CLARK’S NUTCRACKER OCCURRENCE, WHITEBARK PINE STAND HEALTH, AND CONE PRODUCTION IN THE WATERTON-GLACIER INTERNATIONAL PEACE PARK

by

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ABSTRACT

Clark’s nutcrackers (*Nucifraga columbiana*) are the main seed dispersers for whitebark pine and primarily responsible for whitebark pine regeneration through their seed caching behavior. On-going losses of whitebark pine (*Pinus albicaulis*) in the Crown of the Continent Ecosystem, from white pine blister rust (caused by the exotic fungus *Cronartium ribicola*), historical losses of whitebark pine to mountain pine beetle (*Dendroctonus ponderosae*), as well as successional replacement of whitebark pine by fir and spruce exacerbated by fire suppression, may together diminish the likelihood of stand visitation by nutcrackers. In the absence of seed dispersal, management strategies are needed to maintain whitebark pine communities. Here, I focus my studies on the Waterton-Glacier International Peace Park to determine: 1) if nutcrackers occur in whitebark pine communities in the park and at what density, 2) if nutcracker densities vary with whitebark pine cone production, 3) how whitebark pine cone production varies with density and health, and 4) whether the relationship between the likelihood of nutcracker visitation and whitebark pine cone density in the park is predicted by the models in McKinney et al. (2009) and Barringer et al. (2012). To address these objectives, I selected five study areas across the park to examine stand condition and sample nutcracker visitation. Within each study area, I delineated one to three transects per study area, each with two 500 m$^2$ stand assessment plots. For this study, I developed a protocol for estimating both nutcracker (2009, 2010) and whitebark pine cone densities.
using line transect distance sampling. Values were calculated by combining numbers for both plots on each transect (1,000m²). Stand assessments revealed average diameter at breast height (dbh) ranging from 6.5 cm to 37.4 cm across transects, blister rust infection levels ranging from 33% to 80%, and live basal area (LBA) per hectare, ranging from 0.42 m²/ha to 11.05 m²/ha. Across all transects, I found total numbers of live whitebark pine and dead whitebark pine ranging from 20 to 330 and 0 to 290, per hectare, respectively. Over the 2009 and 2010 field seasons, I detected 65 nutcrackers over a total of 5.25 km. Over the study, combining detections, I generated a density estimate of 0.85 nutcrackers per ha with a 95% confidence interval of 0.37-2.62. We detected a total of 1338 whitebark pine cones for 2010 alone over the same transect distance. We generated a density estimate of 66.7 cones per ha with a 95% confidence interval of 28.1-158.5. Both cone production per hectare and proportion of observation hours with one or more nutcrackers were similar to previous studies in the Northern Divide region, including the Waterton-Glacier International Peace Park, and the relationships determined by McKinney et al. (2009) and Barringer et al. (2012). Our study is the third to indicate a low likelihood of visitation of whitebark pine communities by nutcrackers in the Waterton-Glacier International Peace Park.

The form and content of this abstract are approved. I recommend its publication.

Approved: Diana F. Tomback
DEDICATION

I dedicate this work to my mother, Diana Noffke, for her love, encouragement, unwavering support, and for always believing in me.
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LIST OF ABBREVIATIONS

1. GNP  Glacier National Park
2. WLNP  Waterton-Lakes National Park
3. WPB  Whitebark Pine
4. DBH  Diameter at breast height
5. BR  Blister Rust
6. PP  Preston Park
7. NR  Numa Ridge
8. TM  Two Medicine
9. WC  White Calf
10. SL  Summit Lake
CHAPTER I

WHITEBARK PINE BACKGROUND

Natural History and Ecosystem Function

Whitebark pine (*Pinus albicaulis*) is one of five stone pines worldwide and is classified within the family Pinaceae, genus *Pinus*, section *Quinquefoliae*, and subsection *Strobus* (Tomback and Achuff 2010). Characteristics shared by the stone pines are: five needles per fascicle, indehiscent female cones which remain closed at maturity, and wingless seeds which are dispersed by birds of the genus *Nucifraga* (the nutcrackers) (McCaughey and Schmidt 2001). Whitebark distribution is divided into two sections, a western and an eastern range which are connected by a series of isolated stands in southern British Columbia and northeastern Washington. The western range includes the British Columbia Coast Ranges, the Cascade Range, and the Sierra Nevadas, and the eastern range includes the Rocky Mountains from Wyoming to Alberta. Whitebark pine occurs along high elevation ridges in subalpine and treeline forests, as high as 3600 m in the Sierra Nevada (Fig. I.1). The species prefers cold, windy, snowy, and generally moist climatic zones (Arno and Hoff 1989, McCaughey and Schmidt 2001). Regeneration for whitebark pine, which involves three distinct phases, can take up to five years to complete. The phases are (1) cone and seed initiation, development and maturation; (2) seed dissemination; and (3) seed germination. At 20 to 30 years of age, male and female cone production begins, with large seed crops first occurring when the tree is at least 60 to 80 years of age (McCaughey and Tombback 2001).

