RESPONSE OF BLACK SPRUCE TO PRE-COMMERCIAL THINNING: PRELIMINARY META-ANALYSIS RESULTS

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SUMMARY

This study reports on the results of a comprehensive literature review and associated meta-analysis of responses of black spruce (*Picea mariana* (Mill.) B.S.P.) to pre-commercial thinning (PCT). Basically, the approach consisted of 4 steps. The first step consisted of systematically keyword-searching the following electronic databases for relevant PCT studies: (1) WebSPIRS Database (©1997-2000 SilverPlatter Information N.V.); (2) Canadian Forest Service Library Network via the Metafore portal (Natural Resources Canada); (3) Science Direct Database (Elsevier Science B.V.); and (4) World Wide Web via a general Internet search employing the Google search engine (©2001 Google Inc. CA, USA). The maximum temporal coverage of these searches was approximately 71 years (1930-2001) and included consideration of all publications irrespective of language. The second step consisted of assessing the resultant 22 publications for their specific applicability in terms of treatments and yield parameters assessed. The third step consisted of deriving and subsequently calculating effect sizes (response ratio) for quadratic mean diameter (*Dq* (cm)) and merchantable volume (*Vm* (m^3/ha)). The fourth step consisted of quantifying the relationship between each response ratio and mean dominant height at the time of PCT (H_I (m)), change in mean dominant height since PCT ($\Delta H = H - H_I$ (m) where H is mean dominant height (m)), and post-PCT spacing (S_I (m)) via multiple regression analysis. The maximum *Dq* response for the mean data values derived from the selected studies (H_I = 5.53 m; and S_I = 2.14 m) was approximately 15% which occurred at a ΔH of 3.3 m; subsequent positive responses continued until a ΔH of 6.3 m. The maximum *Vm* response was approximately 150% which occurred at a ΔH of 4.0 m; subsequent positive *Vm* responses continued until a ΔH of 8.0 m. It was evident from these response patterns that late heavy thinnings produced the largest positive *Dq* responses, relative to the controls. Conversely, early light thinnings produced the largest positive *Vm* responses, relative to the controls. Furthermore, *Dq* responses were considerably less, maximized earlier, and were shorter in duration in terms of positive response periods, than those observed for *Vm*.

INTRODUCTION

Historically, quantitative yield responses of black spruce (*Picea mariana* (Mill.) B.S.P.) to pre-commercial thinning (PCT) have been documented in numerous individual case studies within the scientific literature. However, there has not been a systematic attempt to evaluate these responses on a collective basis. Thus the objective of this study was to synthesize the results of these individual case studies via meta-analysis in order to derive general inferences regarding yield responses. The scope of this analysis was restricted to evaluating yield responses in terms of mean tree size and merchantable volume production. Refer to Newton and Charlebois (2002) for additional details of the meta-analytical procedures utilized including a complete description of the searching protocol used, studies and associated data sets employed, additional computations, resultant inferences, management recommendations and study limitations.

METHOD

Generally, a fixed-effect unweighted multiple regression meta-analysis approach was utilized in this study. Specifically, multiple regression analysis techniques were used given the number of potential covariates effecting the response ratios (Cooper and Hedges 1994). Furthermore, the lack of replicated experimental designs within the literature negated the usage of weighted regression analysis (Gurevitch and Hedges 1999).

Analytically, the approach involved 4 basic steps. The first step consisted of systematically searching the following electronic databases for relevant PCT publications: (1) WebSPIRS Database (©1997-2000 SilverPlatter Information N.V.) which included Agricola, Biological Abstracts, CAB Abstracts, and TreeCD; (2) Canadian Forest Service (CFS) Library Network via the Metafore portal (Natural Resources Canada; NRCan); (3) Science Direct Database (Elsevier Science B.V.); and (4) World Wide Web via a general Internet search employing the Google search engine (©2001 Google Inc. CA, USA). The maximum temporal coverage of these searches was approximately 71 years (1930-2001) and included consideration of all publications irrespective of language.

