**Preliminary findings towards the use of lidar and digital aerial imagery as sampling tools to characterize volume killed by mountain pine beetle**

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# Abstract

Critical to the understanding of the impact of mountain pine beetle infestation in British Columbia is the ability to determine the volume of lodgepole pine killed across large areas. A methodology using digital aerial imagery and lidar data to estimate the volume of lodgepole pine affected is presented. After employing digital aerial image interpretation to determine species composition, DBH (diameter at breast height), and the severity of attack, and lidar data to measure stand height, species-specific equations were used to estimate volumes killed. Results indicate that total volume estimates generally agree with available forest inventory data. Volumes lost to beetle attack ranged from 0 to 400 $m^3$/ha, with an overall mean and standard deviation of 159 and 109 $m^3$/ha, respectively. This working paper presents initial results from work published in Bater et al (in press).



**Keywords:** Mountain pine beetle, stem volume, remote sensing, lidar, digital aerial imagery, data fusion



# Résumé

Afin de comprendre l'impact d'une infestation de dendroctone du pin ponderosa en Colombie-Britannique, il est essentiel de pouvoir déterminer le volume de pins tordus tués sur de grandes zones. On présente une méthodologie utilisant l'imagerie aérienne numérique et des données lidar pour estimer le volume de pins tordus touché. Après avoir utilisé l'interprétation des images aériennes numériques pour déterminer la composition des essences, le diamètre à hauteur d'homme et la gravité de l'attaque, ainsi que les données lidar pour mesurer la hauteur du peuplement, des équations propres aux essences ont été utilisées pour estimer les volumes tués. Les résultats indiquent que les estimations du volume total correspondent généralement aux données d'inventaire forestier disponibles. Les volumes perdus en raison d'une attaque du ravageur allaient de 0 à 400 $m^3$/ha, soit un écart moyen de 159 $m^3$/ha et un écart-type de 109 $m^3$/ha.



**Mots-clés** : Dendroctone du pin ponderosa, volume de la tige, télédétection, lidar, imagerie aérienne numérique, fusion des données

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# 1 Introduction

The estimation of the area infested by mountain pine beetle (MPB) has been addressed using a variety of survey approaches, and the severity and scale of attack has lead to research into the capacity of digital remote sensing systems to map infestation (Wulder et al. 2006a). To date, research has generally focused on the ability to locate mountain pine beetle across the landscape (Skakun et al. 2003; White et al. 2004; Coops et al. 2006; Wulder et al. 2006b). A challenge not previously addressed, however, is the determination of the volume of wood lost to MPB attack.

Volume is a critical variable in forestry, as wood is the primary commercial product derived from forests (West, 2004). Knowledge of the heights of impacted stands allows for the utilization of information on growth and yield to produce volume estimates for the trees impacted, and light detection and ranging (lidar) may provide the necessary information to achieve that across the landscape.

Lidar is an active remote sensing system capable of simultaneously mapping terrain and vegetation heights with sub-metre accuracy. Lefsky et al. (2002) and Lim et al. (2003) review the capacity of lidar to characterize forest ecosystems, while previous research has demonstrated the utility of laser altimetry for volume estimation in particular (MacLean and Krabill 1986; Nilsson 1996; Næsset 1997a; Holmgren et al. 2003; Maltamo et al. 2004; Popescu et al. 2004).

Using high resolution optical imagery to identify and delineate areas undergoing infestation, and lidar to determine vegetation heights, it may make possible the wide-area estimation of volume impacts – information critical to the management of British Columbia's forest resources. Thus, the goal of this research was to develop a prototype model for the estimation of the volume of lodgepole pine affected by MPB infestation by combining high spatial resolution digital image and lidar data. A thorough description of the methods and results presented here can be found in Bater et al. (in press).

# 2 Materials and Methods

Methods discussed in this section are presented in Figure 1, which summarizes the steps described below.