Both a keystone and foundation species, whitebark pine maintains subalpine biodiversity. Its seeds are a critical food source for grizzly bears (*Ursus arctos horribils*),
red squirrels (*Tamiascurus hudsonicus*) and Clark’s nutcrackers (*Nucifraga columbiana*), as well as other granivorous birds and mammals (Tomback et al. 2001, Ellison et al. 2005, Tomback and Achuff 2010). While red squirrels and nutcrackers compete for seeds, red squirrels act as intermediaries for grizzly bears foraging on pine seeds: Red squirrels cut down and cache cones in middens, which grizzly bears subsequently raid (Podruzny et al. 1999). In addition to providing a crucial food resource for wildlife, whitebark pine communities regulate snowmelt and reduce soil erosion, and whitebark pine is important in facilitating community development and succession in subalpine ecosystems (Farnes 1990, Tomback et al. 2001).

**The Role of Clark’s Nutcracker**

The Clark’s nutcracker and whitebark pine are coevolved mutualists, with whitebark pine depending on nutcrackers almost exclusively for seed dispersal (Tomback 1982, 2001). Nutcrackers, however, also harvest and store the seeds of other conifers with large, wingless seeds, such as limber pine (*P. flexilis*), Colorado piñon (*P. edulis*), single-leaf piñon (*P. monophylla*), and southwestern white pine (*P. strobiformis*). These pines, like the whitebark, are also considered mutualists (Tomback 2001, Tomback and Linhart 1990). Nutcrackers will also consume insects and spiders, small animals and carrion, as well as pine seeds that are smaller and winged (Tomback 1998, 2001). Clark’s nutcrackers have historically ranged from central British Columbia and western Alberta in the north to Arizona and New Mexico in the south, although they have been documented during eruptions as far south as northern Mexico to as far north as Alaska, from the Great Plains to the Pacific coast. They prefer high montane, coniferous forests (Tomback 1998).
Nutcrackers disperse whitebark pine seeds through their seed caching behavior. The nutcracker’s long, pointed bill enables the birds to open both ripe and unripe whitebark pine cones by tearing off cone scales. Nutcrackers will feed upon ripening whitebark pine seeds; and, after seeds ripen in mid to late August, they will begin to cache the seeds (Tombback 1978, 2001). They remove seeds from whitebark pine cones, filling their sublingual pouch with 100 or more seeds, with an average of around 75 seeds per pouch load (Tombback 1978). They then transport the seeds for caching to be used as a food source at a later time (Hutchins and Lanner 1982, Tombback 1978, 1982, 2001).

A nutcracker may store between 35,000 and 98,000 whitebark pine seeds in a highly productive cone year (Hutchins and Lanner 1982, Tombback 1982). Nutcrackers prefer to cache on steep, south-facing, windswept, open slopes and ridges. Typically these cache sites accumulate little snow, and any accumulation melts quickly in the winter and spring. Cache size average ranges from one to 15 seeds per cache, depending on terrain, and are placed at the base of trees, beside rocks, among tree roots, and adjacent to felled logs, as well as in the open (Tombback 1978, Hutchins and Lanner 1982). Nutcrackers have an exceptionally well-developed spatial memory, and use these objects to retrieve cached seeds for use as a food source for up to nine months after the cache is made, from winter through late summer (Vander Wall and Balda 1977, Tombback 1978, Tombback 1980, Vander Wall 1982, Tombback 2001). Seeds that are not recovered may then germinate (Tombback 1982).

**Blister Rust**

White pine blister rust, caused by the exotic fungus *Cronartium ribicola* has ravaged whitebark pine communities throughout most their range. The northern Rocky
Mountains are hardest hit with infection levels in many areas over 70% (Schwandt 2006, Tomback and Achuff 2010). All North American five-needle white pines are susceptible to blister rust (Kinloch 2003).

*Cronartium ribicola*, the pathogen causing white pine blister rust, is native to Eurasia. It was introduced to Eastern North America in 1890, carried by imported seedlings of eastern white pine from Germany and France. It was first detected in Kansas in 1892 on the infected leaves of golden currant (*Ribes aureum*). *Cronartium ribicola* was likely introduced to Western North America from Europe through multiple introductions from infected, imported seedlings (Geils et al. 2010). It was first detected in 1921 in Vancouver, British Columbia (McDonald and Hoff 2001, Geils et al. 2010). The complex life cycle of blister rust involves five spore stages and alternates between two host types, including five-needle white pines and *Ribes* spp. (currants and gooseberries) but may also involve *Pedicularis* spp. (broomrape) and *Castilleja* spp. (Indian paintbrush) (Kinloch 2003, McDonald and Hoff 2001, McDonald et al. 2006). *Ribes* spp. eradication efforts began in 1921, but in the long-run proved ineffective and were terminated in 1966 (McDonald and Hoff 2001).