The second step consisting of assessing each of the resultant 22 studies for their specific applicability in terms of treatments applied and response parameters measured. A final subset of 9 individual studies were selected. These studies were located in Saskatchewan (Steneker 1969), Manitoba (Waldron and Cayford 1961), Minnesota (Erickson 1994), Ontario (Whynot and

Penner 1992) and Newfoundland (Robertson 1949; Newton 1988; Karsh *et al.* 1994). The mean age of the stands at the time of the PCT treatment, post-PCT response period assessed and site quality of the study areas (site index = mean dominant height at 50 yr as calculated from regional-specific site index functions) were respectively: 34 yr (SD = 14; minimum = 18; maximum = 58); 24 yr (SD = 14; minimum = 7; maximum = 51); and 10.6 m (SD = 2.2; minimum = 6.4; maximum = 14.5). From these 9 studies a total of 156 PCT-CONTROL observational pairs were derived. The mean density values for the control and thinned plots were respectively: 10986 stems/ha (SD = 7080; minimum = 2303; maximum = 28634) and 2931 stems/ha (SD = 1654; minimum = 960; maximum = 7662). The mean post-PCT spacing immediately following treatment was 2.14 m (SD = 0.55; minimum = 1.14; maximum = 3.23). The mean dominant height at the time of the PCT was 5.53 m (SD = 2.30; minimum = 2.20; maximum = 10.95). The mean change in mean dominant height since the time of the PCT treatment was 1.97 m (SD = 2.30; minimum = 0.00; maximum = 7.29).

The third step consisted of deriving and subsequently calculating effect sizes for quadratic mean diameter and merchantable volume per unit area employing the response ratio metric (Hedges *et al.*1999): Eqs. [1] and [2], respectively.

[1] $$R_{Dq} = \log_e(Dq_{PCT}) - \log_e(Dq_{CONTROL})$$

where Dq_{PCT} and $Dq_{CONTROL}$ are the quadratic mean diameter (cm) of the trees within the PCT and CONTROL plots, respectively.

[2] $$R_{Vm} = \log_e(Vm_{PCT}) - \log_e(Vm_{CONTROL})$$

where Vm_{PCT} and $Vm_{CONTROL}$ are the merchantable volume per hectare (m^3/ha) of the PCT and CONTROL plots, respectively. Note, merchantability specifications were approximately equivalent among studies (*e.g.,* 0.15 m stump-height and a 7.62 cm top diameter (inside-bark) for all stems greater than 9.5 cm in breast-height diameter).

The fourth step consisted of quantifying the relationship between each response ratio and time of treatment, time since treatment and post-treatment spacing employing multiple regression analysis. Specifically, the relationship between the natural logarithm of each response ratio and time of treatment, time since treatment, and post-treatment spacing (S_I (m)) was quantified employing an all-possible best-subset regression procedure employing Mallow's (1973) C_p selection criteria. Mean dominant height (H (m)) was employed as a measure of biological time in order to minimize the effect of site and age variation among studies (*sensu* Ando 1962; Drew and Flewelling 1977; Newton and Weetman 1993). Consequently, H at the time of treatment (H_I (m)) and change in H since treatment (ΔH where $\Delta H = H - H_I$), were used as surrogates for time of treatment, and time since treatment, respectively.

RESULTS AND DISCUSSION

Response models

According to the selection criteria employed the resultant models had the smallest total mean square error among all candidate models (Draper and Smith 1981). Examination of regression statistics suggested that the functions were successful in describing the underlying relationships as indicated by the acceptable standard error of estimates and multiple coefficients of determination, and significant ($p \leq 0.05$) F-statistics. Graphical analysis of raw residual plots for each model indicated a random scatter of errors suggesting that the assumption of constant error variance was not violated. Furthermore, Mallow's (1973) C_p statistics did not substantially differ from the number of estimated parameters, indicating that resultant models had negligible bias (Draper and Smith 1981).