## 2.1 Study Area

The study area is located in central British Columbia near the town of Quesnel and is found within the Cariboo forest region (52$^{o}$ 31' north, 122$^{o}$ 21' west). According to the biogeoclimatic ecosystem classification (BEC) system (Meidinger and Pojar, 1991) the majority of the study area is classified as sub-boreal spruce (SBS) zone, dry warm subzone (dw), Blackwater variant. The SBS zone is distinguished by the presence of hybrid white spruce and subalpine fir as climax species. As the result of frequent past wildfires, however, lodgepole pine is the most common seral species. Douglas-fir is common at elevations below 1,000 m, as is trembling aspen (Steen and Coupé, 1997). Terrain elevation in the area of interest ranged from 500 to 1,300 m above sea level, with a mean of approximately 900 m above sea level.

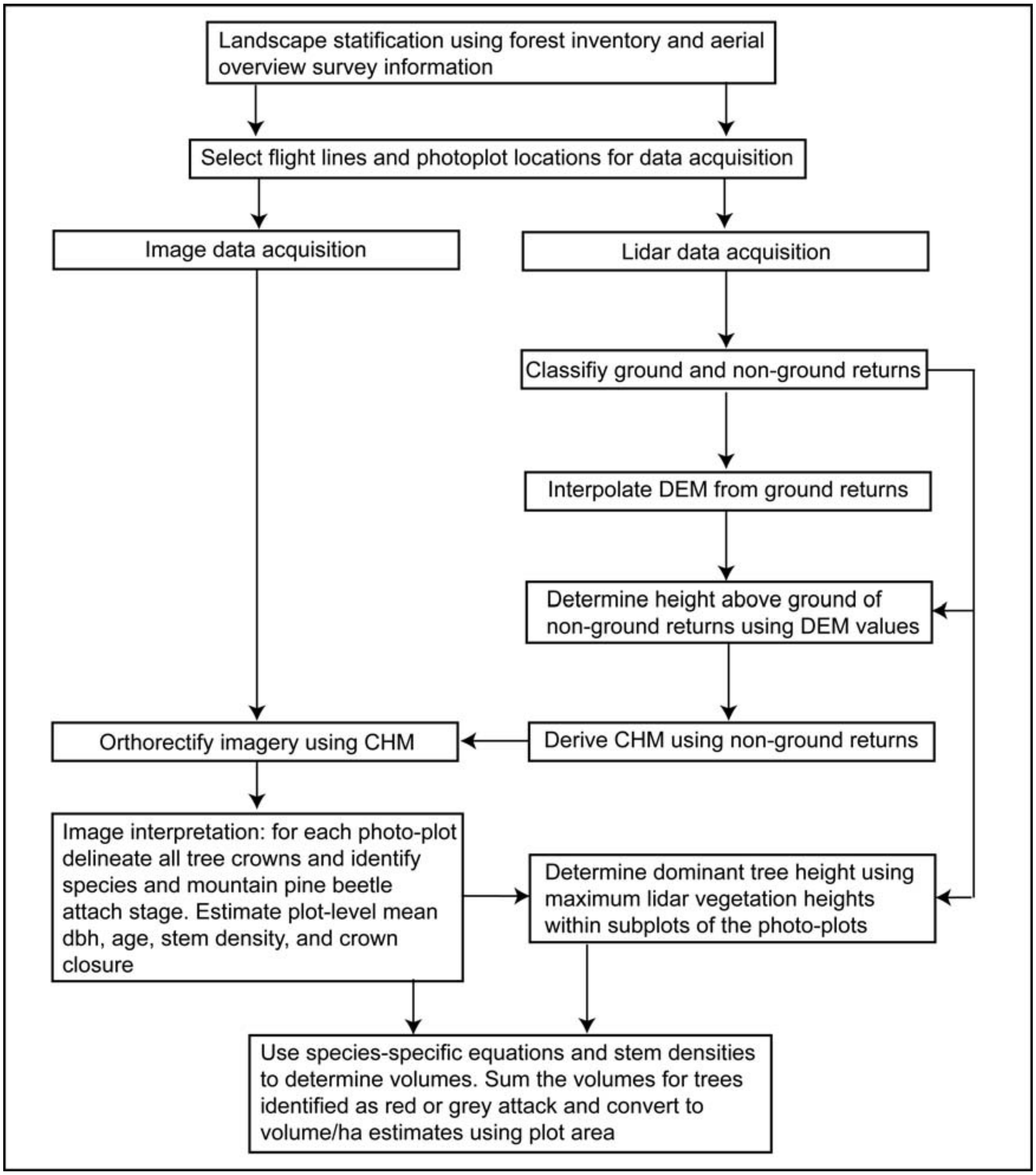


**Figure 1.** Flow chart describing the methodology employed in this study. (DEM = digital elevation model; CHM = canopy height model; DBH = diameter at breast height; MPB = mountain pine beetle).

## 2.2 Data Sets

### 2.2.1 Forest inventory data

Forest inventory of late 1990s vintage was obtained for the area of interest. Typically based on the manual interpretation of moderate-scale aerial photography and augmented by field data collection, standard inventories consist of polygons delineating vegetation communities of similar seral stage, species composition, crown closure, and so on. The forest inventory was used to stratify the study area and identify stands containing lodgepole pine, and as a validation tool against which to compare volume estimates.

### 2.2.2 Lidar data

Small footprint, discrete return lidar data were acquired in 2005 and classified into ground and non-ground returns using Terrasolid software. A digital elevation model (DEM) was produced using methods described in Coops et al. (2004). First, ground returns were converted from discrete points to a triangulated irregular network, a two metre resolution DEM was then generated using linear interpolation. In order to determine vegetation heights above the ground, the DEM values were extracted to the non-ground returns, and those heights subtracted from the original elevations. All returns less than 0.50 m above the ground were removed, resulting in a lidar vegetation return density of approximately 0.9 points/m$^2$. Finally, a 2 m spatial resolution canopy height model (CHM) was generated by gridding the maximum lidar return height within each raster cell.

