influence of variable retention harvests on forest ecosystems. I. Diversity of stand structure. Journal of Applied Ecology **38**(6): 1221-1233.

Sullivan, T. P., and Sullivan, D. S. 2001. Influence of variable retention harvests on forest ecosystems. I. Diversity and population dynamics of small mammals. Journal of Applied Ecology **38**(6): 1234-1246.

Tews, J., Brose, U., Grimm, V., Tielbörger, K. , Wichmann, M. C., Schwager, M., and Jeltsch, F. . (2004) Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. Journal of Biogeography **31**:1, 79-92

Thompson III, F.R., Probst, J.R., Raphael, M.G., 1993. Silviculture options of neotropical migratory birds. In: Finch, D.M., Stangel,, P. (Eds.), Proceedings of the Status and Management of Neotropical, Migratory Birds. General Technical Report RM-229,, 1992 September 21–25; Estes Park, CO, USDA Forest Services,, Rocky Mountain Forest and Range Experiment Station, Fort, Collins, CO, pp. 353–362.

Van Damme, L., Russell, J., Doyon, F., Duinker, P. N., Gooding, T., Hirsch, K., Rothwell, R., et Rudy, A. 2003. The development and application of decision support systems for sustainable forest management in Alberta. Journal of Environmental Engineering and Science. Vol (2): S23-S34.

Van Horne, B. and J.A. Wiens. 1991. Forest Bird Habitat Suitability Models and the Development of General Habitat Models. USDI Fish and Wildlife Service, Washington, DC, Fish and Wildlife Resource Paper 8. 31pp.

Walters, C.J. 1986. Adaptive management of renewable resources. MacMillan Publishing Company, NewYork, N.Y.

Figures

Figure 1. Harvest level over the 200 years for four forest management scenarios in District 15 of Western Newfoundland.

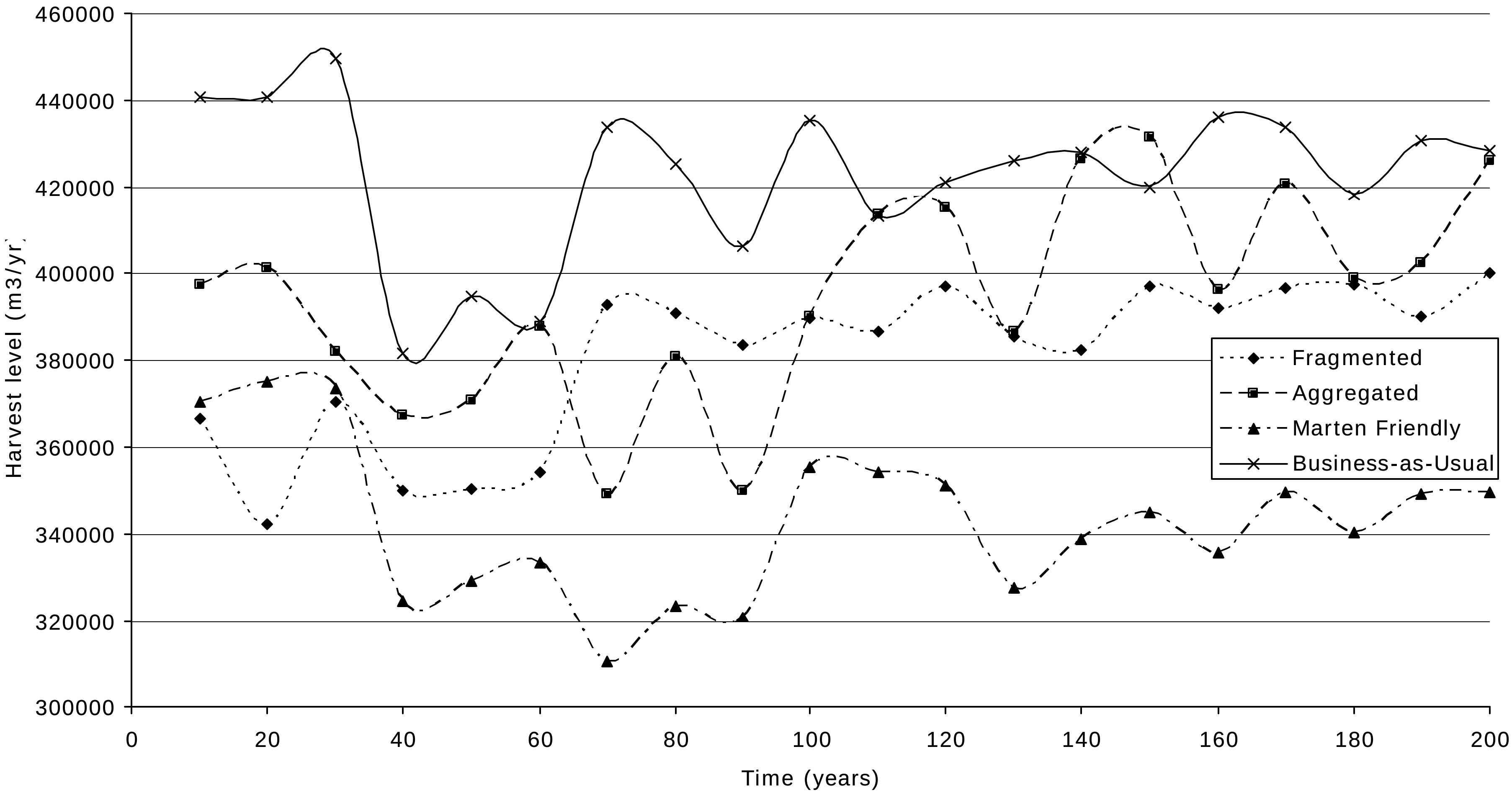
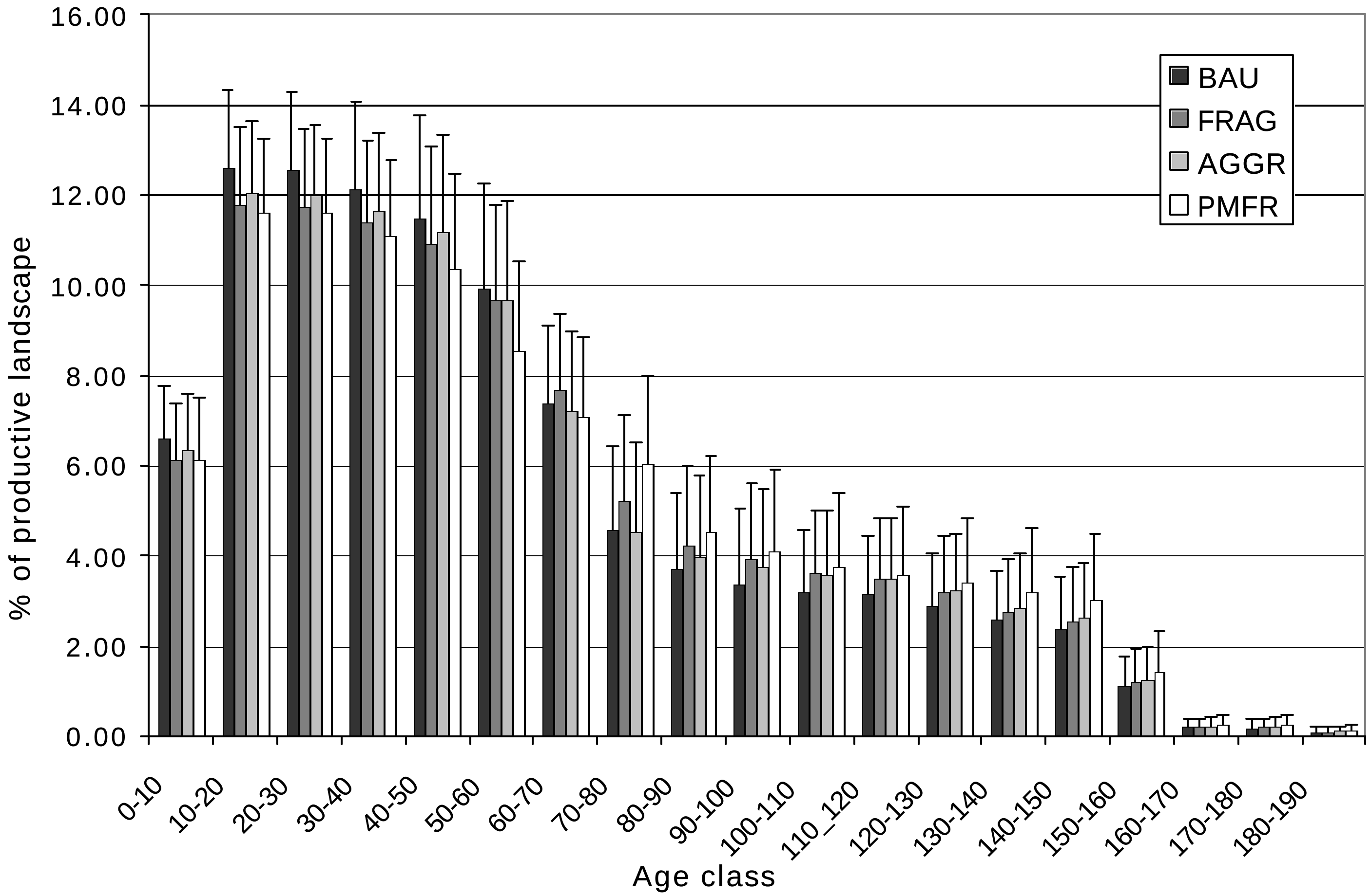
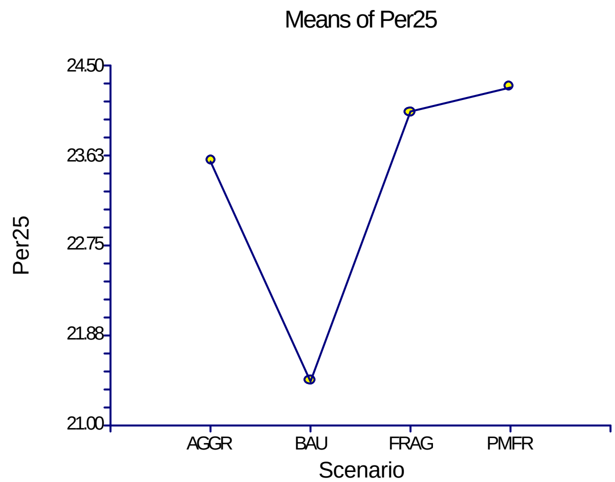
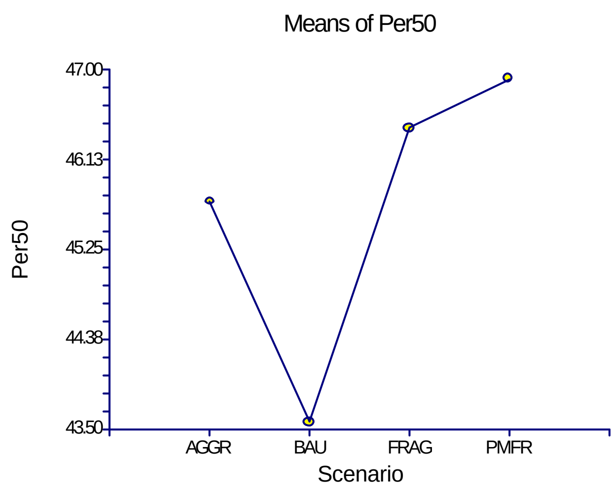


Figure 2. Mean age class distribution over the 200 years for four forest management scenarios in District 15 of Western Newfoundland.

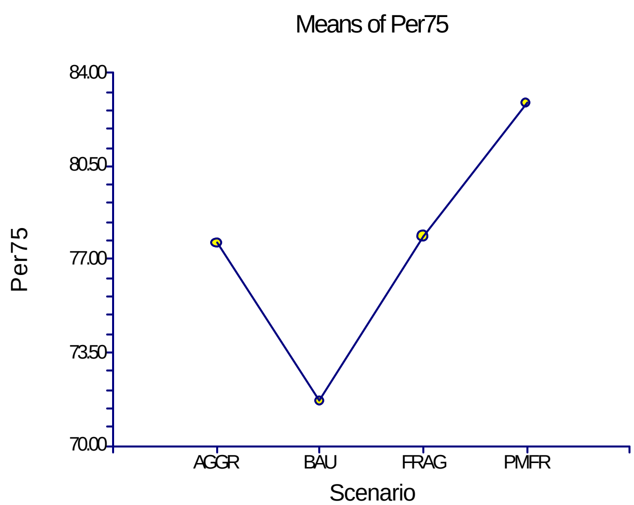




a)



b)



c)

Figure 3. Mean of 25th, (a), 50th, (b) and 75th (c) age percentile for the four forest management scenarios in District 15 of Western Newfoundland.

Figure 4. Age percentile (25^{th}, 50^{th}, and 75^{th}) indicators over the 200 years for four forest management scenarios in District 15 of Western Newfoundland.

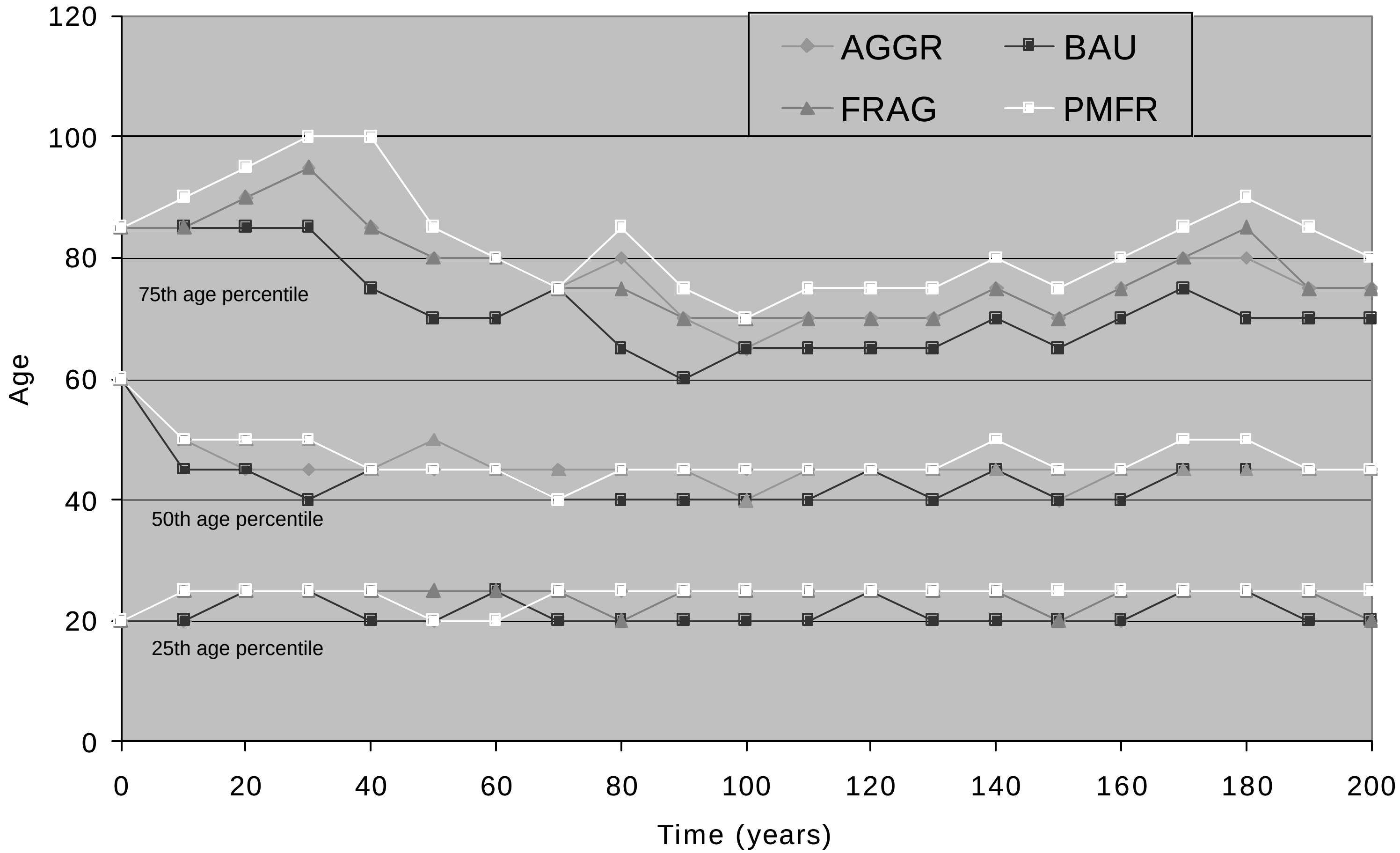


Figure 5. Developmental stage mean distribution over the 200 years for four forest management scenarios in District 15 of Western Newfoundland.

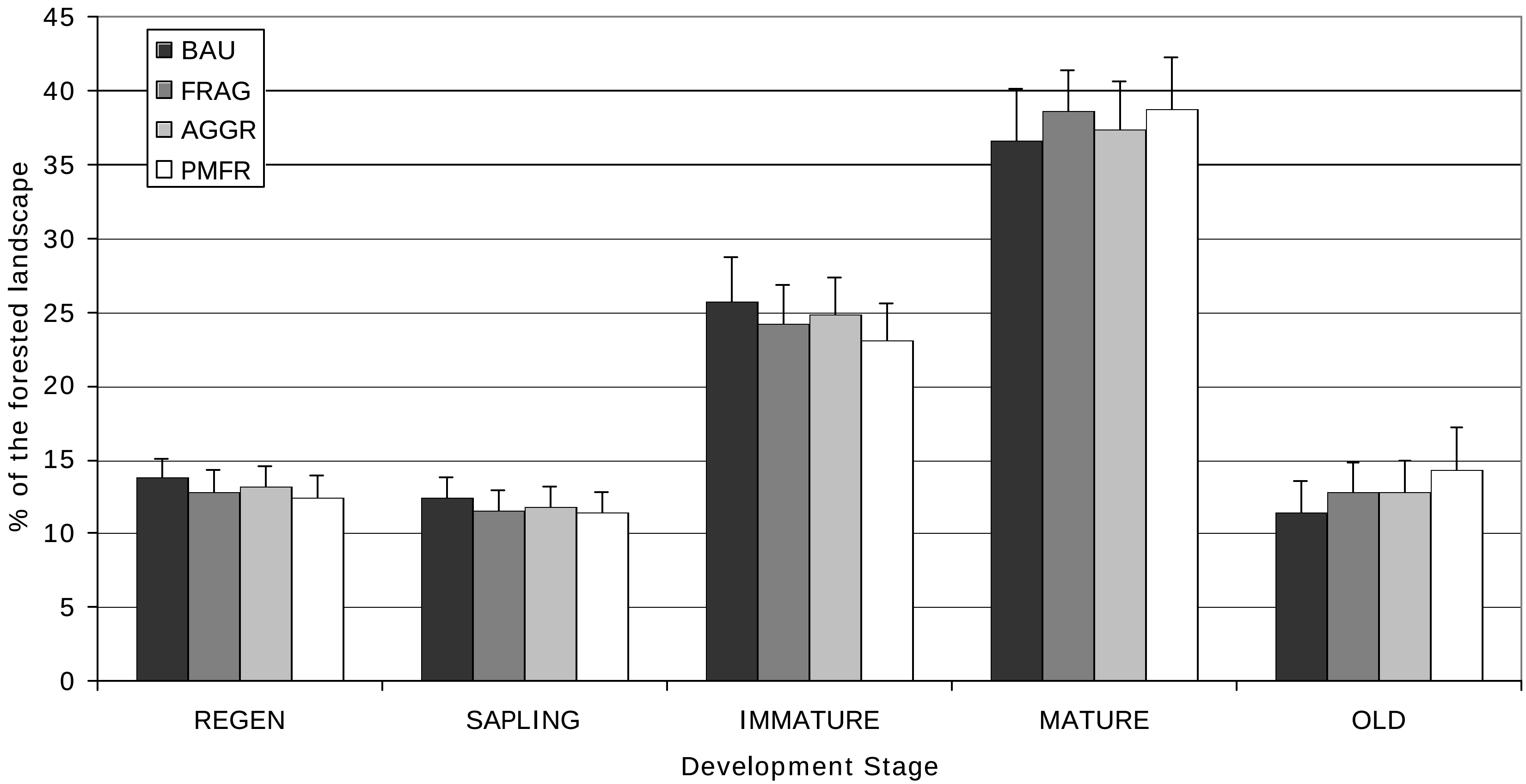


Figure 6. Diversity index over the 200 years for four forest management scenarios in District 15 of Western Newfoundland.