The production by the alternate hosts of basidiospores, which transmit the pathogen to five-needle white pines, requires cool, moist conditions for at least two days. Basidiospores are vulnerable to desiccation and do not typically travel very far from the *Ribes* spp. source (900 feet). However, under the right conditions, the spores can travel well beyond that distance (Kinloch 2003). Definitive signs of blister rust on infected pines include the presence of aeciospores, the spores that transmit *Cronartium ribicola* from the pine hosts to the alternate hosts. These spores are produced in pink-orange sac
structures called aecia, which resemble blisters erupting from the bark of the branches or
the stem of infected pine trees (Fig. I.2). These eruptions, or cankers, will occur annually
on the infected branch until it is ultimately girdled and killed. The cankers can kill the
growth above--branches, the top of the tree (top kill) or kill the entire tree if in the stem
(McDonald and Hoff 2001).

Mountain Pine Beetle

Whitebark pine communities are also at risk from attack by mountain pine beetle
(MPB) (*Dendroctonus ponderosae*), a native bark beetle (Schwandt 2006, Tomback and
Achuff 2010). These beetles feed on and lay their eggs in the living tissue of a tree
(phloem), leaving a characteristic pattern in the wood. A beetle goes through three life
stages while within the tree: egg, larva, pupa and adult. Larvae tunnel outward from the
egg chamber, damaging the phloem as they go, interfering with the flow of water and
nutrients, which can lead to the death of the tree (Bentz 2009).

Blister rust infected whitebark pine is more susceptible to MPB attack. In their
study of MPB and whitebark pine in the southern Greater Yellowstone Ecosystem,
Bockino and Tinker (2012) found that MPB favored whitebark pine with heavy blister
rust infection over trees with less severe symptoms. In the study, average blister rust
severity scores for all whitebark pine selected as host trees by MPB were double that of
trees not selected. In the central Rocky Mountains, whitebark pine is experiencing recent,
serious decline, due to unprecedented mountain pine beetle outbreaks. In some areas,
such as the Greater Yellowstone Ecosystem, mortality has exceeded 95% of cone bearing
trees (Gibson et al. 2008, Logan et al. 2010).
It is thought that the white pines of high elevations did not co-evolve with the MPB. Although these pines are suitable hosts, the environment in which they exist is typically too harsh and cold to allow for the completion of the bark beetle life cycle. However, climate change has opened new doors for the MPB with mild winter temperatures allowing for substantial overwinter survival and the ability of the MPB to complete an entire life cycle in just one year due to lingering summer thermal energy. Unfortunately for whitebark pine, these two factors, which together encourage MPB proliferation, were once rare but are now quite common (Logan et al. 2010). The combination of blister rust infection and a warming climate has left whitebark pine weakened and under great pressure from the aggressive beetle.

**Fire and Whitebark Pine**

Whitebark pine populations are also threatened by altered fire regimes in the northwestern U.S. and southwestern Canada (Tomback et al. 2001, Tomback and Achuff 2010). Fire exclusion has led to successional replacement of whitebark pine by shade tolerant species, which may reduce the potential for regeneration of the shade-intolerant whitebark pine. Additionally, fuel accumulations may lead to increased tree mortality when fire eventually reoccurs (van Mantgem 2004, Tomback and Achuff 2010). Whitebark pine has evolved with fire, both low and high severity. Nutcrackers promote the recolonization of whitebark pine after a stand-replacing burn. Open, burned areas are readily utilized by nutcrackers for seed caching, thus leaving seeds left behind for regeneration (Tomback 1998).
Figures and Tables

Figure I.1  Distribution of *Pinus albicaulis* in North America (Tomback and Achuff 2010).
Figure I.2 Active blister rust stem canker on whitebark pine. The orange eruptive sacs contain aeciospores (Photo by Jennifer Scott).
CHAPTER II

INTRODUCTION

Whitebark pine (*Pinus albicaulis*) depends on the seed dispersal services of Clark’s nutcracker (*Nucifraga columbiana*) for regeneration; both species are coevolved mutualists (Hutchins and Lanner 1982, Tomback 1978, 1982, 2001, Tomback and Linhart 1990). The seeds of whitebark pine are large and wingless and the cones indehiscent, requiring the birds to open cones and remove seeds. Nutcrackers harvest seeds from ripe whitebark pine cones in late summer and transport as many as 100 or more seeds within an expandable sublingual pouch from a few meters to as far as about 29 km per seed caching trip (Tomback 1978, Lorenz and Sullivan 2009). Seed dispersal is accomplished through the caching or scatter-hoarding behavior of nutcrackers; caches are dispersed from montane to tundra in diverse terrain, and typically contain 1 to 15 or more seeds, with a mean of 3 to 5 seeds per cache (Tomback 1978, 1982, Hutchins and Lanner 1982).

Whitebark pine populations are currently declining from a combination of white pine blister rust, a disease caused by the invasive fungal pathogen *Cronartium ribicola*, mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, and altered fire regimes (Tomback et al. 2001, Schwandt 2006, Tomback and Achuff 2010, Schwandt et al. 2010, U.S. Fish and Wildlife Service 2011). Furthermore, the northern Rocky Mountains of the U.S. and southern Canada have the highest blister rust infection and mortality rates, reaching more than 90% in some areas (Kendall and Keane 2001, Smith et al. 2008). In the Northern Divide Ecosystem (Crown of the Continent Ecosystem), and specifically Glacier National Park, white pine blister rust has killed an average 44% of the whitebark
pine trees on assessed plots. Within 20 years, 75% of Glacier National Park’s remaining whitebark pine trees are expected to die (Carolin 2006). About 50% of whitebark pine trees in the combined Waterton Lakes National Park, Alberta, Canada, and Glacier National Park, Montana, U.S. (Waterton-Glacier International Peace Park), are dead from various factors, with the remaining 70% infected with *Cronartium ribicola*, and an estimated 5% per year increase in mortality in Waterton Lakes National Park (Smith et al. 2008).