### 2.2.3 Aerial imagery

Five true-colour aerial digital images were acquired in 2005 and orthorectified using the lidar-derived CHM and a cubic convolution interpolation algorithm, with output spatial resolutions of both 0.50 and 2.0 m. Images ranged in size from approximately 120–400 ha.

## 2.3 Height, Diameter, and Volume Estimation

While the most accurate method to estimate stem volume is xylometry, where a stem is immersed in water and the volume displaced is measured, volume estimates may be made using regression-derived functions incorporating tree height and diameter at breast height (DBH) (West 2004).

The aerial imagery vendor provided individual tree- and plot-level mensuration data derived from manual interpretation of the imagery. Within each image, eleven 0.25 ha photo plots were established where the forest inventory indicated that lodgepole pine was present (Figure 2). Then, within each plot, individual tree crowns were manually delineated, and each was assigned a species and crown health status (green, red or grey). Mean DBH for each species was then estimated for each plot, and total stem density was calculated.

To determine dominant tree height, methods similar to those described in Næsset (1997b) and Lovell et al. (2003) were employed. Lidar vegetation returns were extracted for each plot and the maximum return height within 10 × 10 m subplots were determined. These maximums were then averaged for each plot to determine a dominant height.

Volumes were calculated using the following species-specific equations developed by the British Columbia Ministry of Forests (1976) (Table 1). Areal-based volumes (m$^3$/ha) were then calculated based on stem densities and the proportion of each species within the plots. Finally, the proportion of stems attacked as determined by the aerial image interpretation was used to determine the volume of pine lost to mountain pine beetle.