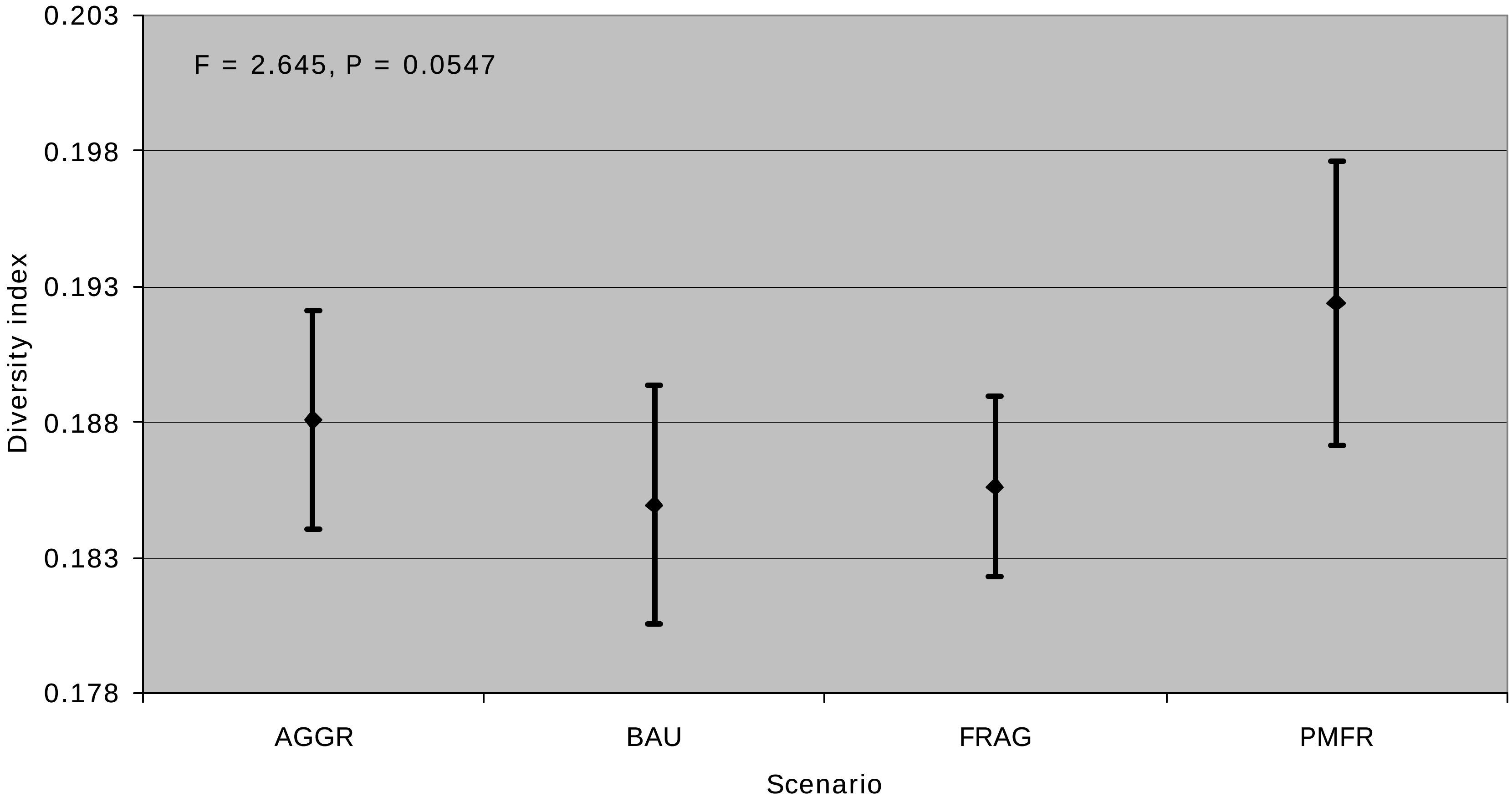


Figure 7. Diversity index over the 200 years for four forest management scenarios in District 15 of Western Newfoundland.

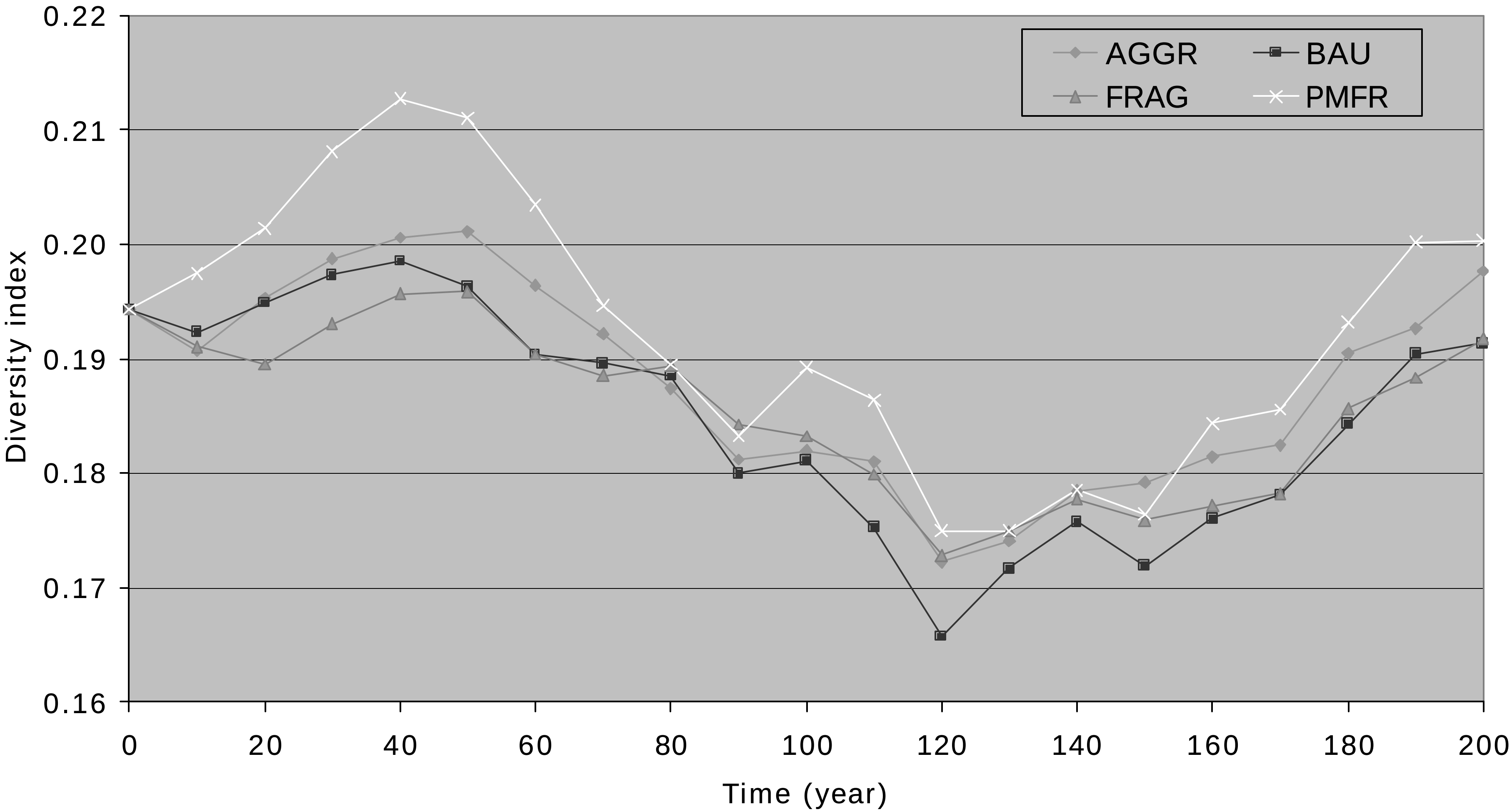


Figure 8. Hardwood habitats over the 200 years for four forest management scenarios combined in District 15 of Western Newfoundland

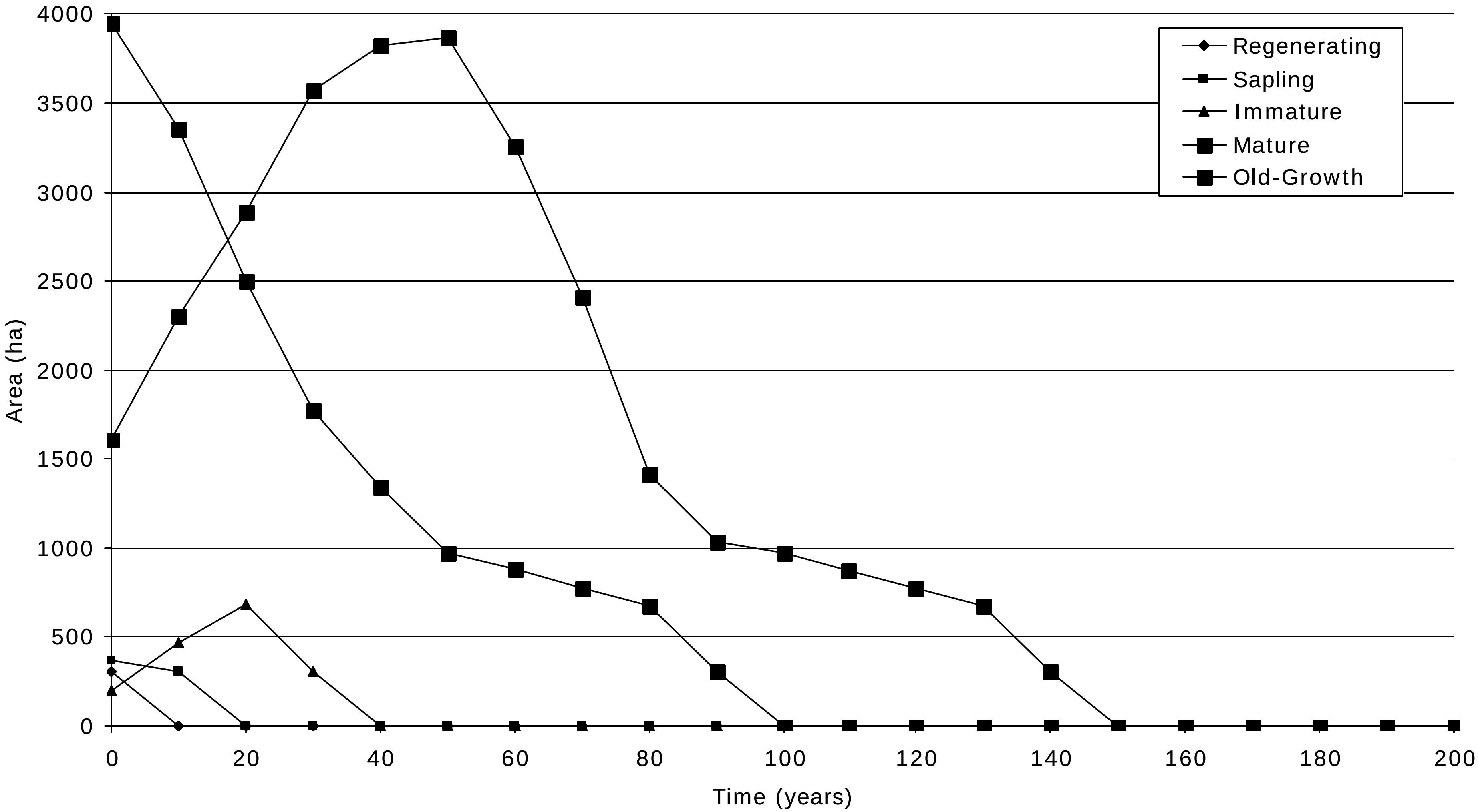


Figure 9. Factor scores positioning the habitat types in the space defined by the two first principal components of a PCA of habitat types in District 15 of Western Newfoundland. Arrow head number refers to the habitat type code (see Table 2).

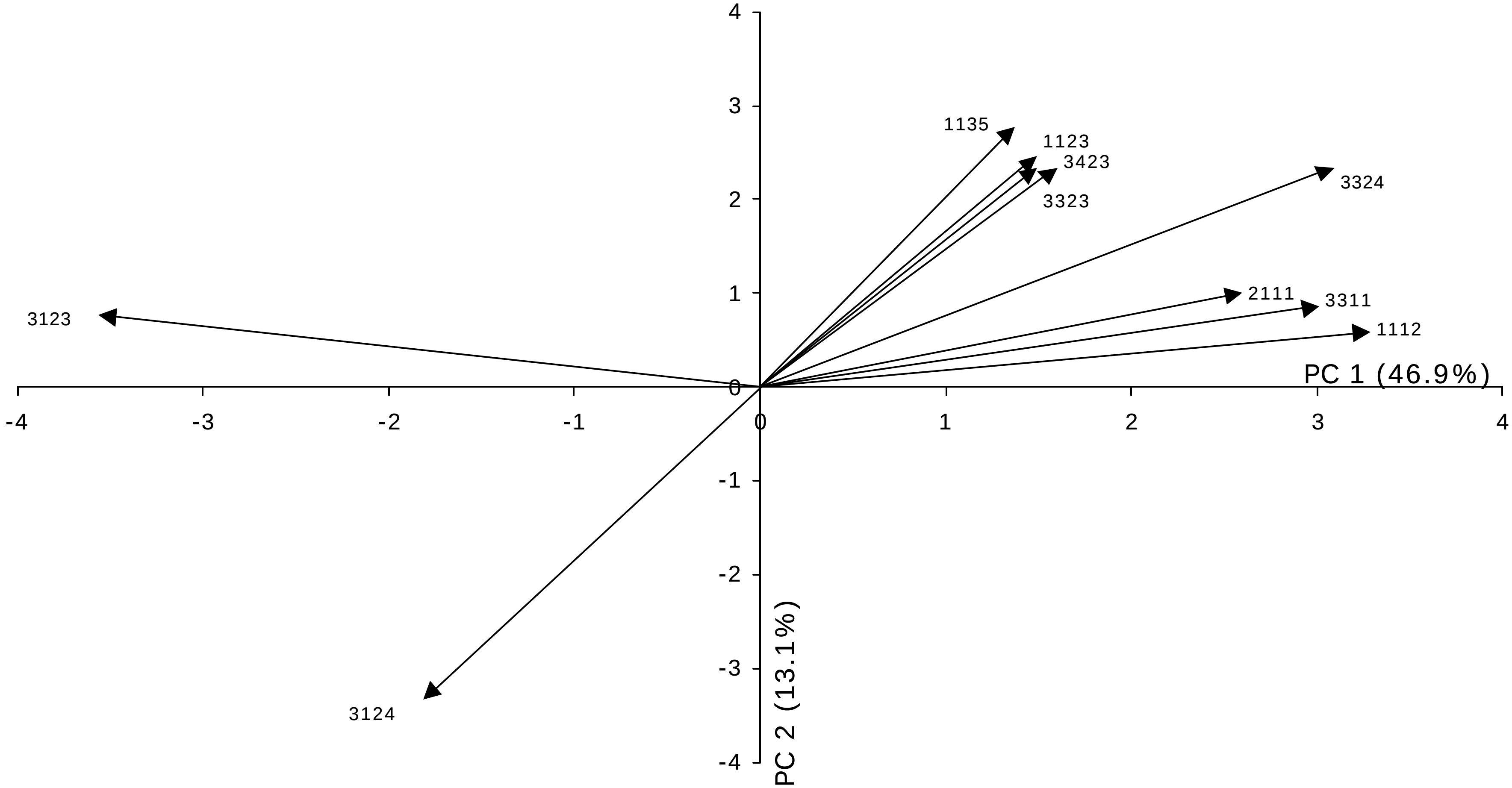


Figure 10. Composition shift along the 200 years horizon for the four scenarios all combined as expressed in the space defined by the 2 first principal components of a PCA. Number refers to the simulation year (0=2000, 10=2010, etc.)

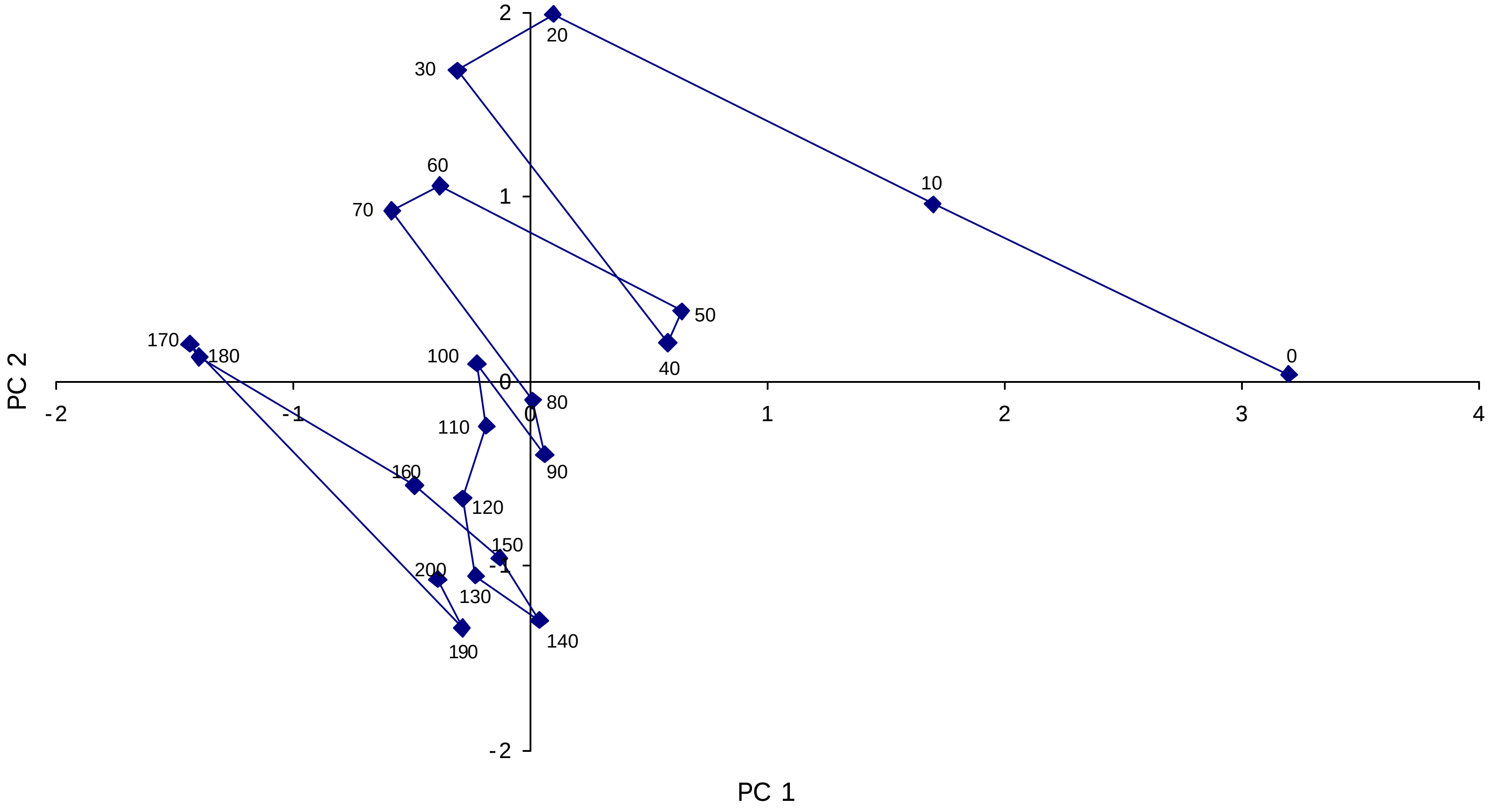


Figure 11. Factor scores positioning the adjacency types in the space defined by the 2 first principal components of a PCA.