Losses of trees to mountain pine beetle and blister rust, as well as canopy damage from blister rust, has led to a rapid decline in cone availability for seed dispersal and regeneration. Consequently, nutcrackers may no longer be attracted to these ecosystems and thus the potential for regeneration will be lost (Tomback et al. 2001). Previous studies in the central and northern Rocky Mountains have compared whitebark pine stand health and cone production with the likelihood of occurrence of Clark’s nutcrackers, and especially across regions, including the Northern Divide Ecosystem (McKinney and Tomback 2007, McKinney et al. 2009, and Barringer et al. 2012). Here, we examine whitebark pine cone production and stand health in five different study areas in the Waterton-Glacier Peace Park to determine whether nutcrackers are, in fact, visiting whitebark pine communities, and to estimate their densities by using line transect distance sampling, which had not previously been used to estimate nutcracker densities and also to assess blister rust infection levels and cone densities in areas of the park not previously evaluated.

Previously, McKinney and Tomback (2007) found in their study of the Bitterroot and Salmon National Forests, Montana and Idaho, that whitebark pine stands with higher
levels of blister rust infection and damage had lower cone densities than those with lower levels of infection and damage, that stands with lower cone densities had a lower proportion of cones surviving to time of seed dispersal, and that stands with a lower proportion of cones surviving were less likely to have seeds dispersed by nutcrackers. McKinney et al. (2009) developed a mathematical model to estimate cone production that would be required to attract and maintain nutcrackers in whitebark communities at their study sites, which included the Northern Divide Ecosystem (Glacier National Park and Flathead National Forest), Bitterroot Mountain Ecosystem, and the Greater Yellowstone Ecosystem. In the Northern Divide Ecosystem, they found blister rust infection and tree mortality levels to be the highest and live basal area and cone production the lowest among the three ecosystem study areas. They also discovered low nutcracker visitation rates over the three year study, with nutcrackers present in only 14% of the total hours sampled and seed dispersal activities in only 20% of their research sites. They estimated that 5.0 m$^2$/ha of whitebark pine live basal area would be able to produce about 1000 cones/ha in high production years. McKinney et al. (2009) conclude that with the “high levels of blister rust infection and tree mortality, and the low levels of live basal area documented, it is likely that many whitebark pine forests in the Northern Divide are no longer sustainable without restoration planting” but that sites “that exceed the 5.0 m$^2$/ha threshold can still rely on nutcracker seed dispersal in some years”.

Barringer et al. (2012) conducted their study in both the Greater Yellowstone Ecosystem (southern region) and Northern Divide Ecosystem (northern region). They found regeneration to be 74 times lower in the northern region than in the southern region, and cone density 57 times lower in the northern region than in the southern
region. They also found blister rust infection rates to be significantly higher in the northern region when compared with the southern region. In addition, because of the greater abundance of live whitebark pine trees (higher live basal area and greater proportion of live trees) in the Greater Yellowstone Ecosystem, they observed far more Clark’s nutcrackers in the southern region that in the northern region.

McKinney and Tomback (2007), McKinney et al. (2009), and Barringer et al. (2012) suggest that loss of whitebark pine cone production will lead to a reduction in future whitebark pine regeneration (Fig. II.1). With continued losses of whitebark pine, it is likely that nutcrackers will no longer be attracted to whitebark pine communities and thus the potential for future regeneration will be lost (Tomback et al. 2001, Tomback and Kendall 2001). Given that McKinney et al. (2009) and Barringer et al. (2012) found whitebark pine losses the highest and cone production the lowest in the Northern Divide Ecosystems, we report here on a detailed investigation of whether nutcrackers are occurring reliably in whitebark pine communities in the Waterton-Glacier International Peace Park. Previous studies (McKinney and Tomback 2007, McKinney et al. 2009, Barringer et al. 2012) used a variety of techniques to quantify nutcracker visitation, but none provided a density estimate with confidence intervals. In order to assess the density of nutcrackers in my study areas in relation to cone production, I developed a protocol for estimating both nutcracker and whitebark pine cone densities using line transect distance sampling based on Buckland et al. (2001).