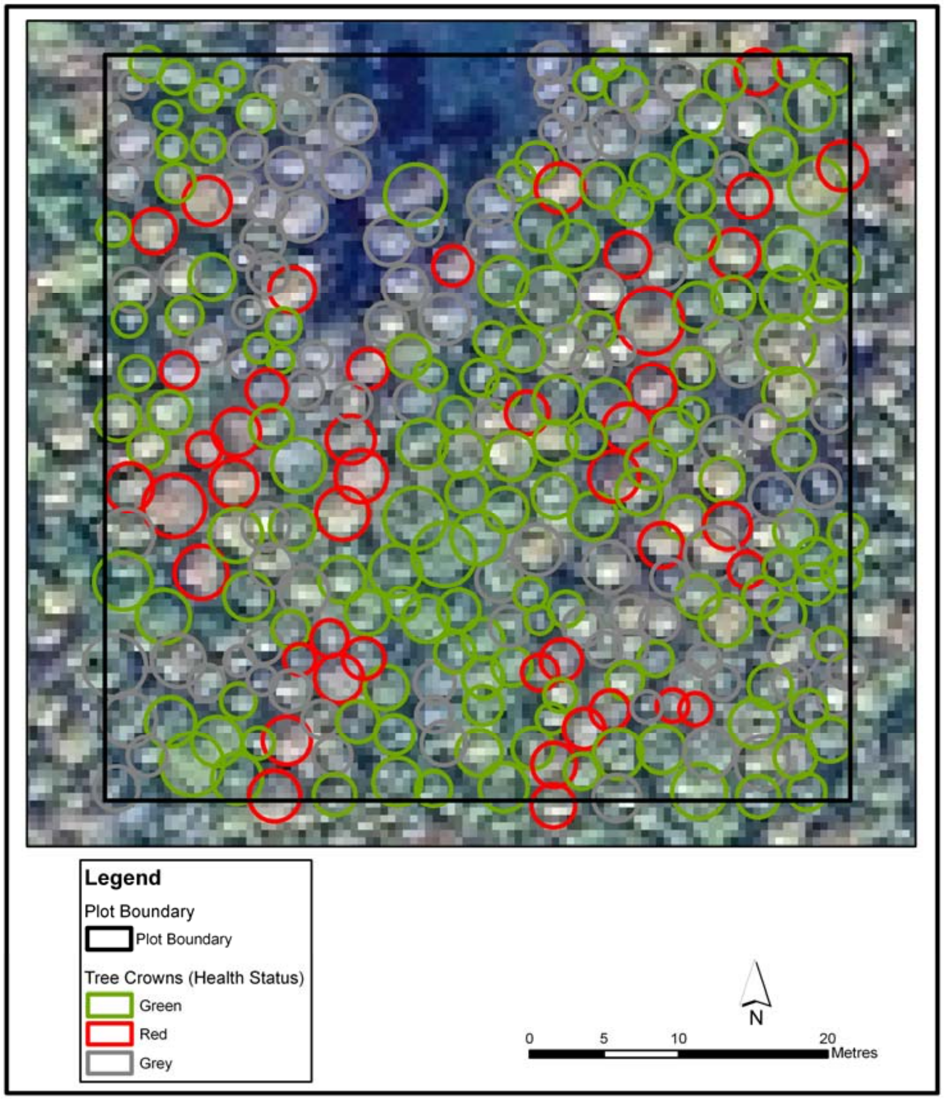


**Figure 2:** An example of a photo plot with individual crowns delineated. Each crown was assigned a species and health status. Mean diameter at breast height was estimated for each species.

**Table 1:** Species-specific equations used to estimate volumes. Heights were derived from lidar vegetation returns, and diameter at breast heights were derived from manual image interpretation.

| **Species** | **Equation (British Columbia Ministry of Forests, 1976)** |
|---|---|
| Lodgepole pine | log(V) = -4.349504 + 1.822760 x log(D) + 1.108120 x log(H) |
| Douglas-fir | log(V) = -4.383102 + 1.742940 x log(D) + 1.156410 x log(H) |
| Spruce species | log(V) = -4.294193 + 1.858590 x log(D) + 1.007790 x log(H) |
| Trembling aspen | log(V) = -4.419728 + 1.894760 x log(D) + 1.053730 x log(H) |

Where V = gross volume of tree stem ($m^3$) D = mean DBH (cm) H = dominant height (m) log = logarithm to base 10

# 3 Results and Discussion

To develop confidence in the volume estimates presented here, results were compared to those found in the forest inventory data (Figure 3). Mean volumes for all species, and for lodgepole pine specifically, are in general agreement; however, the estimates made in image 334 differ from the forest inventory by approximately 200 $m^3$/ha for all species combined, and lodgepole pine only. This may be the result of differences between image interpreters, the vintage of the forest inventory, the difference in scale between the two datasets, or a combination thereof.