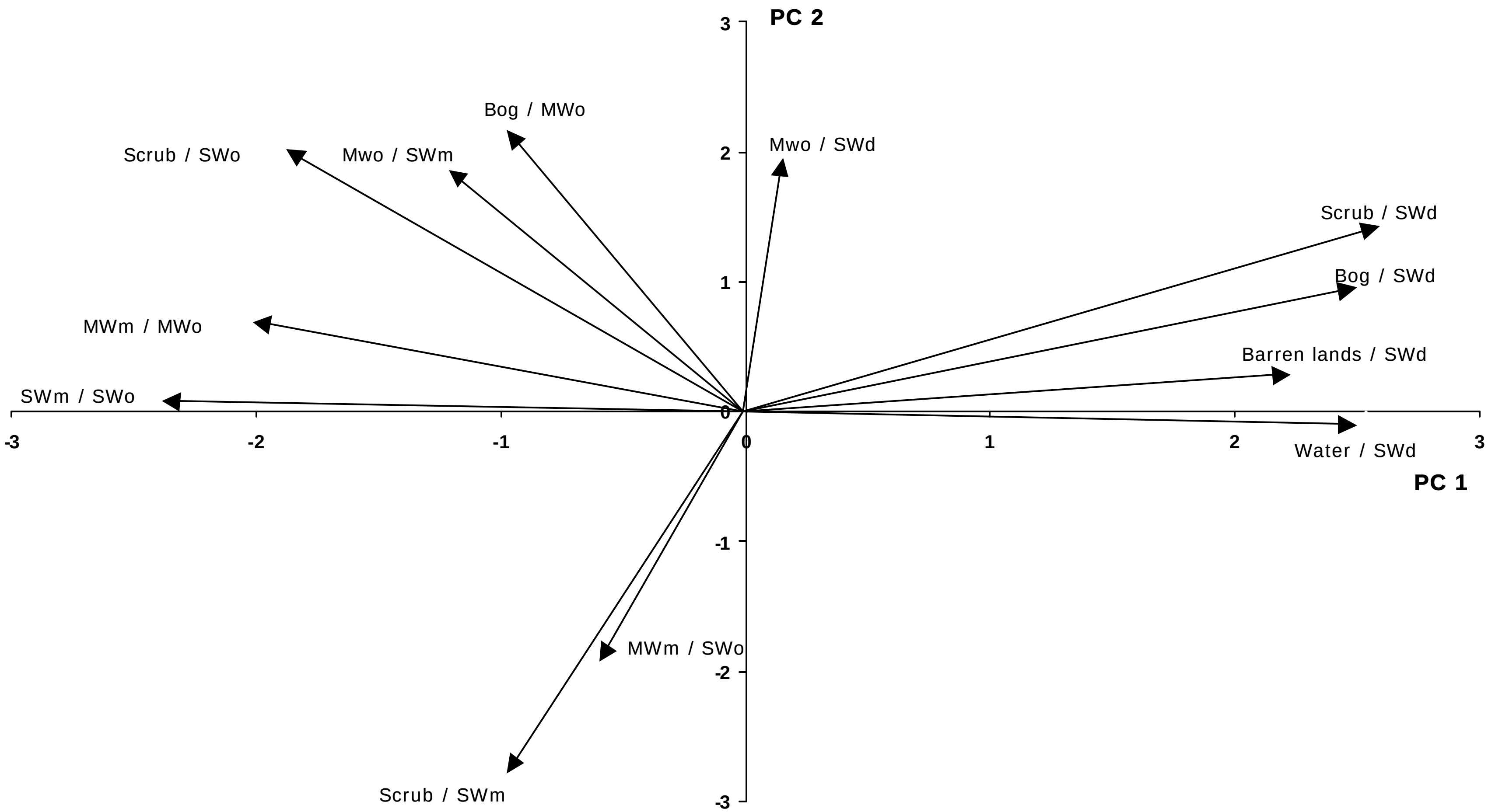


Figure 12. Mean and 95% confidence interval (red cross) of the adjacency scores and adjacency distribution shifts in the space defined by the first two principal components along the 200 years horizon for the four scenarios. Number refers to the simulation year (0=2000, 10=2010, etc.)

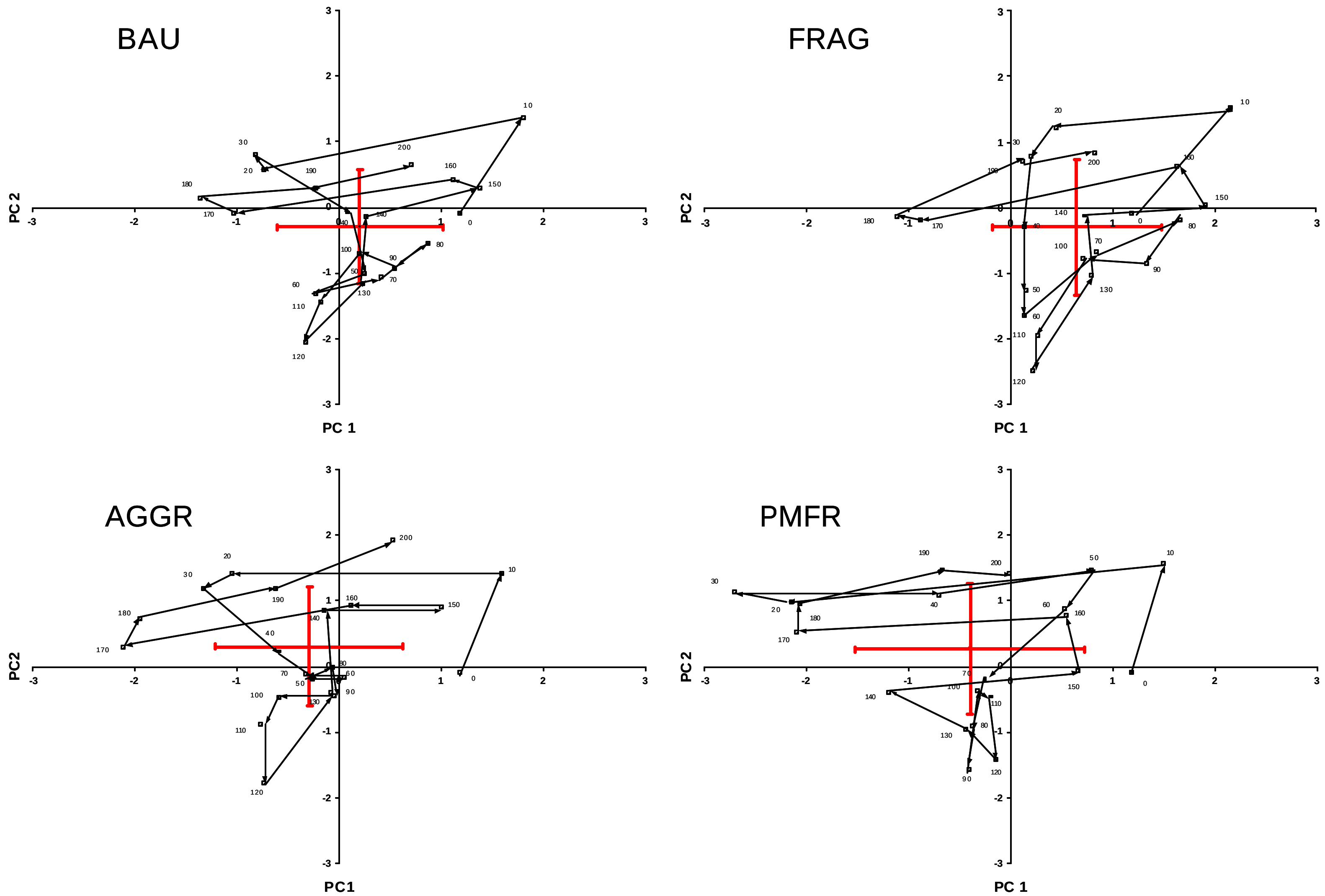


Figure 13. Mean patch size among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland

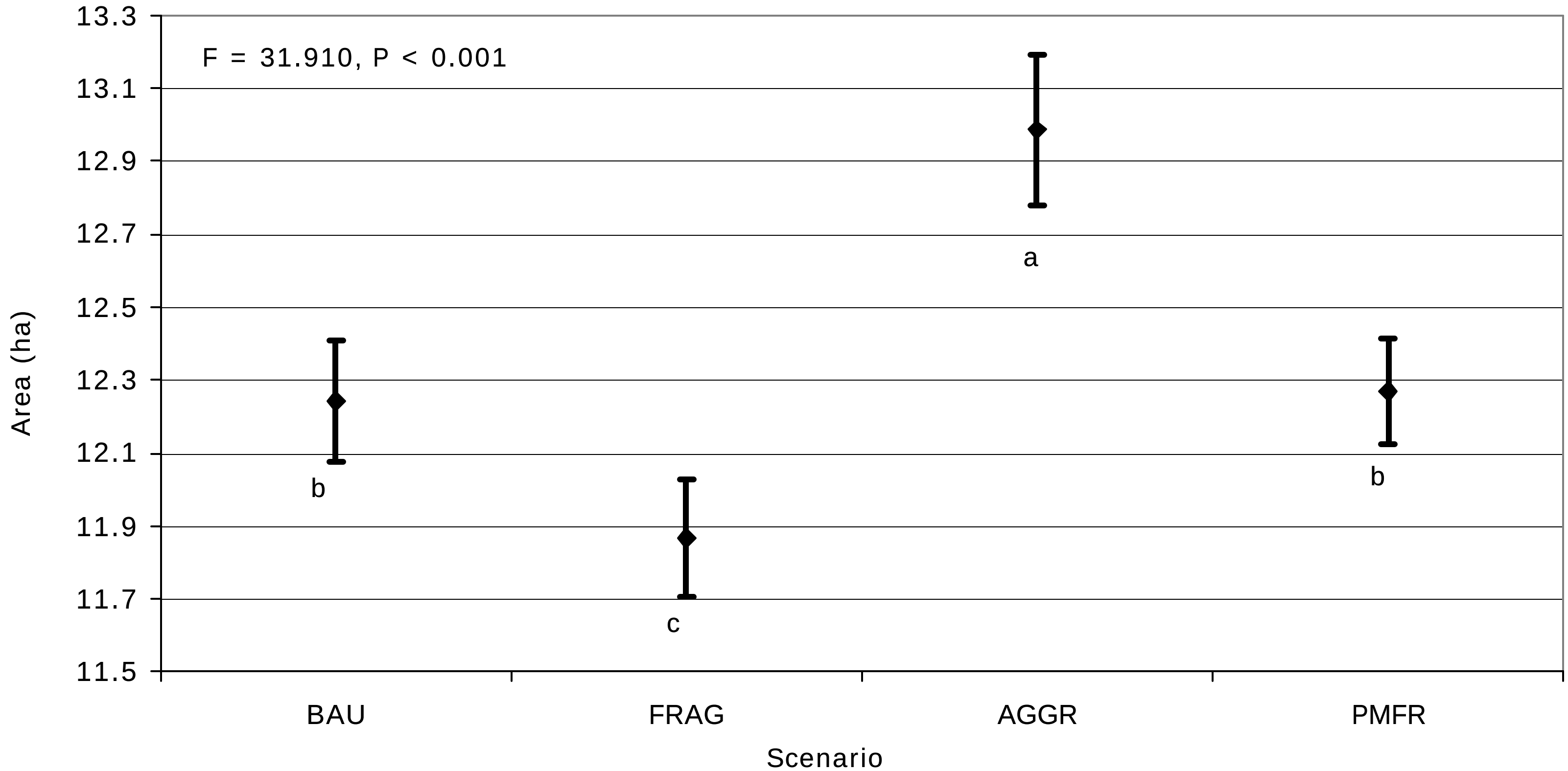


Figure 14. Mean patch size among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland

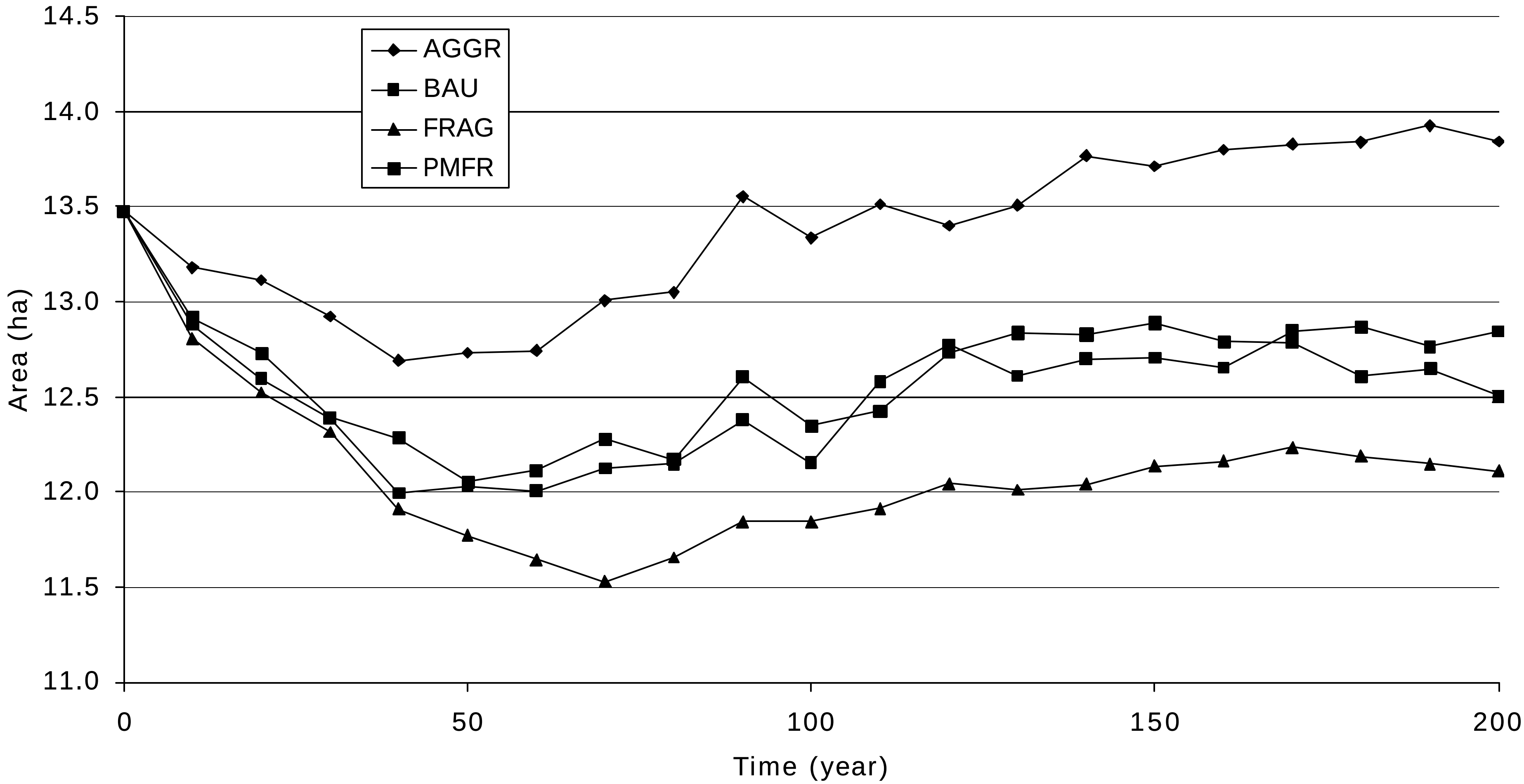


Figure 15. Patch size percentile threshold for softwood habitats among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland. Letters show statistically significant difference among scenario by percentile class.

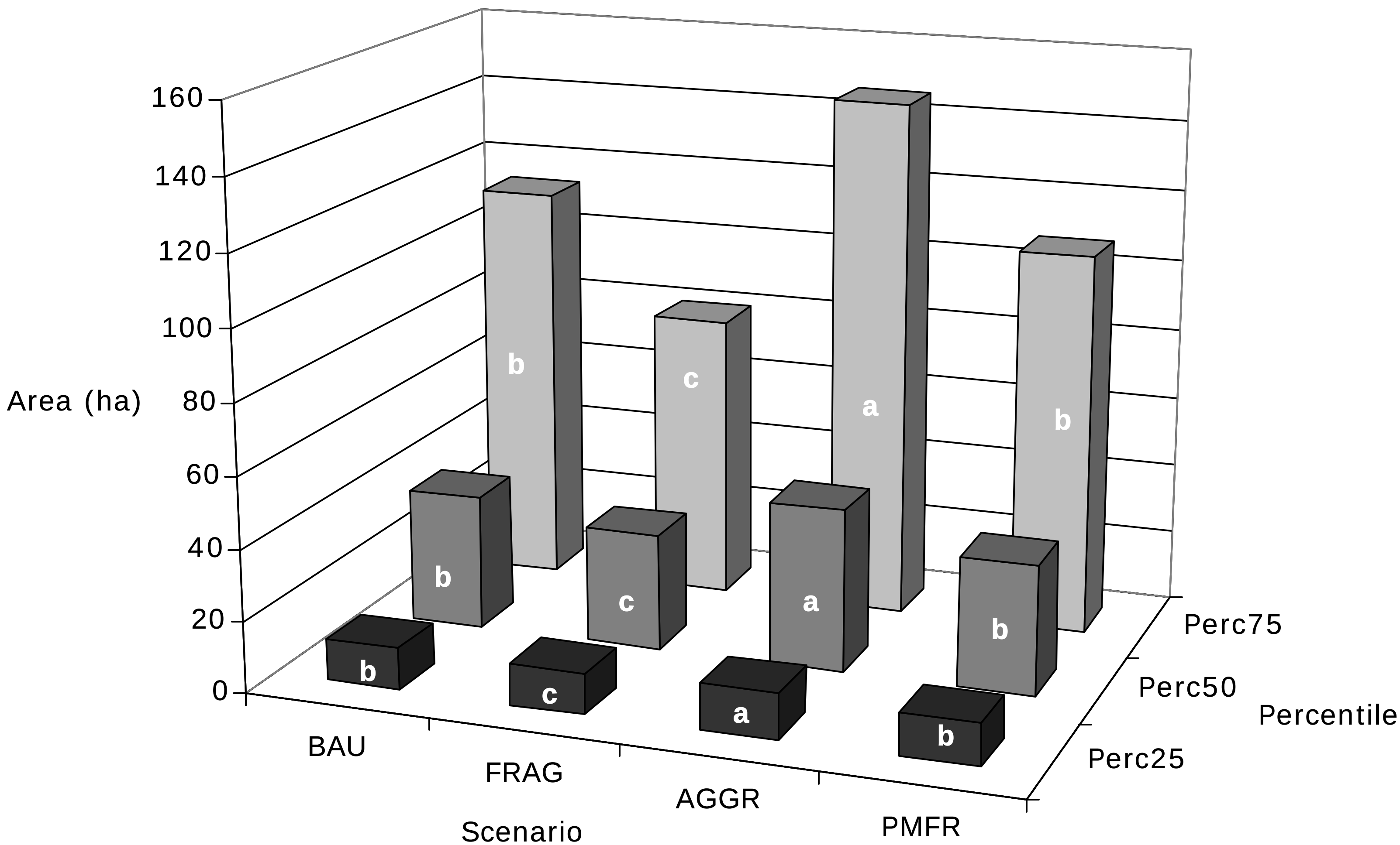


Figure 16. Patch size percentile threshold for softwood developing habitats among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland. Letters show statistically significant difference among scenario by percentile class.