Objectives

The objectives in this study were to determine: 1) if nutcrackers occur in whitebark pine communities in the park and at what density, 2) how or if nutcracker
densities vary with whitebark pine cone production, 3) how cone production varies with whitebark pine prevalence and health in Waterton-Glacier International Peace Park, and 4) whether the relationship between the likelihood of nutcracker visitation and whitebark pine cone density is similar to the results in McKinney et al. (2009) and Barringer et al. (2012).
Figure II.1 Depiction of predictions based on McKinney et al. (2009). Whitebark pine mortality and damage to cone bearing branches will result in a loss of cone production, which in turn will likely result in a decline of nutcracker visitation to whitebark pine communities. Long term effects of damage and mortality to whitebark pine can ultimately lead to a reduction of future whitebark pine regeneration.
CHAPTER III
METHODS

Study Areas and Transect Establishment

Glacier National Park, Montana, MT, USA, and Waterton Lakes National Park, Alberta, Canada, are continuous protected areas that cross the US-Canadian border. They are managed collaboratively as the Waterton-Glacier International Peace Park, because they represent a single greater ecosystem—the Crown of the Continent. Waterton Lakes covers 50,500 ha of one of the narrowest places in the Rocky Mountain chain. Here, ecological regions of the Great Plains, Rocky Mountains and the Pacific Northwest overlap. Waterton Lakes has a mild, moist, and windy climate, receiving approximately 1,072 mm of precipitation a year and is home to more than 1000 species of vascular plants, more than 60 species of mammals, over 250 species of birds, 24 species of fish, and 10 reptiles and amphibians (Parks Canada 2013). Glacier National Park covers 4.1 million hectares of which 55% is forested. Of that, 60% is moist coniferous forest, 30% is dry coniferous and 10% is deciduous. The park receives approximately 584 mm of rain each year, and the climate is influenced by warm, wet Pacific air to the west and cold, dry arctic air to the northeast. Glacier National Park is home to more than 1,132 vascular plants, 70 species of mammals and over 270 species of birds (National Park Service 2013). Whitebark pine comprises 10 to 15 percent of forested regions of the upper alpine zone within the parks (Arno and Hoff 1990).

In July 2009, four study areas were established in Glacier National Park and one in Waterton Lakes National Park (Fig.III.1), based on both accessibility by trail and location across the Peace Park. Study areas were also distributed across the parks in order
to capture variation in the community types and health of whitebark pine stands, although they were not selected randomly. I selected study areas in locations as follows: Numa Ridge, west of the Continental Divide on the northwest side of Glacier National Park; Preston Park, centrally located in Glacier National Park, just east of the Continental Divide below Siyeh Pass; White Calf Mountain and Two Medicine, located east of the Continental Divide and near the eastern Glacier National Park boundary; and Summit Lake, east of the Continental Divide and near the western boundary of Waterton Lakes National Park.

Transects within study areas were placed off trail. They varied in number and length, based on our ability to walk each transect, (avoiding heavy deadfall, non-traversable creeks, steep slopes, etc.) and to remain within whitebark pine stands (Table III.1). I placed two transects along Numa Ridge, which were characterized by an early successional forest community comprising young whitebark pine, Douglas fir (*Pseudotsuga menziesii*), and lodgepole pine (*Pinus contorta*). The forest surrounding the transect was very open and on steep, rocky slopes with understory dominated by beargrass (*Xerophyllum tenax*). Three transects were placed in Preston Park, just below Siyeh Pass. They passed through successionaly advanced whitebark pine communities with small numbers of alpine larch (*Larix lyellii*), subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*), and large, mature whitebark pine, with an understory dominated by beargrass and huckleberry (*Vaccinium* spp.). Two Medicine and White Calf each had one transect. At Two Medicine, the transect ran through dense canopy consisting of mostly Douglas fir and lodgepole pine and widely spaced old growth whitebark pine, with heavy deadfall in the understory. The habitat at White Calf
Mountain was characterized by large, mature whitebark pine surrounded by dense subalpine fir and heavy deadfall in the understory, which was nearly impassable and impeded visibility for bird observations. Above the dense subalpine forest, I found an open ecotone from subalpine to the treeline communities. I ran the transect through this open community; since it paralleled a portion of the denser forest. The open community above the transect was composed of younger whitebark pine with a beargrass understory. Within Waterton Lakes National Park, I selected Summit Lake as the study area, which was characterized by successional communities with both mature and young whitebark pine and an understory of beargrass, and globe huckleberry (*Vaccinium globulare*). Each transect was named by study area and assigned a number.

Within each study area, the transects were between 0.5 and 1 km in length and were oriented along a fixed heading. I marked the beginning and end points with a 10 inch metal nail, surveyor’s flag, and aluminum tag. Every 50 m endpoint along each transect was marked with an aluminum tag. These points were geo-referenced with a Garmin GPSmap 60CSx unit. Slope and aspect were taken at the mid-point of each transect using a clinometer and compass respectively.

**Stand Assessment Plots**

The starting point and mid-point of each transect, respectively, were selected for the establishment of two 50 m x 10 m stand assessment plots to survey stand structure and composition and whitebark pine cone production and health; methods generally followed Tomback et al. (2005). The stand assessment plots were created by measuring with transect tape 50 m from the start point and mid-point of each transect in the direction of the transect endpoint and 5 m to either side of the transect line, which was demarcated
with surveyor’s tape. Pin flags outlined the boundaries of the plot. The start and endpoints of each plot were geo-referenced (latitude and longitude) with the Garmin GPSmap 60CSx unit and marked with a metal spike and tag. Once the data were taken, the pin flags and surveyor’s tape were removed and the process was repeated later for each cone count.