Response patterns and related inferences

Transforming the parameterized regression equations to a percentage basis results in gross relative percent response estimates: denoted $\hat{R}_{Dq}$ and $\hat{R}_{Vm}$ for Dq and Vm, respectively. However, the intrinsic treatment effect on the response parameters must be removed before the net effect of PCT can be ascertained. Specifically, the PCT treatment will result in an instantanous increase in Dq due to the removal of smaller-sized trees. Furthermore, PCT may result in a reduction in Vm if the thinning treatment removes merchantable-sized trees. Subtracting an estimate of the PCT treatment effect (obtained by setting $\Delta H = 0$ in the resultant gross response equations) from the gross relative percent responses, results in net relative percent responses: denoted $\hat{N}_{Dq}$ and $\hat{N}_{Vm}$ for Dq and Vm, respectively. Figures 1 and 2 graphically contrast the gross and net relative percent Dq responses to PCT for an S_I of 2.0 m. Similarly, Figures 3 and 4 illustrate the corresponding contrast for *Vm*. The treatment effect on *Dq* exhibited a non-linear pattern with increasing H_I, irrespective of S_I: the treatment effect initially increased, reached a maximum and then declined. The treatment effect on *Vm* exhibited a linear positive-to-negative pattern with increasing H_I; furthermore, this effect decreased with increasing S_I.

Generally: (1) *Dq* responses increased with increasing S_I whereas *Vm* responses decreased with increasing S_I; (2) *Vm* responses were greater than *Dq* responses irrespective of S_I (*e.g.,* Figure 2 versus Figure 4); (3) *Dq* responses increased with increasing H_I whereas *Vm* responses decreased with increasing H_I irrespective of S_I (*e.g.,* Figures 2 and 4, respectively); and (4) *Dq* and *Vm* responses exhibited a nonlinear ∩-shaped pattern with increasing ΔH for all S_I examined (*e.g.,* Figures 2 and 4, respectively). The maximum *Dq* response for the mean data values derived from the studies (H_I = 5.53 m; and S_I = 2.14 m) was approximately 15% which occurred at a ΔH of 3.3 m; subsequent positive *Dq* responses continued until a ΔH of 6.3 m. Similarly, the maximum *Vm* response for the mean data values was approximately 150% which occurred at a ΔH of 4.0 m; subsequent positive *Vm* responses continued until a ΔH of 8.0 m.

The relative response patterns observed in this study are reflective of the differential between thinned and unthinned stands in terms of their responses to increasing and decreasing resource levels, respectively. Specifically, the reduction in density-stress via the PCT treatment reallocates critically required resources to the residual crop trees resulting in positive *Dq* and *Vm* responses. However, as the stands start to re-close and regain full site occupancy, the thinning effect rapidly diminishes: individual tree growth rates declined resulting in the collapse of the *Dq* responses, followed by reductions in *Vm* responses due to a reduction in overall growth rate and increased density-dependent mortality (self-thinning) within the merchantable size classes.

Basically, in terms of stand dynamics, the size-density trajectories of the thinned and unthinned stands started to re-converge over time. Hence, the management challenge is to avoid this re-convergence via planning PCT treatments accordingly. For example, late heavy thinnings will produce the largest *Dq* responses relative to the controls; in terms of dominant height, maximum responses could be obtained by PCT at approximately 3.3 m from rotation *H*. Conversely, early light thinnings will produce the largest positive *Vm* responses relative to the controls. However in order to avoid re-convergence and merchantable production losses, such stands would have to be re-thinned within the 8.0 m ΔH widow.

CONCLUSION

It was evident from the response patterns that late heavy thinnings produced the largest positive *Dq* responses, relative to the controls. Conversely, early light thinnings produced the largest positive *Vm* responses, relative to the controls. Furthermore, *Dq* responses were considerably less, maximized earlier, and were shorter in duration in terms of positive response periods, than those observed for *Vm*. Thus responses to PCT were more in accord with the single management objective of maximizing merchantable volume per unit area than the dual management objective of attempting maximize both individual tree size and volume production, simulatenously. However, given data and analytical restrictions, these results and related inferences should be considered as a first-approximation of the response of black spruce to PCT.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to L. May, Great Lakes Forestry Centre, CFS, NRCan for data acquisition and management, D. Harris, Newfoundland Department of Forest Resources and Agrifoods for data contributions, and to the Canadian Ecology Centre - CFS - Ontario Ministry of Natural Resources - Tembec Inc. Forest Research Partnership, and Ontario Living Legacy Trust, for fiscal support.