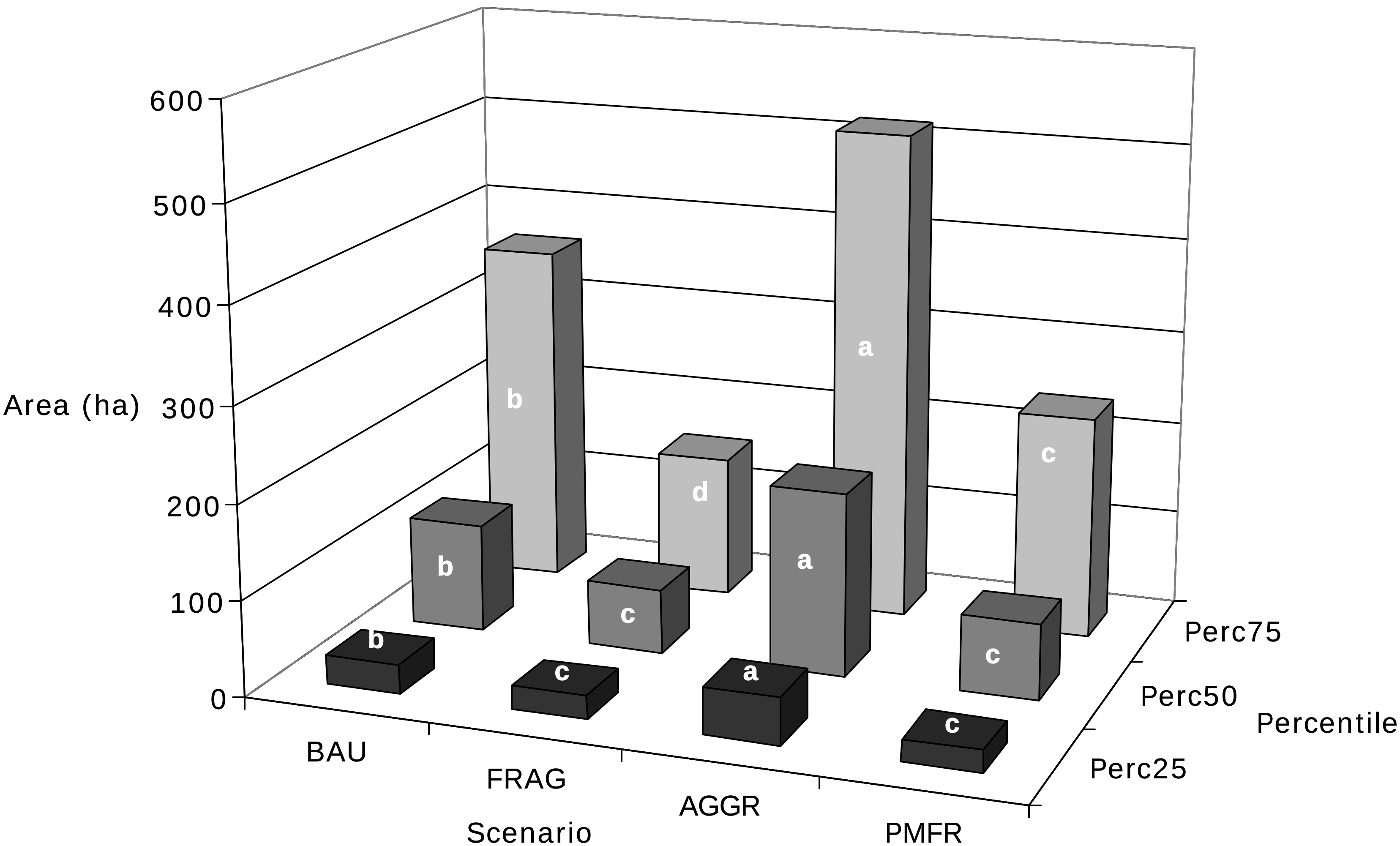


Figure 17. Patch size percentile threshold for softwood forest habitats among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland. . Letters show statistically significant difference among scenario by percentile class.

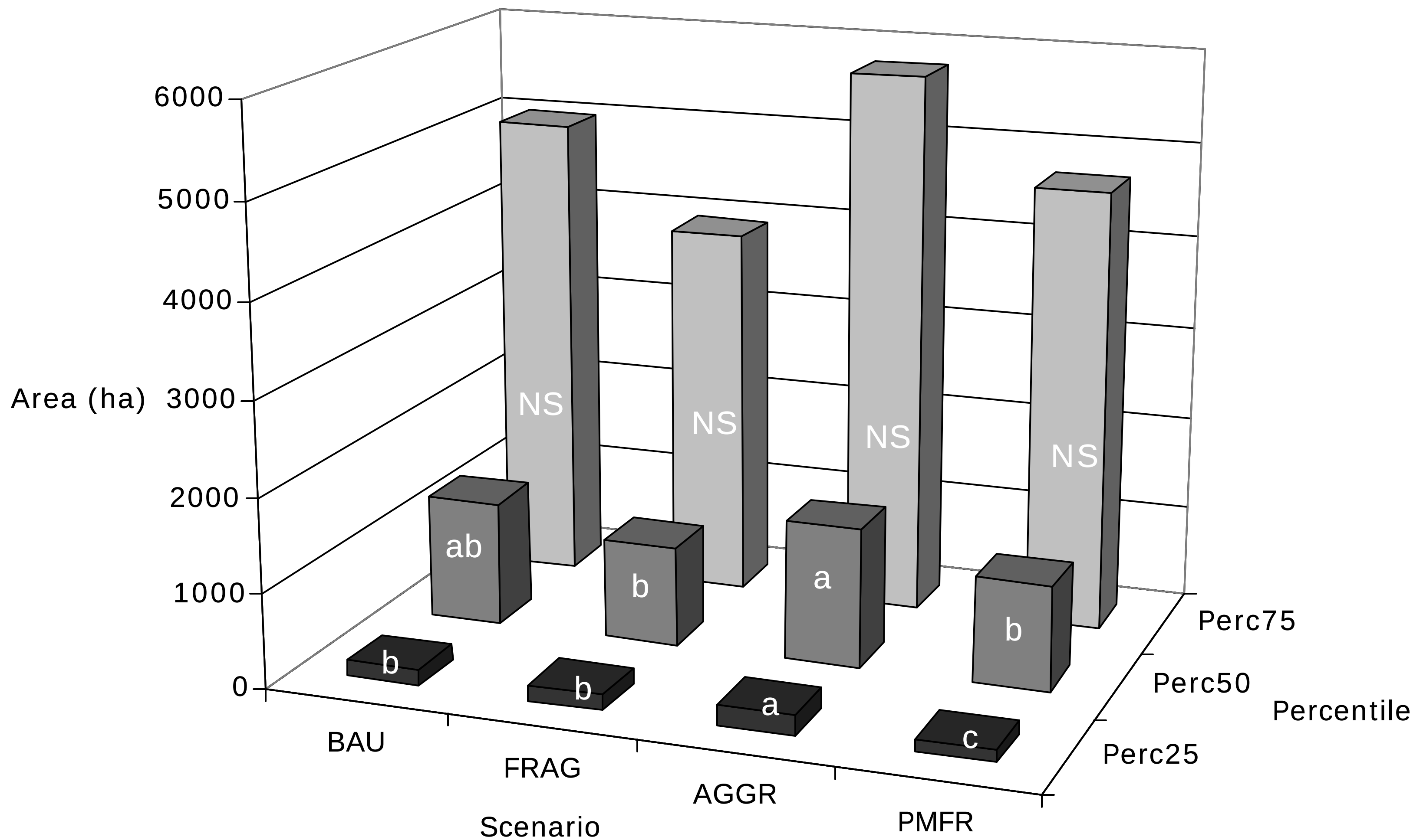


Figure 18. Patch size percentile threshold for softwood over- mature habitats among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland. . Letters show statistically significant difference among scenario by percentile class.

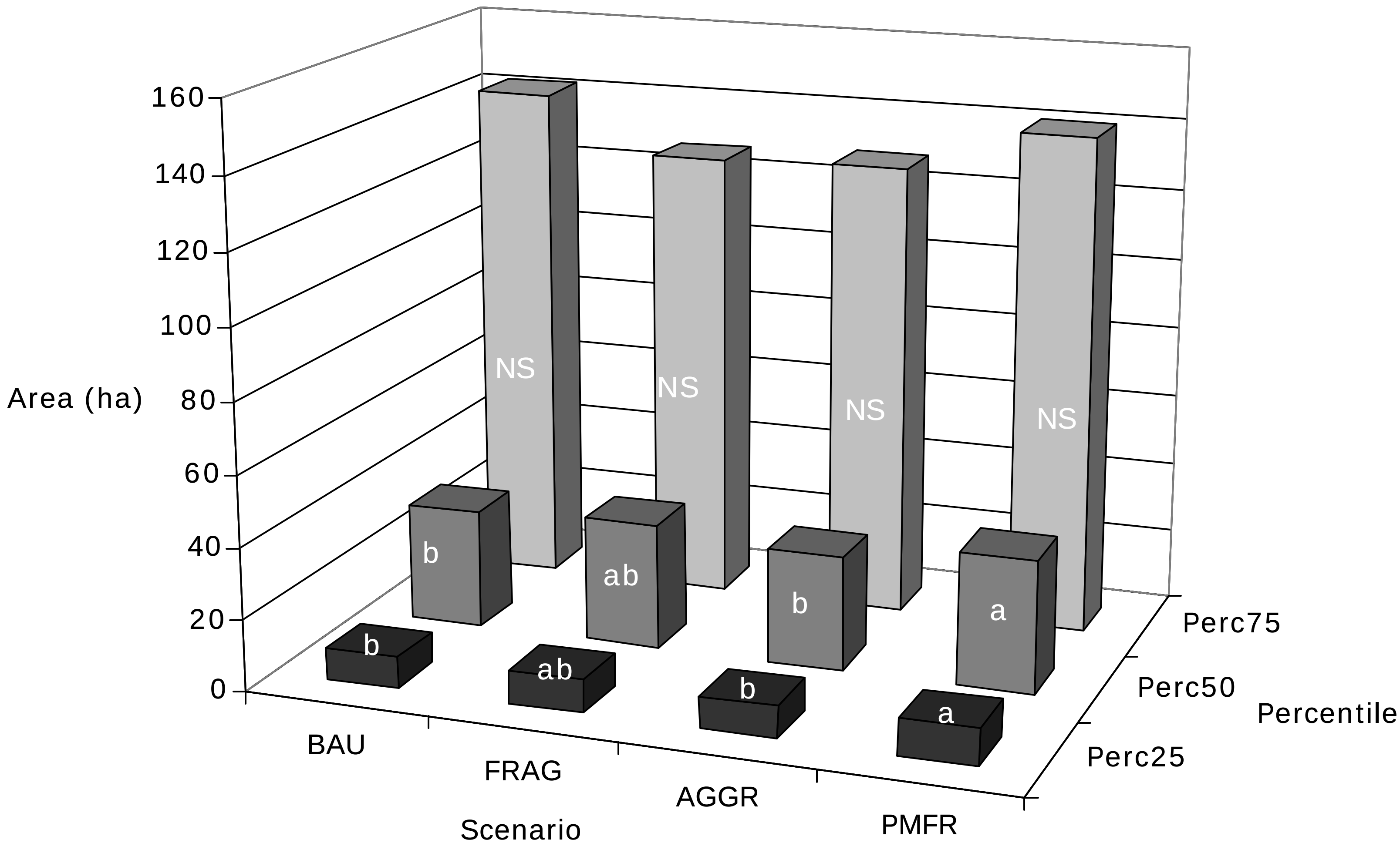


Figure 19. Mean core are patch size, regardless of habitat type, among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland.

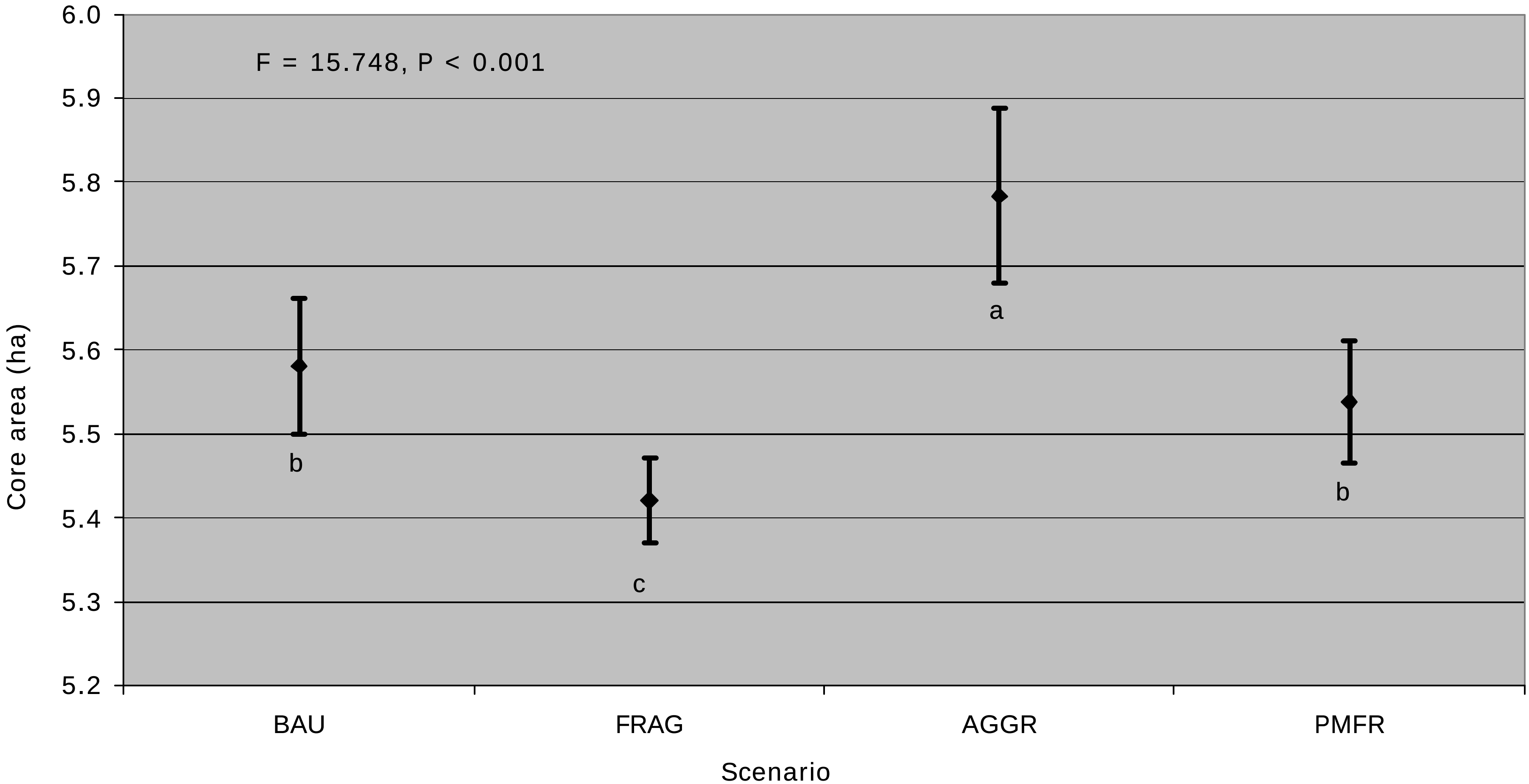


Figure 20. Mean patch shape index, regardless of habitat type, among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland.

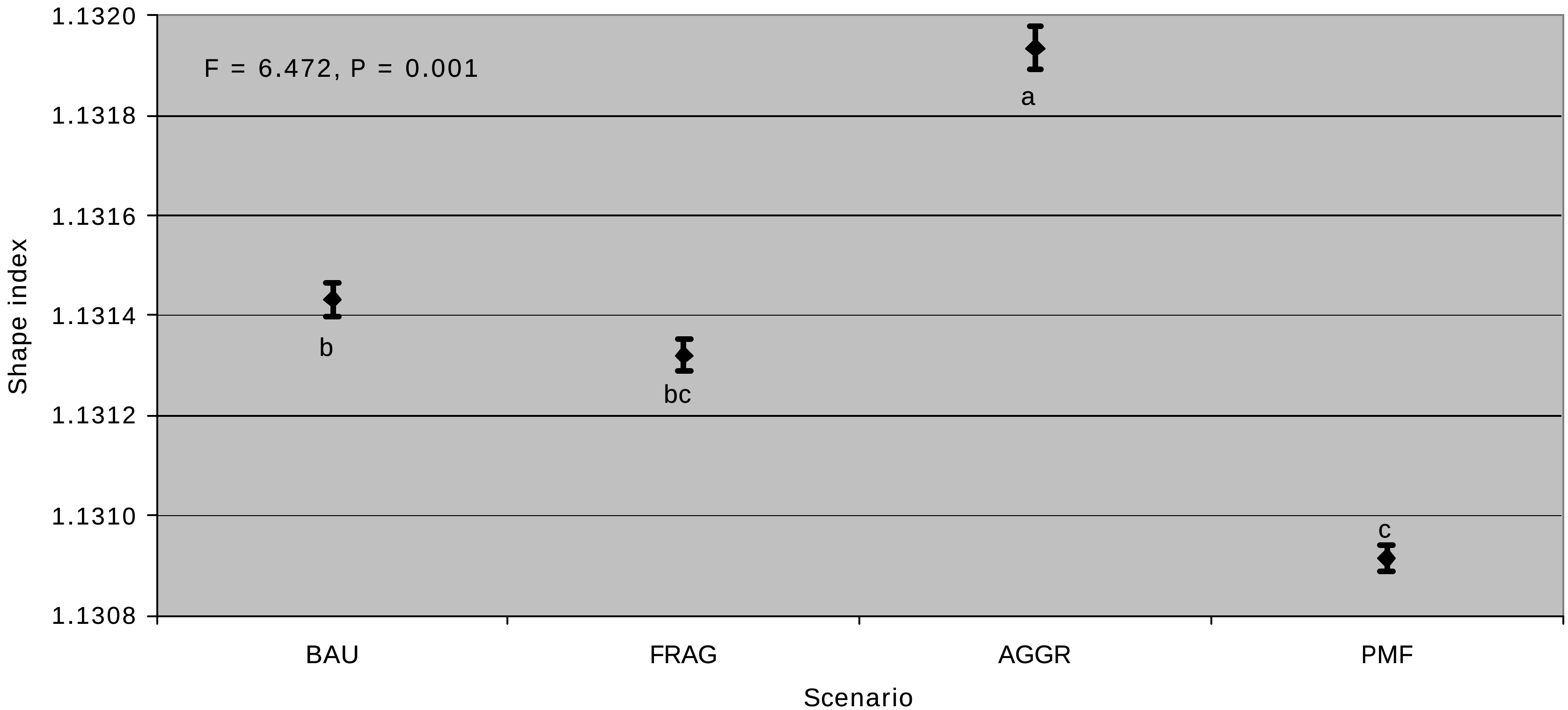


Figure 21. Mean patch shape index, regardless of the habitat type, over the 200 years for four forest management scenarios in District 15 of Western Newfoundland.