Individual whitebark pine that were greater than 2 cm in diameter at breast height (DBH) were classified as living or dead, and if living, examined for white pine blister rust, canopy damage, and mountain pine beetle infestation. The 50 m x 10 m plots were assessed for percent whitebark pine represented by the mature forest canopy, number and percent of trees with recent mountain pine beetle infestation symptoms (such as pitch tubes or boring dust), percent dead trees and causes, percent live trees, number of whitebark pine seedlings per ha, and number of cones. A whitebark pine was considered to be infected with blister rust if I found one or more active, sporulating cankers or old, inactive cankers. If canker presence could not be determined because of tree size or canopy density, a tree was considered to be infected with blister rust if it had two or more of the following symptoms: branch flags, resin weeping, and bark stripping by rodents (Tomback et al. 2005). Canopy damage, defined by dead branches, and assessed as a percent of the entire canopy, was classified as follows: 1(0-5%), 2(6-15%), 3(16-25%), 4(26-35%), 5(36-45%), 6(46-55%), 7(56-65%), 8(66-75%), 9(76-85%), 10(86-95%), 11(96-100%). A tree was considered living if it had >1% green foliage, even if we found signs of blister rust infection. Mountain pine beetle infestation was indicated by beetle entry holes with pitch plugs, fading foliage, or J-shaped galleries in the wood of dead trees (Gibson et al 2008).
To obtain whitebark pine cone counts on plots, one observer, aided by binoculars, counted the cones produced by each whitebark pine tree, examining the tree from two sides of the tree. The stand assessment was performed once in 2009, while I counted cones three times over the field season both in 2009 and 2010. Whitebark pine seedlings \( \leq 50 \text{ cm} \) in height were counted within each plot and the numbers per plot summed for each transect, in order to compare regeneration among study areas. Additionally, mature cone-bearing canopy level trees within each stand assessment plot were counted to determine percent stand composition by species.

**Cone Counts and Nutcracker Distance Sampling Surveys**

For each visit to a study area, nutcrackers were counted by the line transect distance sampling protocol (Buckland et al. 2001) (Fig. III.2). Surveys were conducted on each transect during optimal light conditions (avoiding early morning and evening), and avoiding inclement weather. Two observers began at the transect start point and moved at a slow, steady pace, 10 m apart, along the transect. The amount of time it took to complete the transect was noted, which was later used to calculate the proportion of hours spent surveying in which one or more nutcrackers was observed. When a nutcracker was sighted, one observer used a rangefinder (Nikon ProStaff 550 laser rangefinder) to determine the distance between the transect line and the tree that the nutcracker occupied, or the nearest tree to a bird in flight. The other observer fixed and recorded the GPS point on the transect line. A standard compass was used to determine the angle of the sighting from the transect line, with the observer oriented toward the endpoint of the transect line. This information was later used to determine the direct perpendicular distance of the sighted bird to the transect line. The nutcracker’s activity was also noted, as well as the
number in a group (if more than one), and the tree species where the nutcracker was 
observed. Vocalizations were considered an observation. If a vocalization was heard 
nearby, distance and direction to the bird was estimated by observers.

In 2010, in addition to counting cones within the stand assessment plots, the same 
protocol for distance sampling of nutcrackers was implemented to estimate cone density. 
These counts were conducted three times in 2010, in order to document density of cones 
prior to ripening through the time nutcrackers typically forage, harvest and cache 
whitebark pine seeds. One observer conducted all distance sampling cone counts to 
maintain consistency and reduce sources of variability.

**Study Timeline**

The study was conducted over two field seasons, 2009 and 2010. Transects and 
stand assessment plots were established in early July 2009. Nutcracker distance sampling 
surveys and cone counts for each transect were conducted three times in 2009: in mid-
July, mid-August and mid-September. In 2009, one nutcracker survey was conducted 
each visit.

In 2010, surveys of each transect were conducted beginning July 5\(^{th}\), as soon as 
snow melt permitted access, and each study area was visited seven times from July 
through mid-September. Two nutcracker surveys were conducted during each visit, one 
in the morning, and one in the afternoon. The study areas were visited generally in the 
same order throughout the season to ensure that each study area was surveyed equally 
during the various stages of cone development. Cone counts using the line transect 
distance sampling protocol (Buckland et al. 2001) were conducted on the same days that 
the stand assessment plot cone counts were conducted.
**Data Analysis**

**Nutcracker and cone density estimates.** We used transect-based distance sampling (Buckland et al. 2001) to estimate nutcracker and cone densities within the park. Although objects are missed in surveys, distance sampling achieves an unbiased estimate of density (Bardsen et al. 2006). By using the line-transect sampling method, I was able to estimate detection probability as a function of the distance from the transects. From this function, population size can be estimated from the basic relationship: \( D = \frac{n}{a*p} \), where \( D \) is nutcracker or cone density, \( n \) is number of animals or objects sighted, \( a \) is area sampled, and \( p \) is probability of detection. For line transects, \( a \) is written as \( 2wL \), resulting in the following equation: \( D = \frac{n}{2wLP_a} \), where \( P_a \) is the average probability of detecting nutcrackers or cones, \( w \) is the effective detection distance or effective strip width, and \( L \) is the total transect length of all sampled transects. \( P_a \) and \( w \) are both derived from detection probability function described above.