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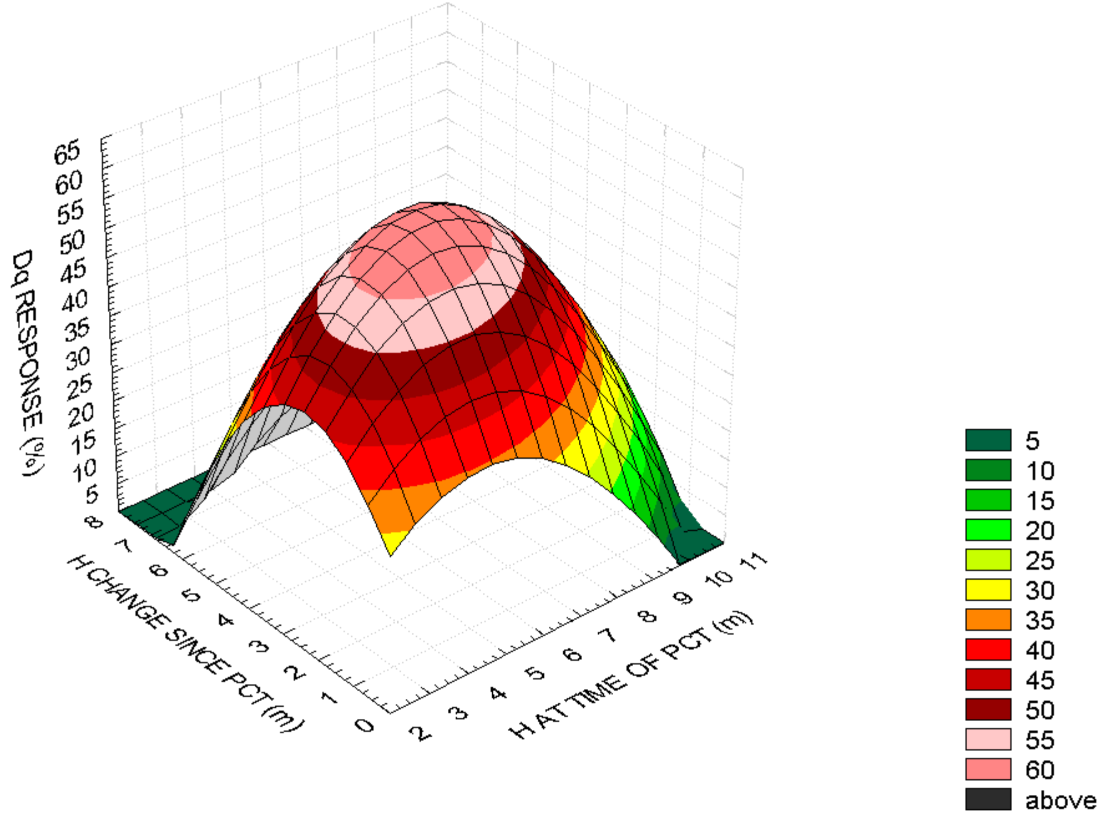

Figure 1. Example illustration of the PCT treatment effect on relative percent *Dq* responses for an S_I of 2.0 m. Note, the quadratic pattern of the effect can be visualized at $\Delta H = 0$.