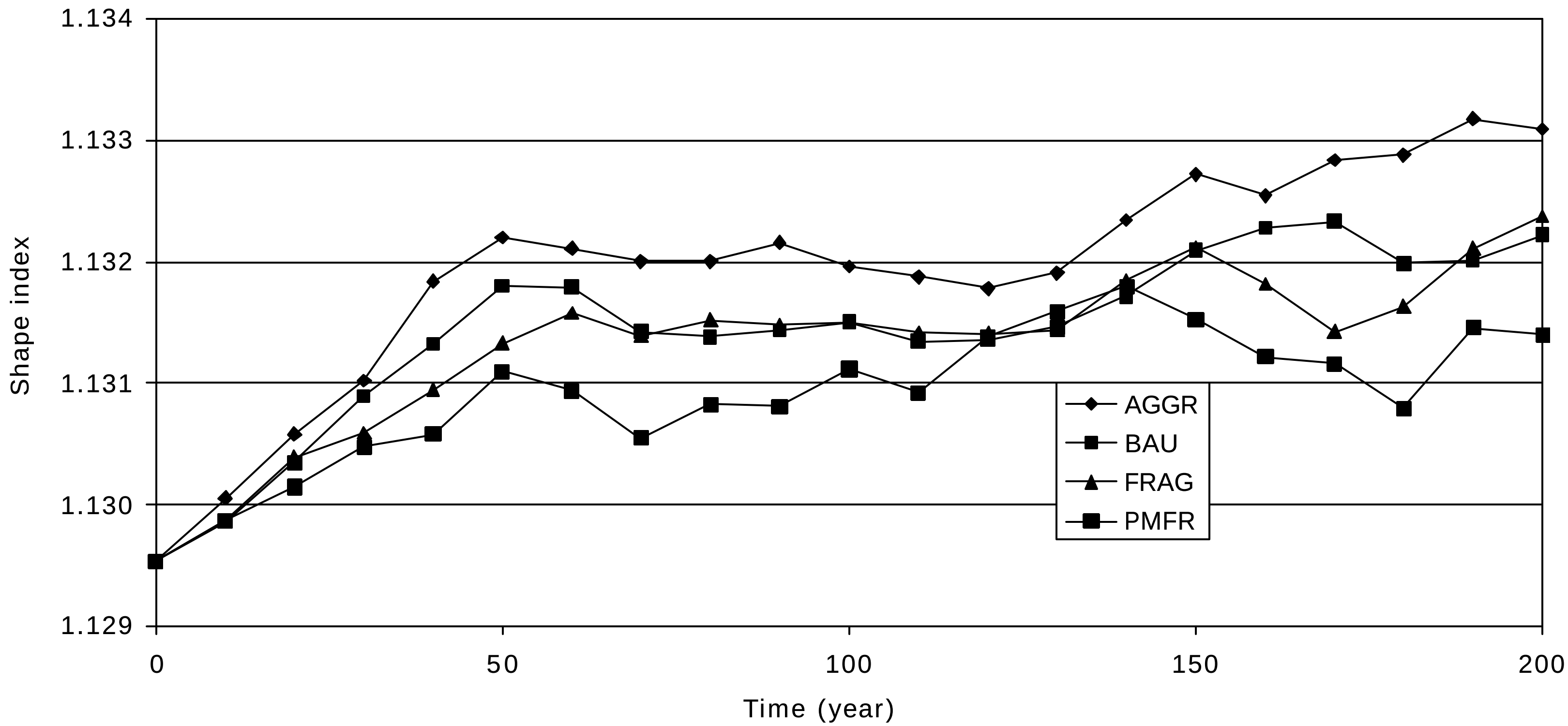


Figure 22. Mean contrast-weighted edge length among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland.

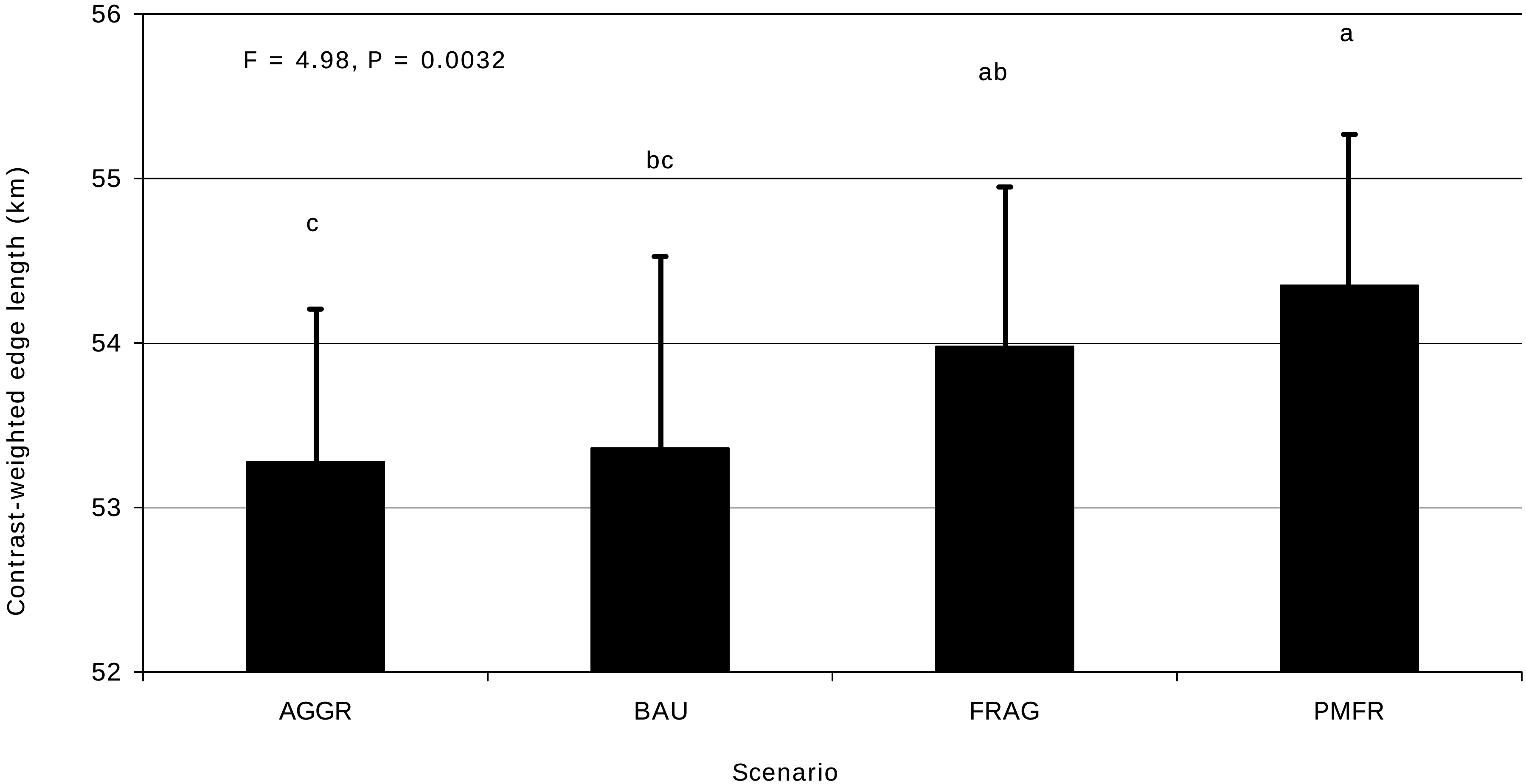


Figure 23. Mean edge contrast index among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland.

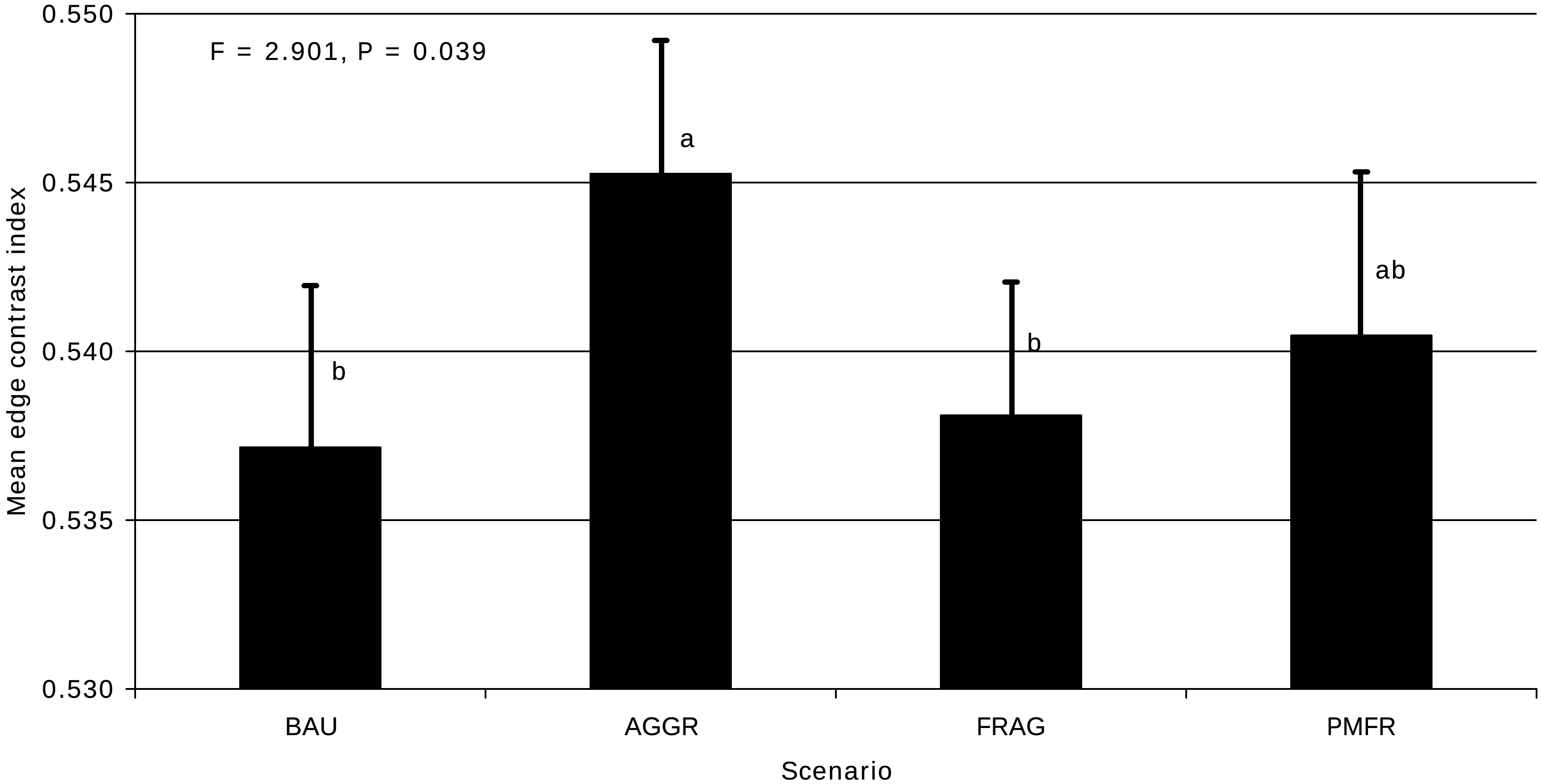


Figure 24. Mean male pine marten population size among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland.

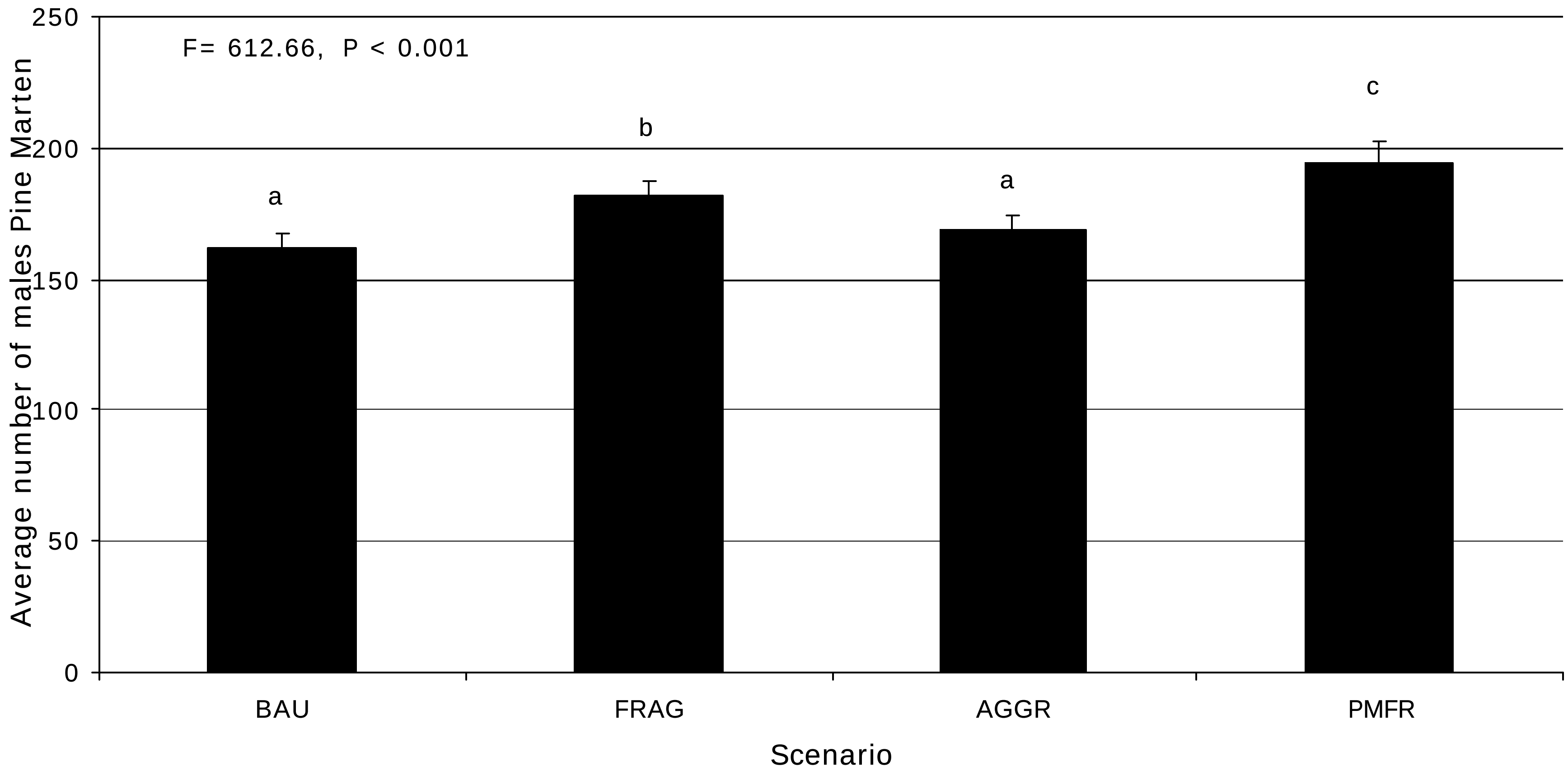


Figure 25. Change over time of the simulation of male pine marten population size among the four scenarios in District 15 of Western Newfoundland.

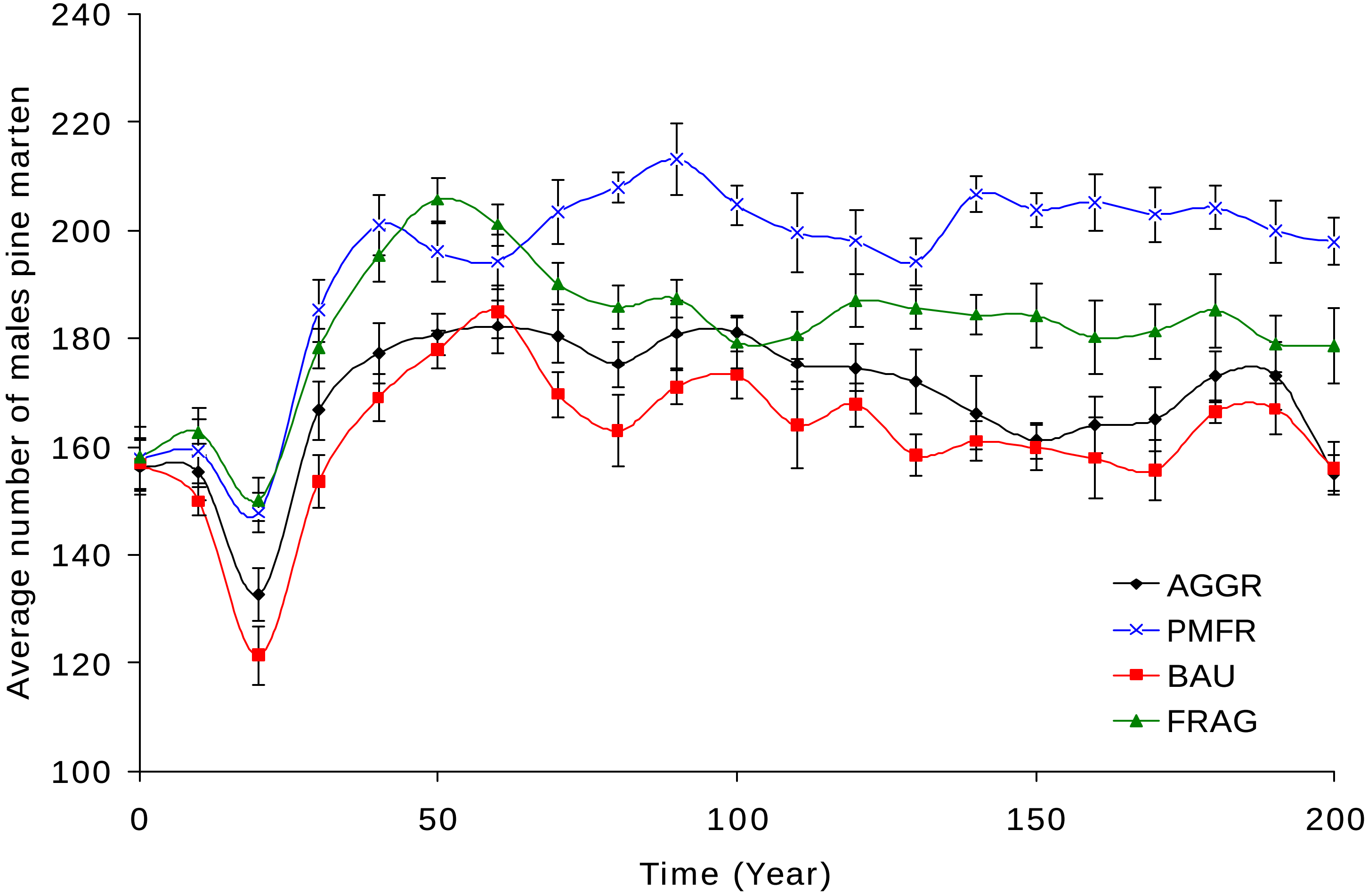


Figure 26. Change over time of the simulation of total suitable pine marten habitat area among the four scenarios in District 15 of Western Newfoundland