Distance sampling requires counts of individuals as well as a perpendicular distance to the objects of interest from the transect line. Assuming that detection probability decreases with increasing distance to the transect line or observation point, a detection function is fitted to distance data in order to obtain a density estimate (Buckland et al. 2001, Bachler and Liechti 2007). The assumptions of line transect distance sampling per Buckland et al. (2001) are as follows; all objects on the transect line were detected, objects (nutcrackers or cones) did not move before being detected, and there were no measurement errors. I modeled the detection probability for nutcrackers across both years because my sample sizes were very small in some cases, and I wanted a single estimate for the two years combined. In order to obtain a density estimate for the entire
Peace Park, in Montana and Alberta, I modeled the detection probability across all study areas and transects for both cones and nutcrackers.

Analyses were carried out using DISTANCE 6.0 release 2 (Thomas et al. 2010). The Akaike’s Information Criterion (AIC) was computed in the DISTANCE software for each of the models used. The AIC values provide a means to select the model that best fit the data. Measures of this goodness of fit for a given model illuminate the discrepancy between observed values and the values expected under that model. An AIC, while measuring goodness of fit, also discourages increasing the number of parameters to fit the data. The most parsimonious model is given by the model with the lowest AIC value (Buckland et al. 2001). Due to model selection uncertainty, I used Akaike weights, or the probability that the given model is the best model, to determine which model to select in estimates of densities for cones and nutcrackers.

I used this method to estimate nutcracker densities in 2009 and 2010 and used the same method for cone density estimates in 2010 alone. I compared the stand assessment method for cone density estimates with the cone density estimates derived from using DISTANCE. I also compared the individual observation estimates for number of nutcrackers or cones (N) in a specified area produced by DISTANCE to the number of individual nutcracker and cone observations that I actually recorded in the field. This allowed me to evaluate differences in actual observations and observations that were estimated using a detection function. Although not analyzed in this study, the number (N) derived in DISTANCE could be used to plot proportion of hours spent surveying in which one or more nutcrackers were observed against cone density as in Barringer et al. (2012).
**Stand assessment plots.** I used whitebark DBH measurements to calculate live basal area density (LBA) (m²/ha). Basal area, for a given tree, can be found by using the formula \(3.14 \times \left(\frac{\text{dbh}}{200}\right)^2\). I summed the basal area for all living whitebark pine trees > 2 cm DBH from each of the two 500 m² stand assessment plots per transect, and multiplied by a factor of 10 to achieve LBA per hectare. By using the Anderson-Darling test for normality, I determined that my data were not normally distributed. Using an alpha value of 0.05, I ran the Kruskal-Wallis non-parametric ANOVA and the Wilcoxon rank sum test in my post hoc analyses to determine if there were significant differences in the DBH among study areas. I found percent whitebark pine canopy by dividing the number of canopy level live, mature, cone bearing whitebark by the total number of all species of canopy level trees within the plots. I also reported percent of live trees with blister rust, mean canopy kill class, and DBH (with standard error) based on means of both stand assessment plots per transect. Additionally, live basal area, total number of dead and live whitebark pine and regeneration numbers reported were based on sums across both health plots of each transect.

**Cone and nutcracker observations.** In order to compare my data with those of McKinney et al. (2009) and Barringer et al. (2012), I calculated the proportion of total observation hours resulting in at least one nutcracker observation from the number of nutcracker observations per transect and the total number of hours spent on each transect. I then added my data points to the graph of proportion of observation hours resulting in one or more sightings of a nutcracker vs. average number of whitebark pine cones per hectare, based on survey plots in Barringer et al. (2012). I then incorporated into a graph our 2009 and 2010 observed values for proportion of observation hours resulting in
nutcrackers with the values from the McKinney et al. (2009) and Barringer et al. (2012) studies.
Figures and Tables

Figure III.1 Research study areas. Geographic locations of study areas in Waterton-Glacier International Peace Park (black rectangles). (Maps contributed by GLAC GIS program and NPS).
Table III.1. Transect and stand assessment plot descriptions. Elevation and aspect were measured at transect mid-point. Latitude/longitude were taken from GPS readings taken at the start point of each transect.