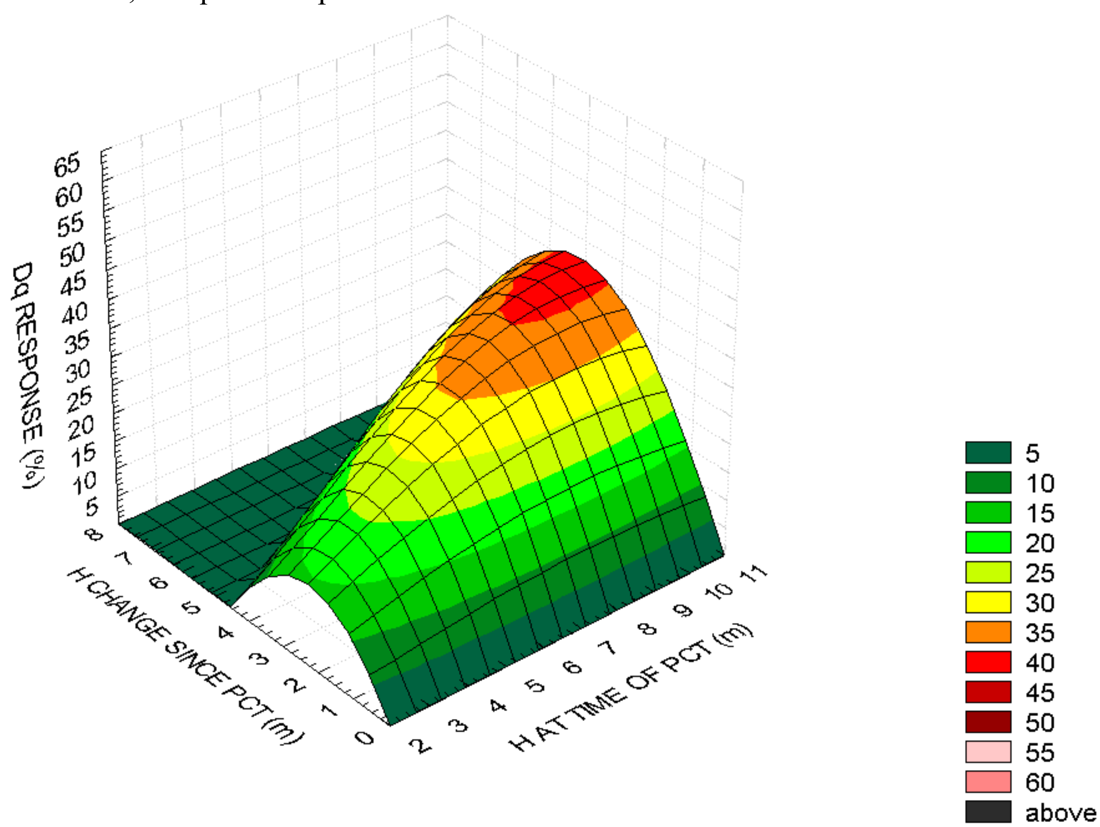

Figure 2. Example illustration of the relative percent *Dq* responses for an S_I of 2.0 m following the removal of the PCT treatment effect. Note, the removal of the effect can be visualized at $\Delta H = 0$ where the relative percent *Dq* response is equal to zero.