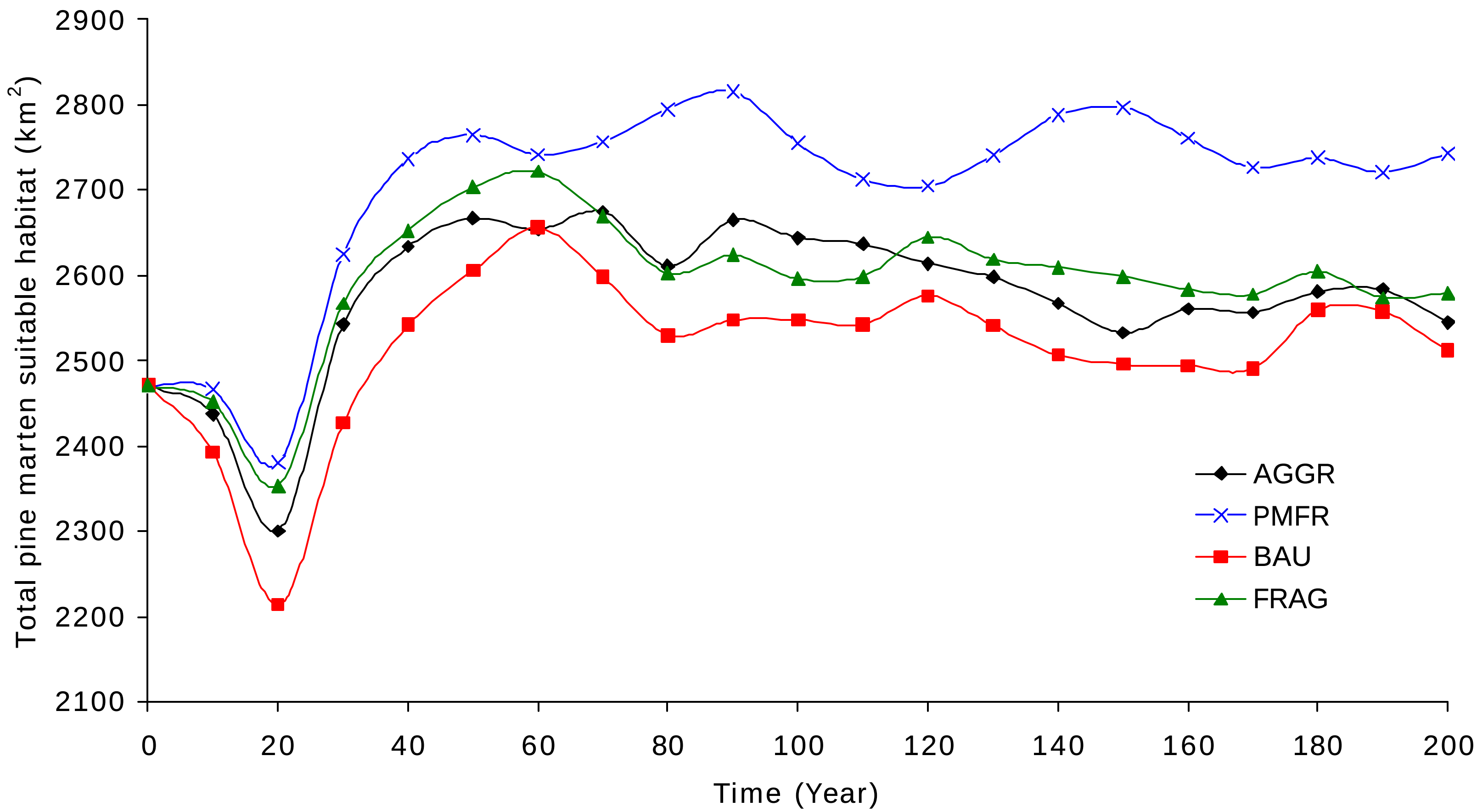


Figure 27. Mean woodland caribou wintering habitat suitability value among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland

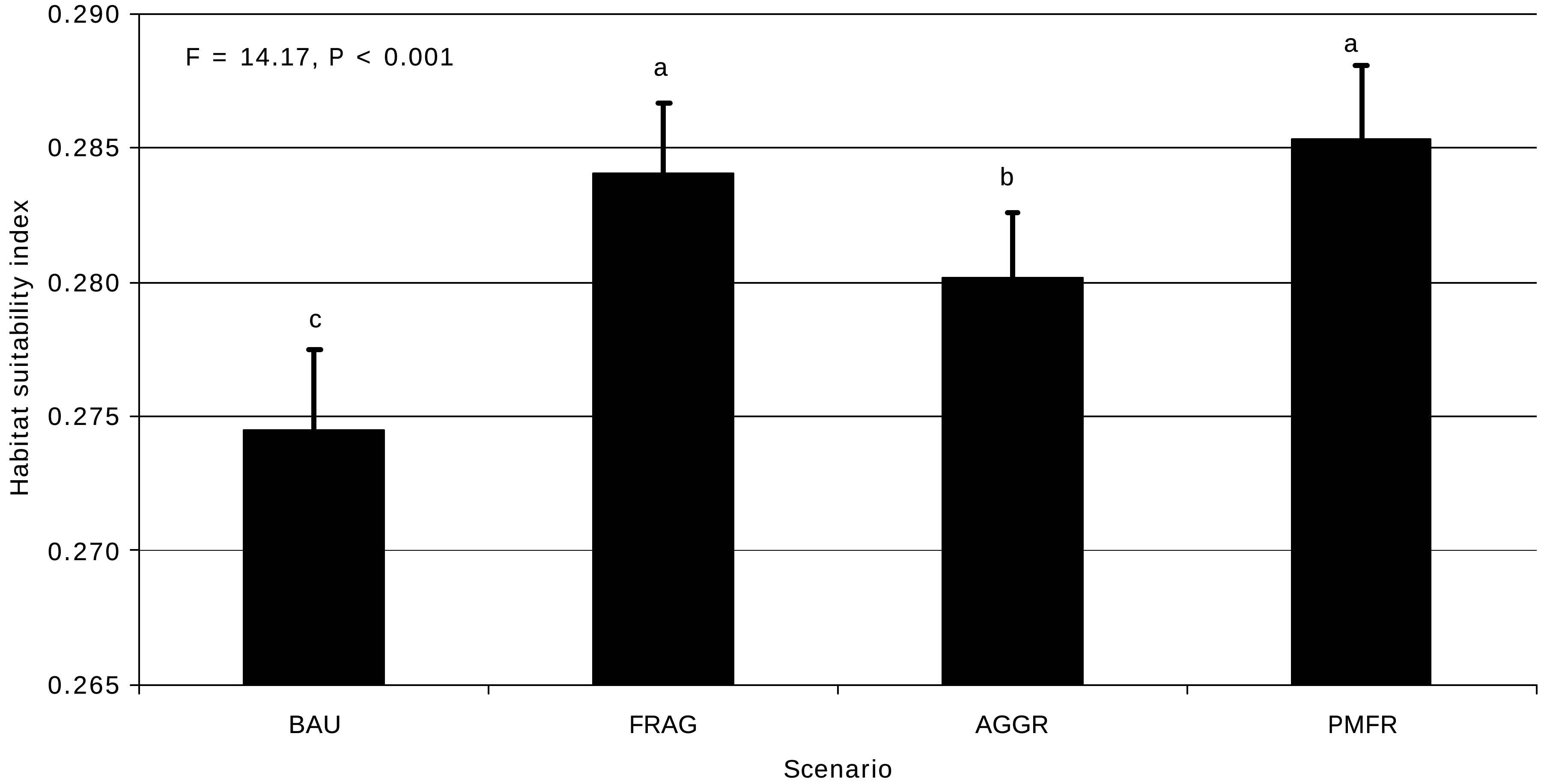


Figure 28. Change over time of the simulation of woodland caribou wintering suitability habitat index value among the four scenarios in District 15 of Western Newfoundland

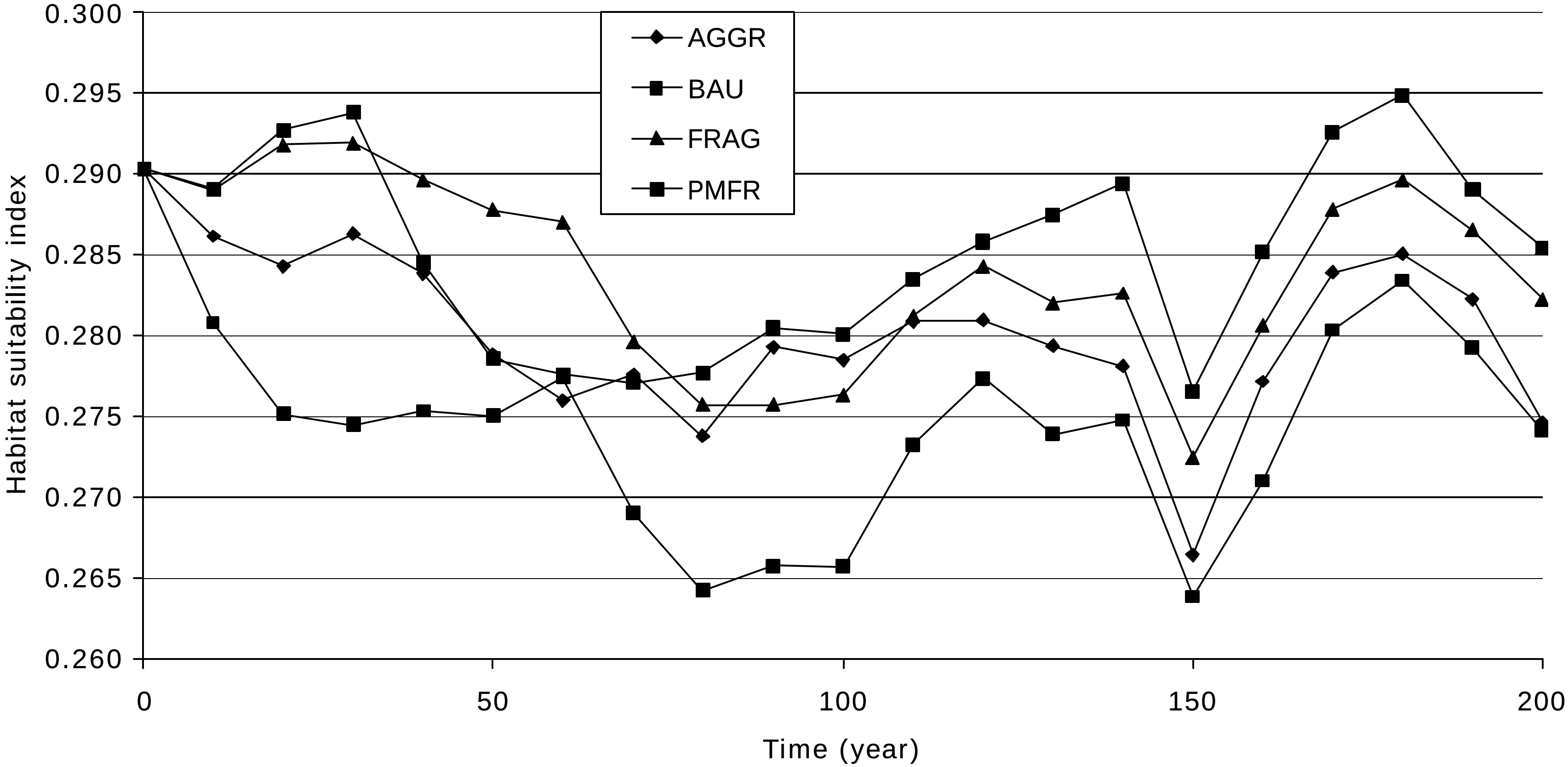


Figure 29. Mean woodland caribou calving habitat suitability value among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland.

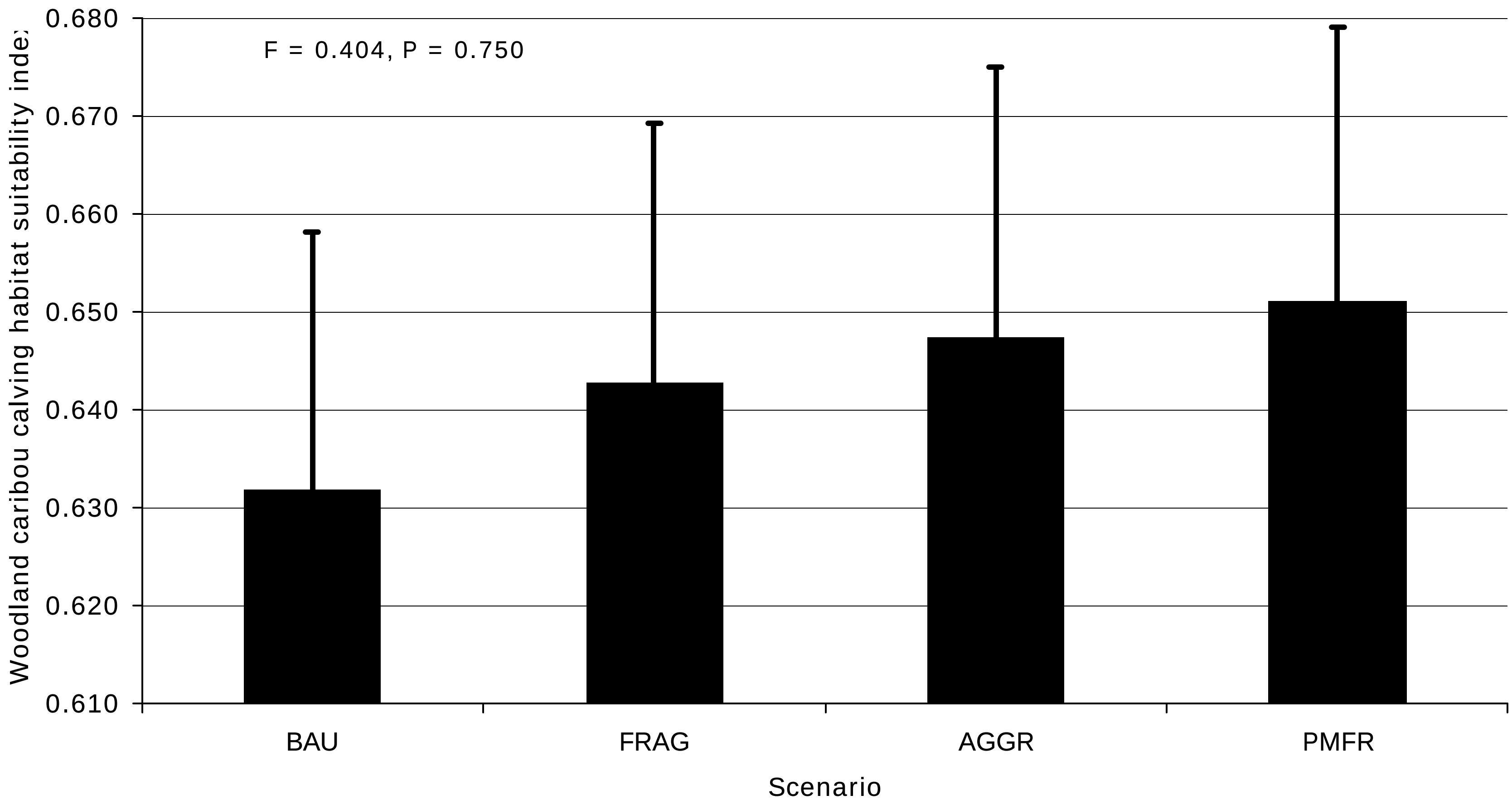


Figure 30. Change over time of the simulation of woodland caribou calving suitability habitat index value among the four scenarios in District 15 of Western Newfoundland.

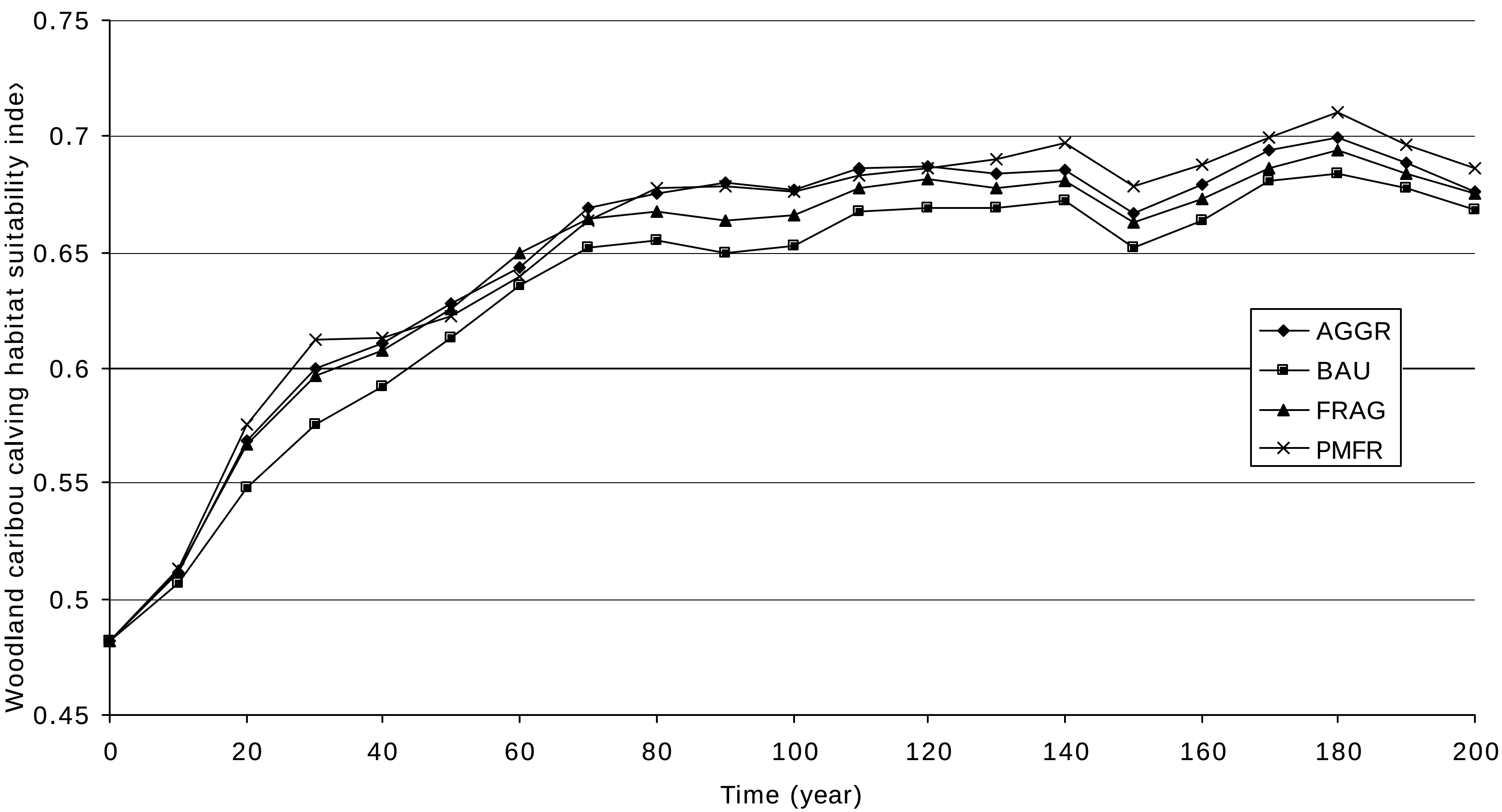


Figure 31. Mean boreal owl habitat suitability value among the four scenarios over the 200 years horizon in District 15 of Western Newfoundland.