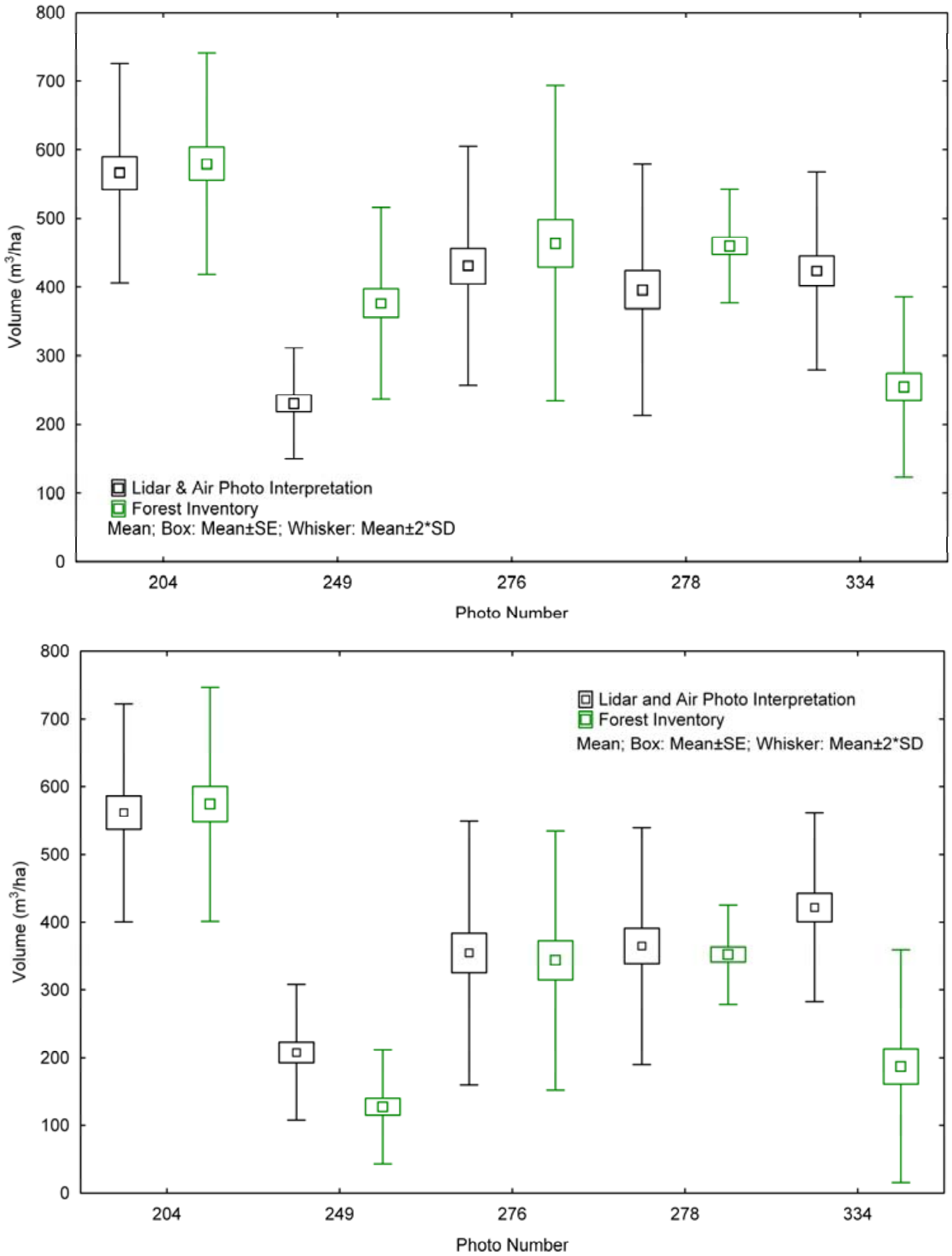


**Figure 3:** Comparison of plot-level volumes estimated in this study and those estimated by the forest inventory for all species (top) and for lodgepole pine only (bottom). The plot-based volume estimates are grouped by the aerial image in which they were located.