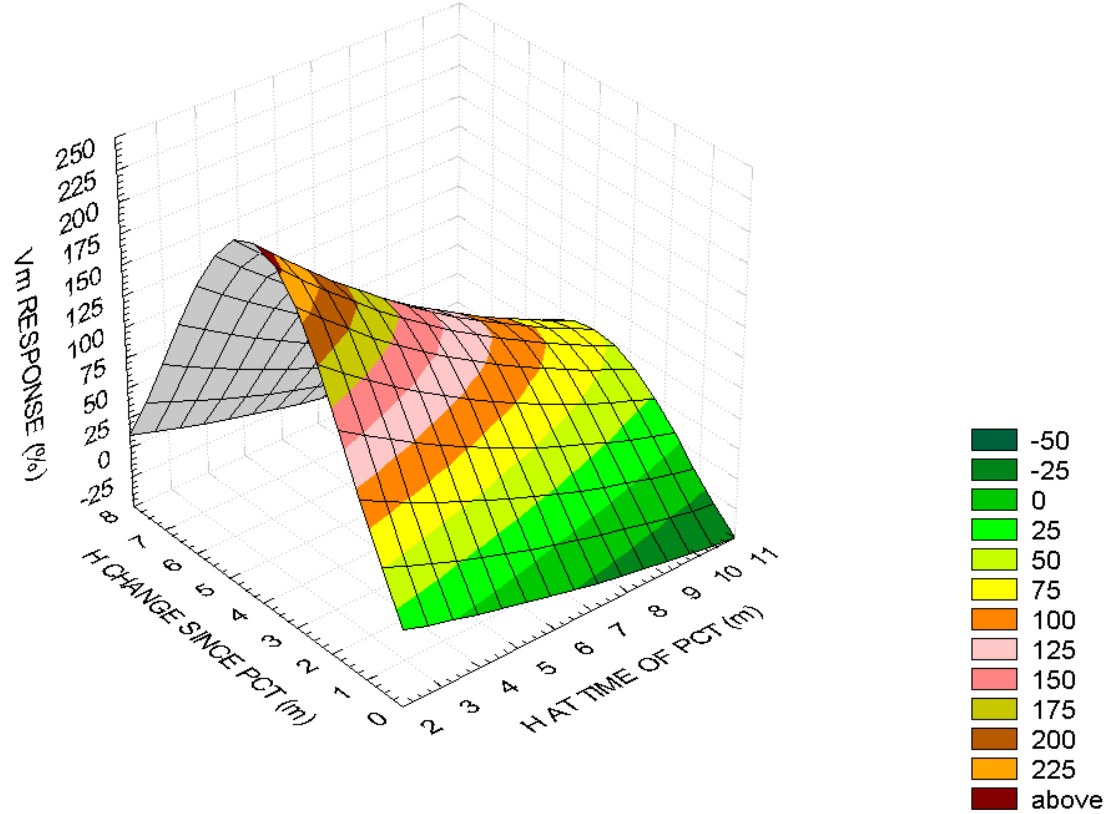

Figure 3. Example illustration of the PCT treatment effect on relative percent *Vm* responses for an S_I of 2.0 m. Note, the linear pattern of the effect can be visualized at $\Delta H = 0$.

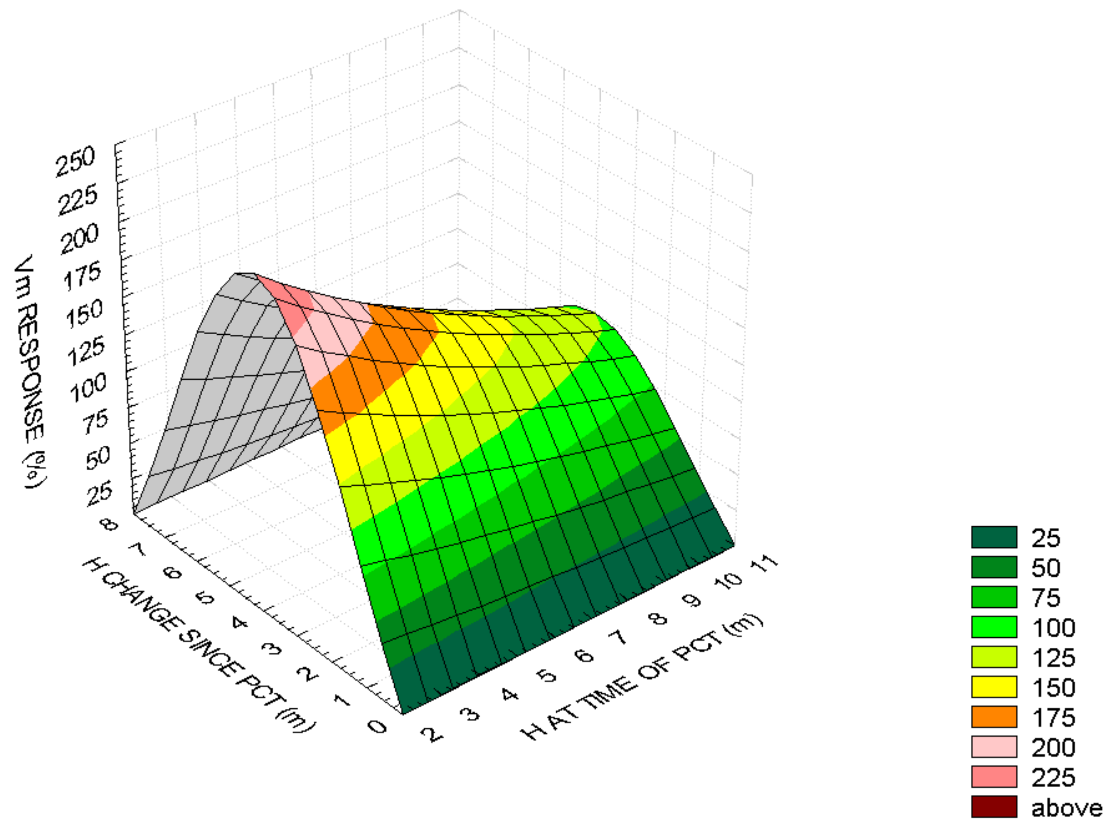

Figure 4. Example illustration of the relative percent *Vm* responses for an S_I of 2.0 m following the removal of the PCT treatment effect. Note, the removal of the effect can be visualized at ΔH = 0 where the relative percent *Vm* response is equal to zero.

BIOSKETCH

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