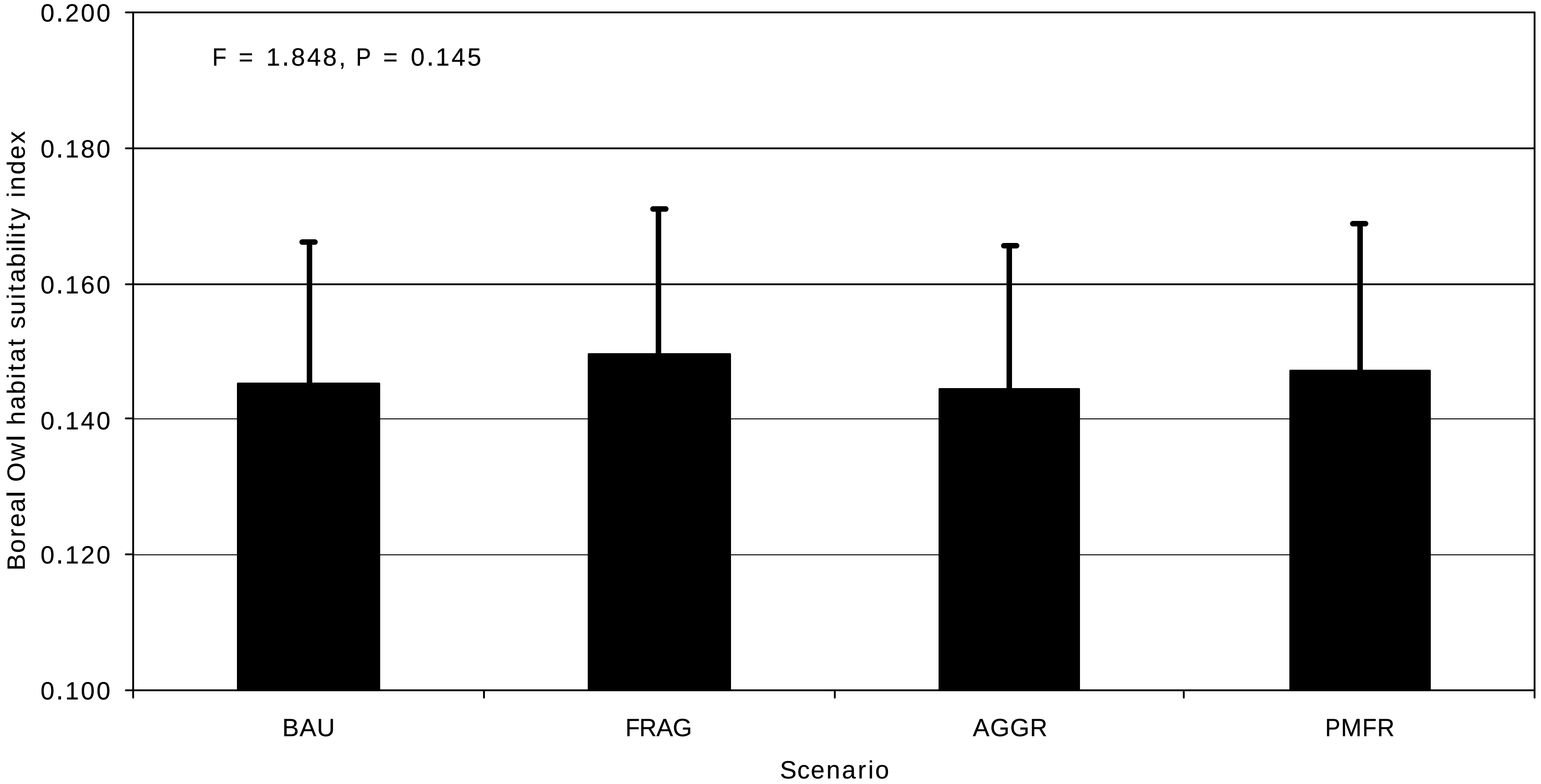


Figure 32. Change over time of the simulation of boreal owl suitability habitat index value among the four scenarios in District 15 of Western Newfoundland.

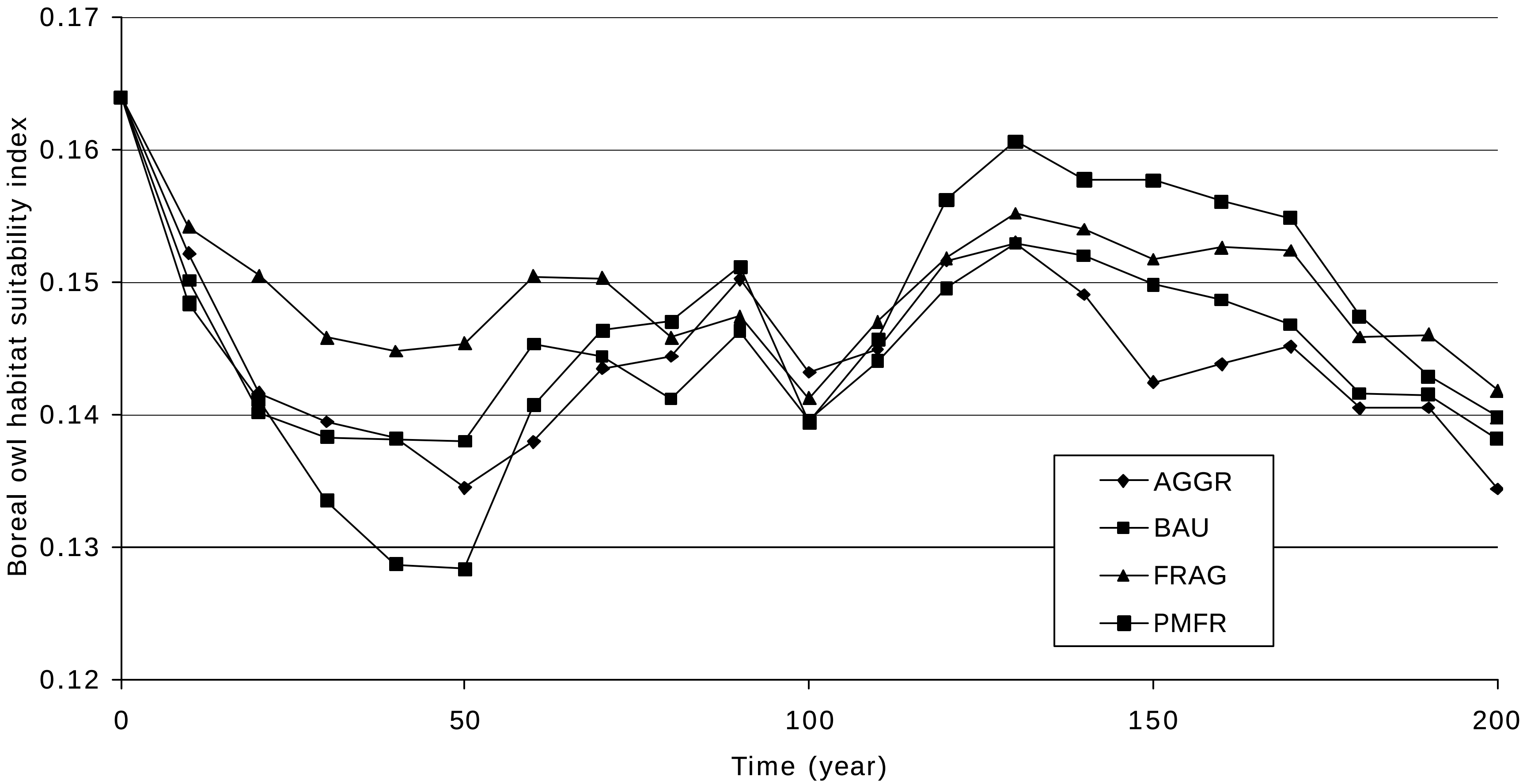


Figure 33. Age class structure for the first six periods for the BAU scenario in District 15 of Western Newfoundland.

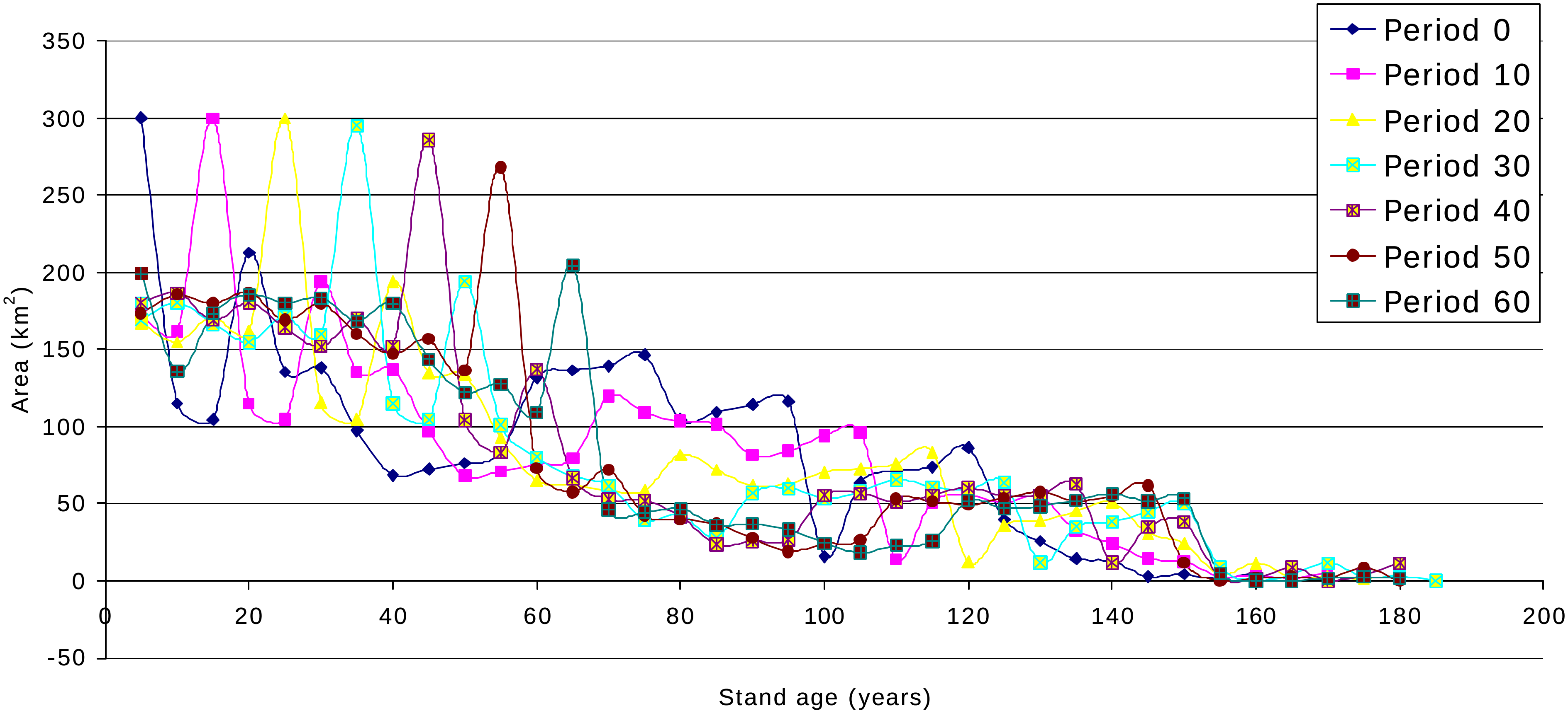


Figure 34. Satellite scene of southwest portion of D15.

Figure 35. Satellite scene of a forest management unit in Alberta.

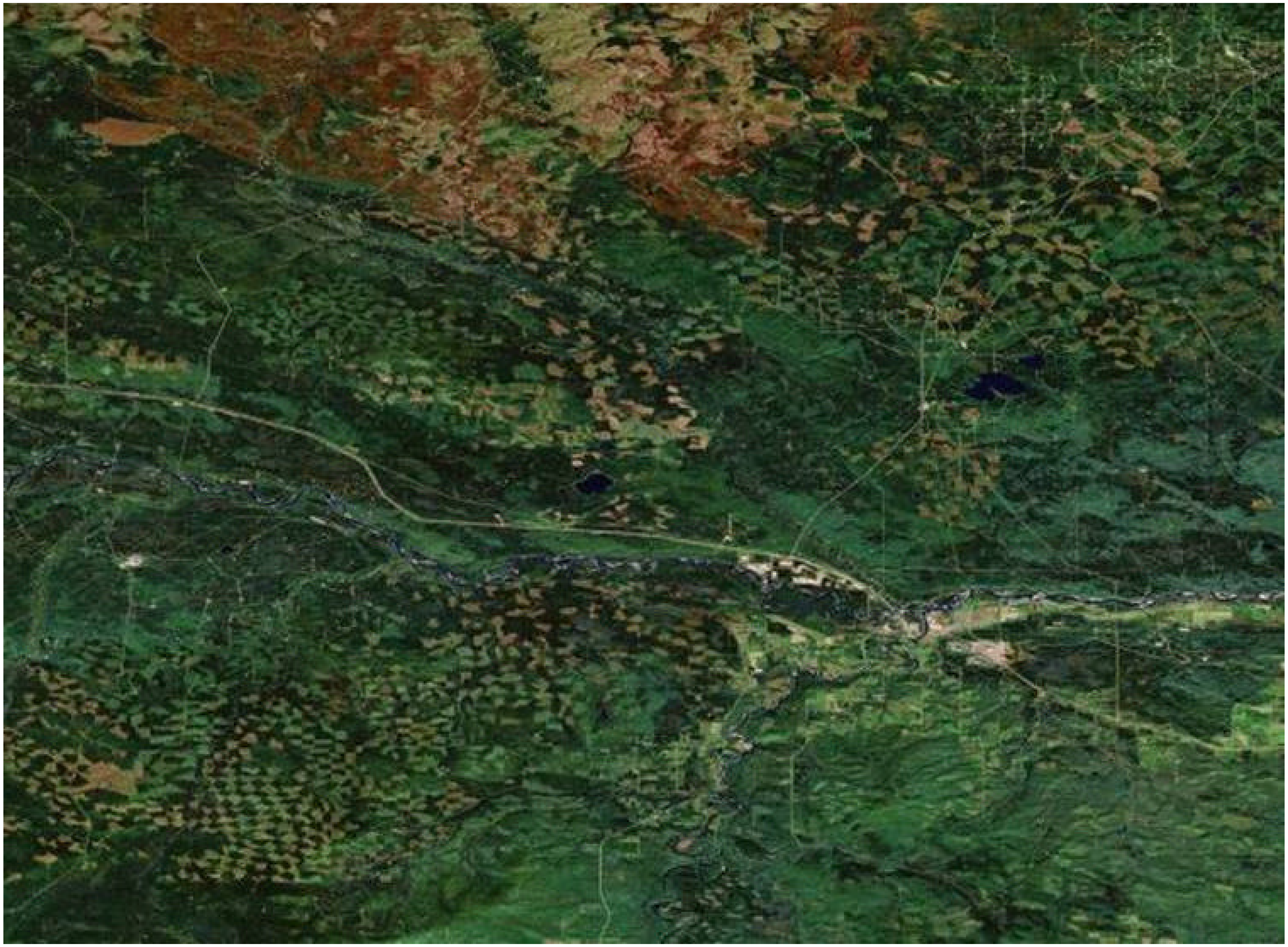


Figure 36. Cutblock layout in District 15 under the Business-As-Usual scenario. Each color represents a different 30 year period of the simulation. (From Pond 2004)

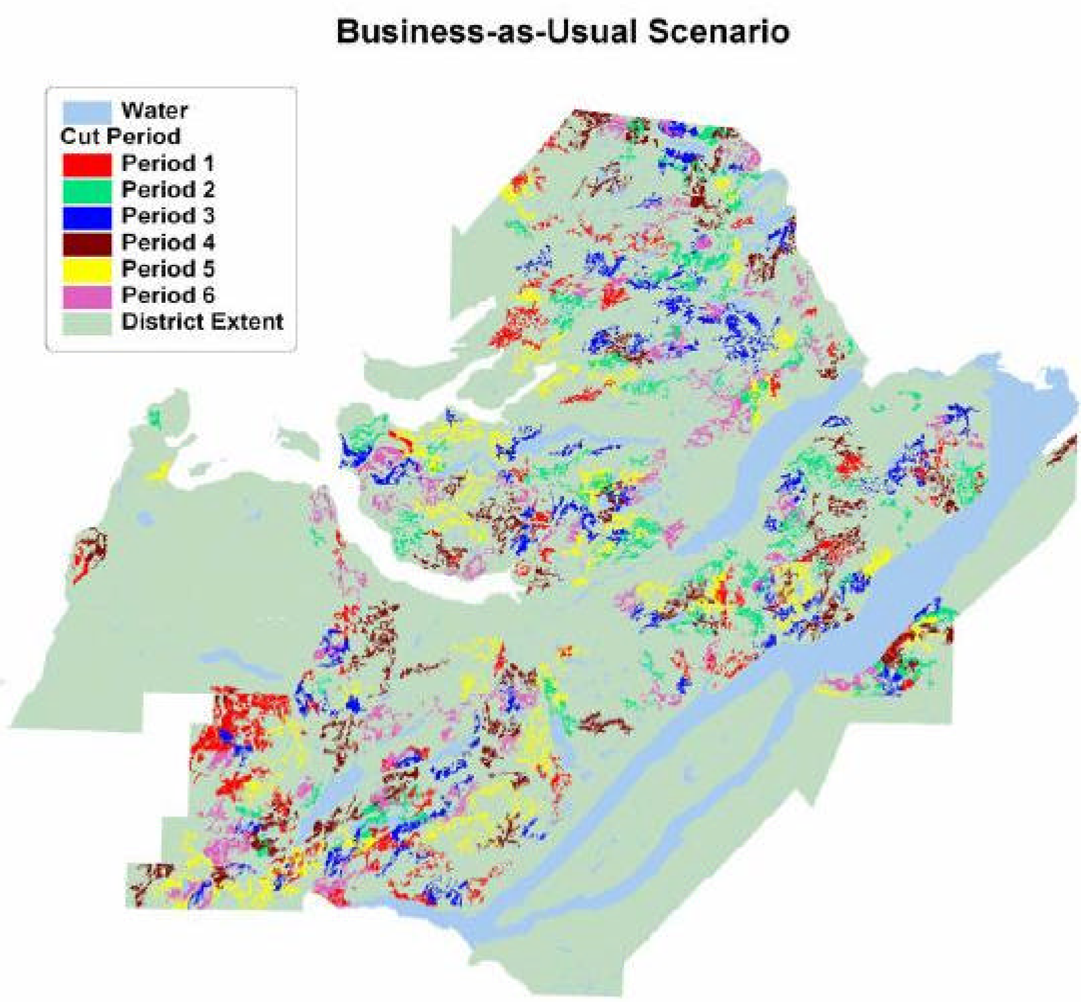


Figure 37. Cutblock layout in District 15 under the Aggregated scenario. Each color represents a different 30 year period of the simulation. (From Pond 2004)