Results for the estimation of the amount of lodgepole pine are summarized in Figure 4 and presented in detail in Bater et al. (In Press). Attack severity within the plots ranged from none to as many as 75% of pine exhibiting red or grey attack. The true amount of MPB infestation may be underestimated, as green crowns may indeed be under an early stage of attack. Volumes lost to beetle attack ranged from 0 to 400 $m^3$/ha, with an overall mean and standard deviation of 159 and 109 $m^3$/ha respectively.

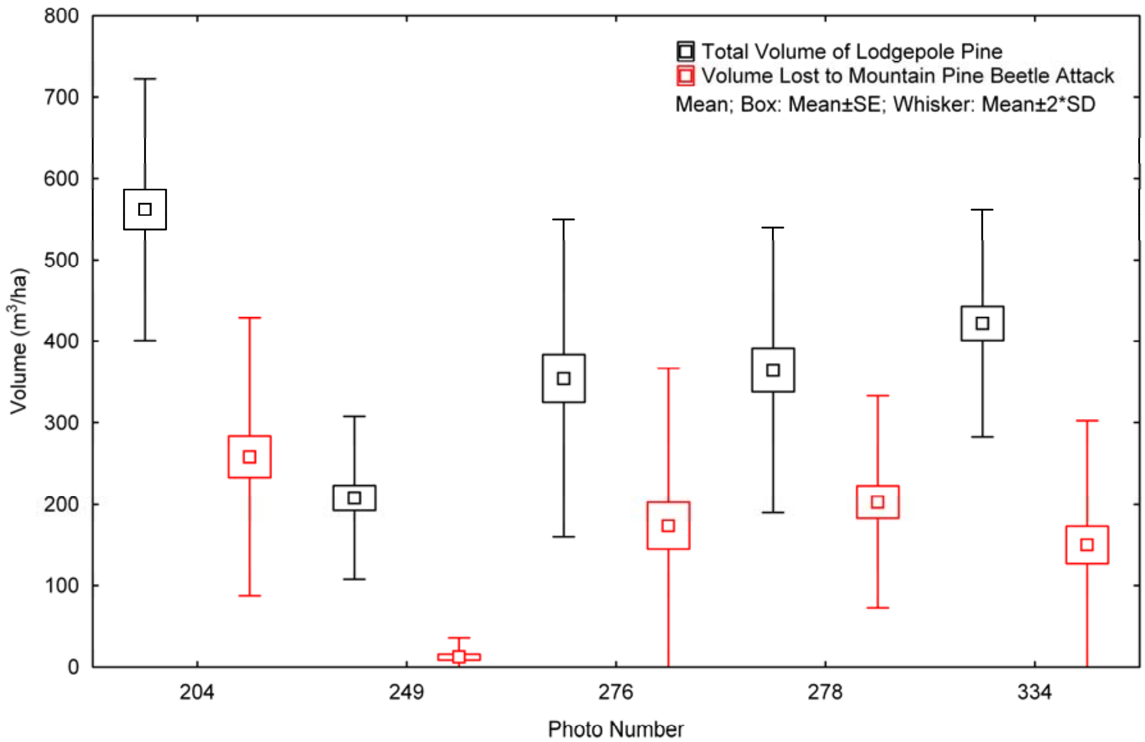


**Figure 4:** Total volume of lodgepole pine, and estimated volume lost to mountain pine beetle attack. The plot-based estimates are grouped by the aerial image in which they were located.

# 4 Conclusions

This working paper presents initial results from work published in Bater et al. (in press). A prototype model to estimate the amount of lodgepole pine affected by MPB attack is presented. After employing digital aerial image interpretation to determine species composition, DBH, and the severity of attack, and lidar data to measure stand height, species-specific equations were used to estimate volumes killed. Volumes for all species combined, and for lodgepole pine specifically, were in general agreement with those found in the forest inventory data, lending confidence to the estimates presented here. Ultimately, this research will contribute to our capacity to estimate volumes affected by mountain pine beetle across the landscape.

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