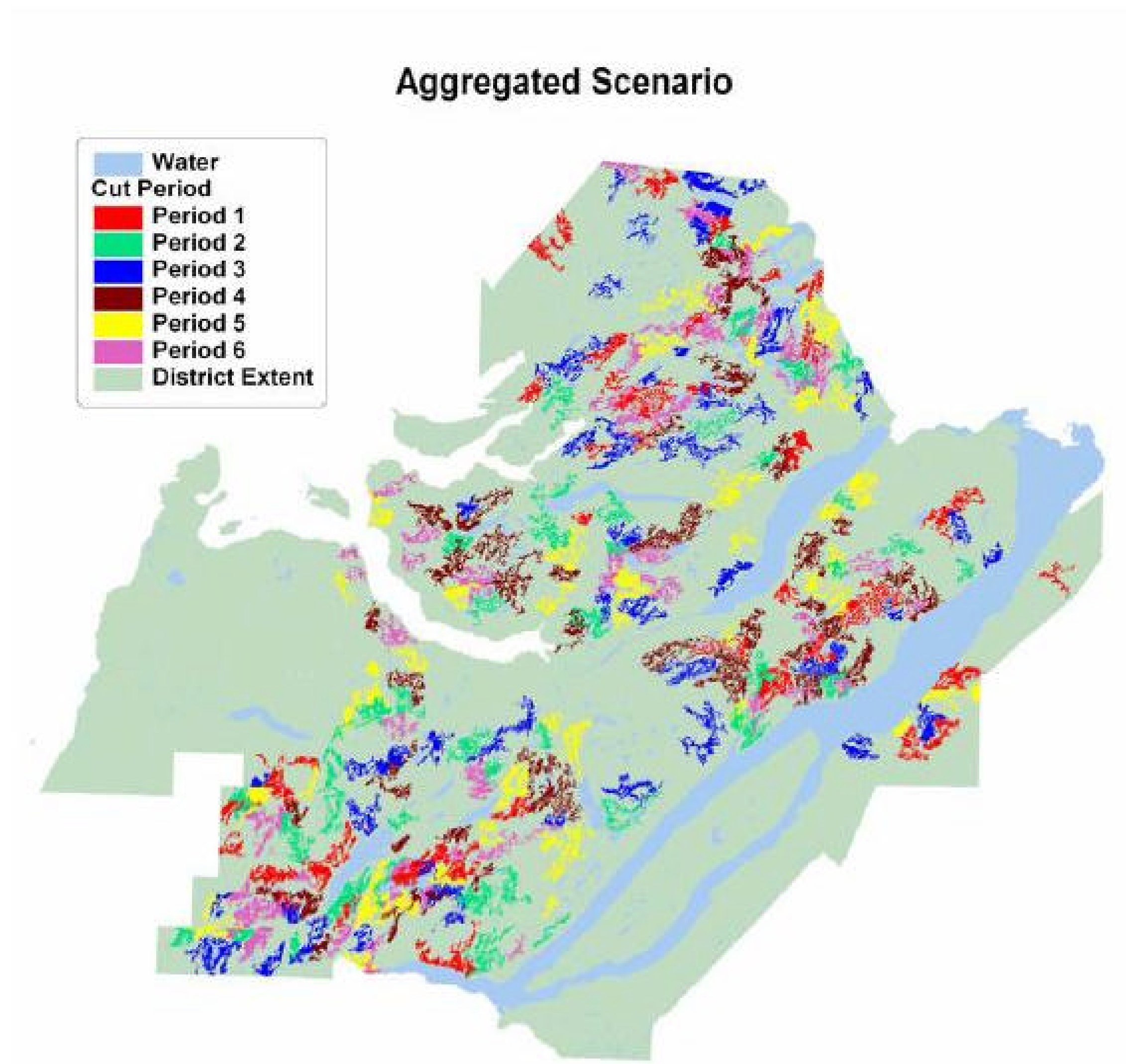


Figure 38. Cutblock layout in District 15 under the Fragmented scenario. Each color represents a different 30 year period of the simulation. (From Pond 2004)

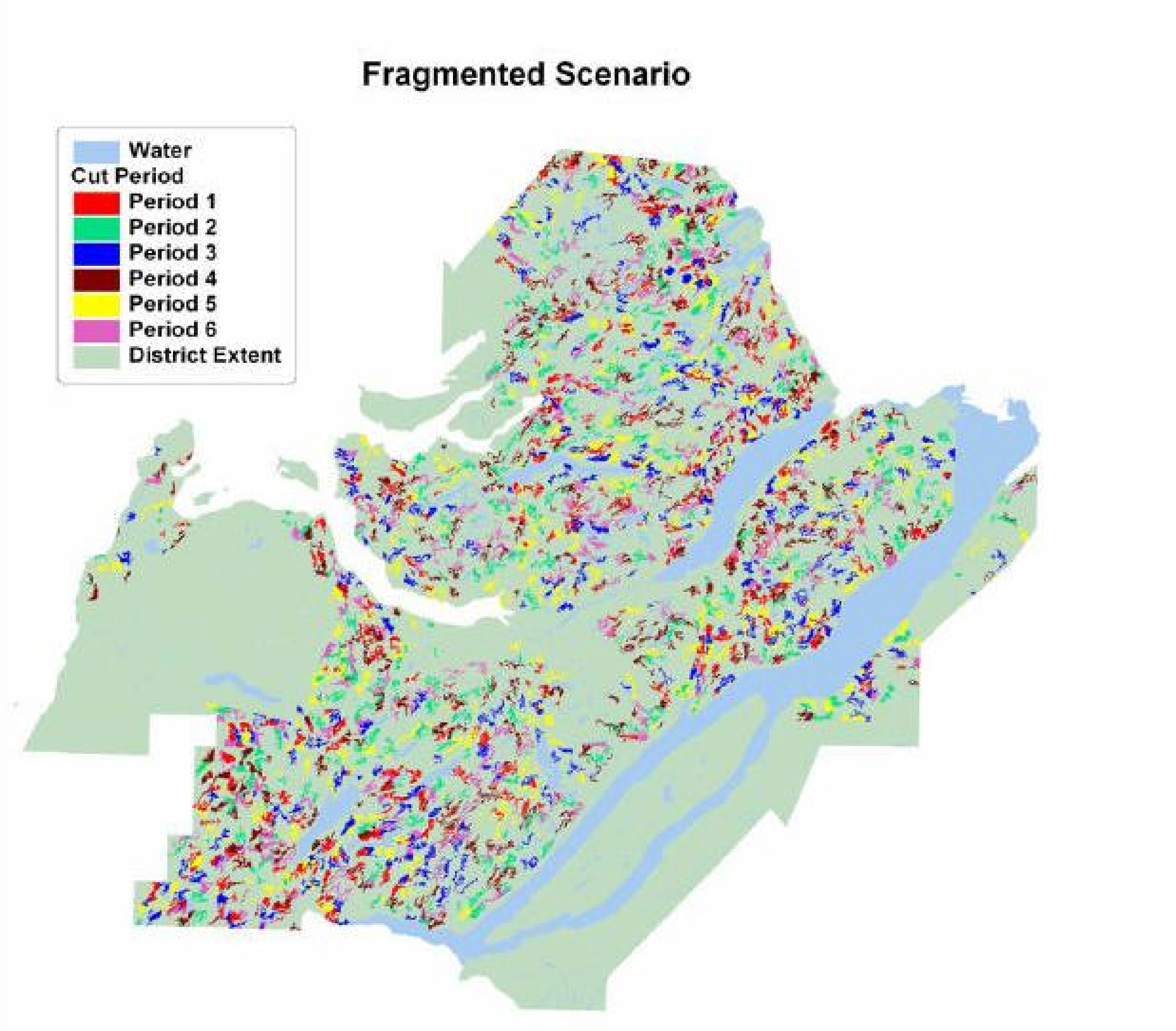


Figure 39. Cutblock layout in District 15 under the Pine-Marten-Friendly scenario. Each color represents a different 30 year period of the simulation. (From Pond 2004).

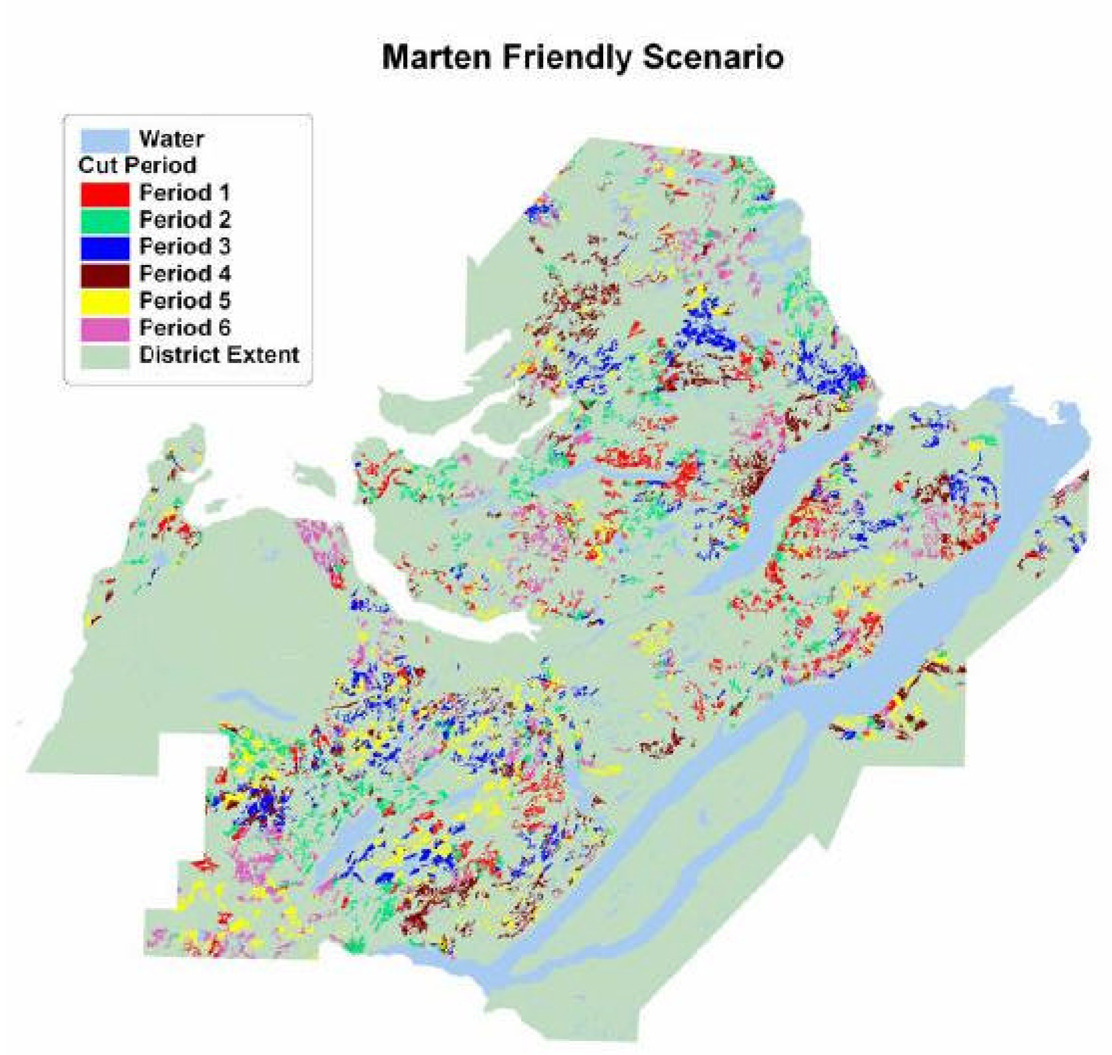


Figure 40. Relationship between male pine marten population level and harvest level for the four scenarios in District 15 of Western Newfoundland.

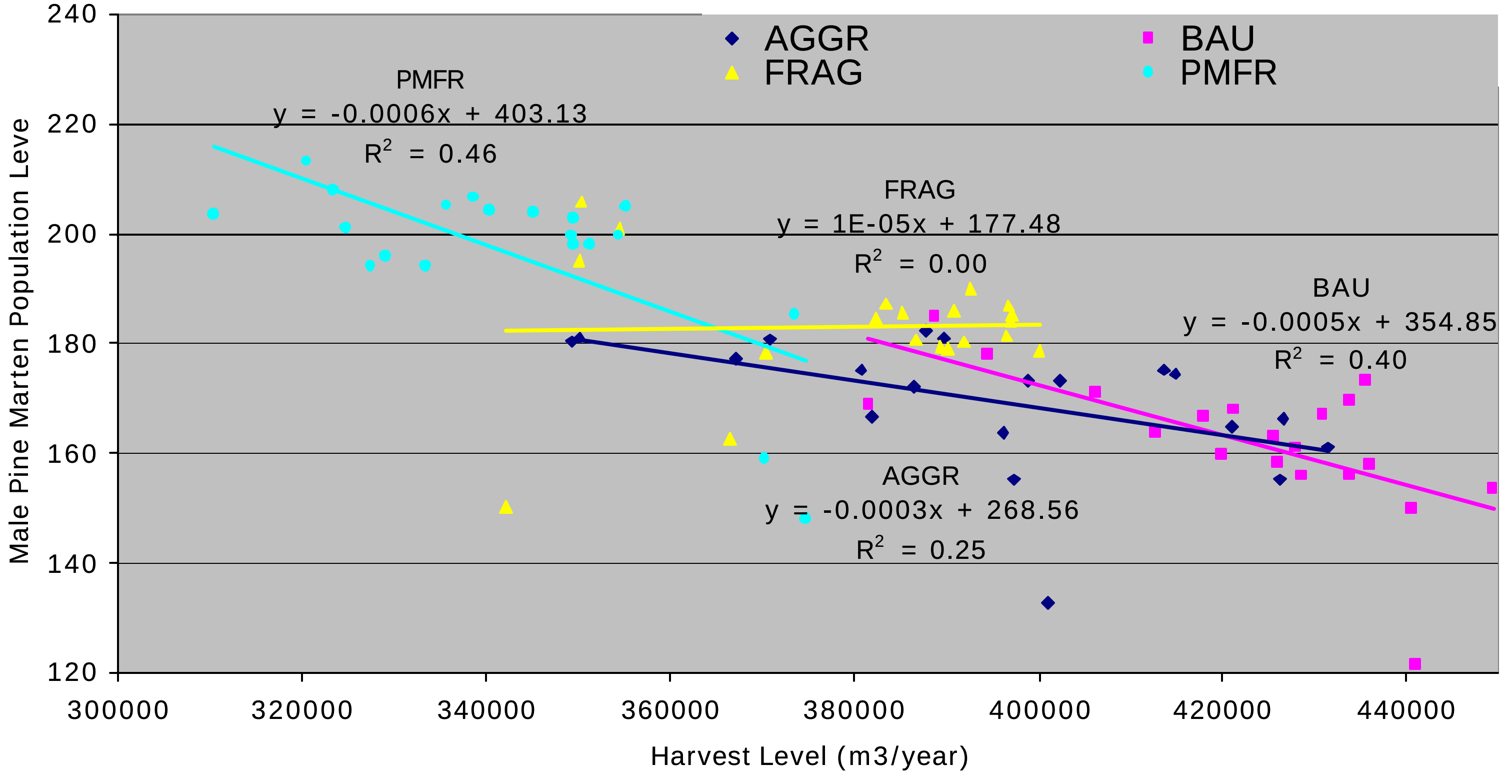
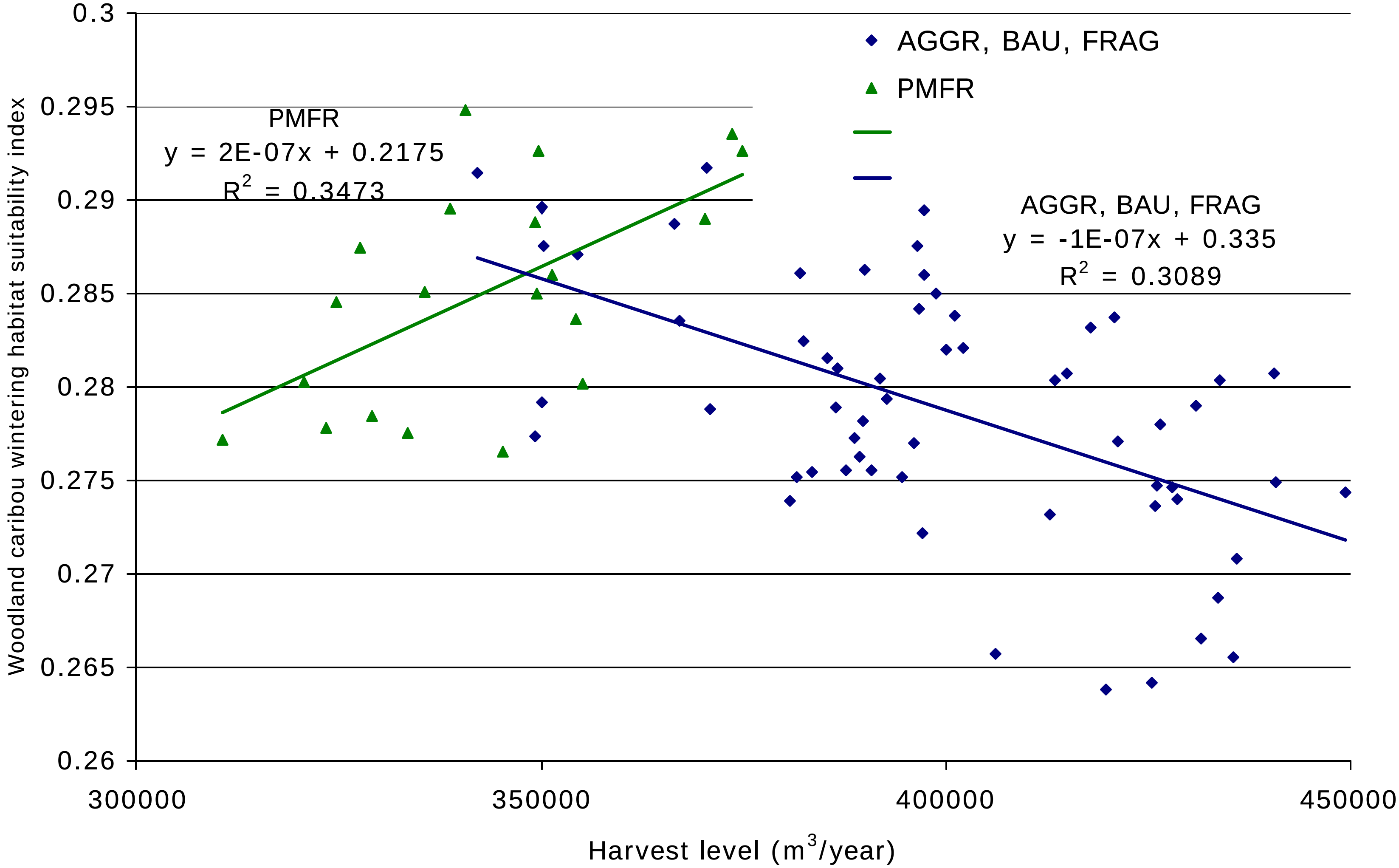


Figure 41. Relationship between woodland caribou wintering habitat suitability index and harvest level for the four scenarios in District 15 of Western Newfoundland.



Appendix