<table>
<thead>
<tr>
<th>Park</th>
<th>Study Area</th>
<th>Transect</th>
<th>Length of Transect (m)</th>
<th>Elevation (m)</th>
<th>Habitat</th>
<th>Lat/Long</th>
<th>Aspect (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>450</td>
<td>A-2032 B-2054</td>
<td></td>
<td>48°52.907 114°10.602</td>
<td>A-204 B-204</td>
</tr>
<tr>
<td></td>
<td>Preston Park</td>
<td>1</td>
<td>700</td>
<td>A-2121 B-2155</td>
<td>Subalpine fir, Engelmann spruce</td>
<td>48°42.471 113°39.296</td>
<td>A-250 B-260</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>500</td>
<td>A-2151 B-2175</td>
<td></td>
<td>48°42.764 113°39.366</td>
<td>A-210 B-210</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>450</td>
<td>A-2055 B-2050</td>
<td></td>
<td>48°42.583 113°39.342</td>
<td>A-160 B-160</td>
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<tr>
<td></td>
<td>Two Medicine</td>
<td>1</td>
<td>700</td>
<td>A-1772 B-1977</td>
<td>Lodgepole, Douglas fir</td>
<td>48°38.882 113°38.882</td>
<td>A-290 B-200</td>
</tr>
<tr>
<td></td>
<td>White Calf</td>
<td>3</td>
<td>500</td>
<td>A-1946 B-1958</td>
<td></td>
<td>49°00.407 114°01.427</td>
<td>A-220 B-64</td>
</tr>
<tr>
<td>Waterton Lakes NP</td>
<td>Summit Lake</td>
<td>1</td>
<td>500</td>
<td>A-1961 B-1964</td>
<td>Subalpine fir</td>
<td>49°00.556 114°01.291</td>
<td>A-210 B-220</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>500</td>
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<td></td>
<td>49°00.605 114°01.416</td>
<td>A-290 B-290</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>500</td>
<td>A-1946 B-1958</td>
<td></td>
<td>49°00.407 114°01.427</td>
<td>A-220 B-64</td>
</tr>
</tbody>
</table>
Figure III.2 An illustration of how both nutcracker and cone surveys were conducted for distance sampling. Nutcracker and whitebark pine cone density were estimated by use of the line transect-based distance sampling protocol (Buckland et al. 2001).
CHAPTER IV

RESULTS

Nutcracker Observations and Activities

In July 2009, I first spotted a family group of two adults and juveniles birds in Preston Park, flaking whitebark pine bark from branches, presumably looking for insects. This was, however, prior to transect establishment, and no nutcrackers were recorded on transects in Preston Park for the entire season. That same year in mid-August, nutcrackers were counted once on Numa Ridge, where individuals were observed harvesting whitebark pine seeds. No birds were observed at Two Medicine for either year; they were heard once at White Calf in 2009; and they were observed flying over, perching and calling at Summit Lake in August of 2009. Although effort was increased in 2010, I did not observe nutcrackers at either Two Medicine or Numa Ridge in that year. However, in late July 2010, I often observed nutcrackers at White Calf; and, on one occasion I saw them transporting seeds upslope for caching. First, I saw them harvest whitebark pine seeds and then fly in groups upslope at White Calf Mountain into treeline and subalpine habitat. I attempted to confirm seed caching by climbing to an upper bowl, and remaining under cover, as the nutcrackers flew back and forth. However, I was not able to confirm caching activity. At Preston Park, I observed nutcrackers foraging in Engelmann spruce in early July 2010 and spotted the occasional individual flying in, perching, and flying away. At Summit Lake in 2010, I heard calls and observed transect flyovers on several occasions, but could not confirm seed harvesting or caching.
Stand Assessments

The mean DBHs of whitebark pine recorded from each of the 20 stand assessment plots ranged from $6.5 \pm 3.2$ cm to $37.4 \pm 13.6$ cm (Table IV.1). The White Calf assessment plots had the smallest diameter and presumably youngest whitebark pine measured of any of the study areas (mean of $6.5 \pm 3.2$ cm, respectively). The two assessment plots at Two Medicine had the largest and presumably the oldest whitebark pine on average ($37.4 \pm 13.6$ cm). Preston Park consistently had the largest whitebark pine measured among the assessment plots of all its three transects ($30.5 \pm 12.1$ cm, $34.2 \pm 11.9$ cm, and $36.6 \pm 27.3$ cm, respectively). Using an alpha value of 0.05, normal distribution tests of the DBH data for each study area indicated that the data were generally not normally distributed. P-values for the study areas were as follows: Preston Park 0.8, White Calf 0.5, Two Medicine (sample size too small), Numa 0.02 and Summit Lake 0.009. Non-parametric ANOVA indicated that DBH differed significantly among study areas (Kruskal-Wallis One-Way ANOVA, $P < 2.2e-16$, $\chi^2 = 81.9$, df = 4). Wilcoxon Rank Sum post hoc analyses showed significant differences in DBH among study areas with the exception of Summit Lake vs. Numa Ridge and Two Medicine vs. Preston Park. (Fig. IV.1, Table IV.2).

We found no recent MPB mortalities or active infestations in our study areas. Per transect, the highest percent of live trees with blister rust was found on the assessment plots for transect 2 at Preston Park, with 80% infection. The lowest percent of live trees with blister rust was found on the assessment plots at Summit Lake on transect 2 with 33% infection (Table IV.1, Fig. IV.2). The greatest canopy kill for whitebark pine occurred on the assessment plots for transect 2 at Numa Ridge (category 6.0, or 46-55%...
canopy kill). The lowest average canopy kill class was found at White Calf (category 2, or 6-15% canopy kill) (Table IV.1). Based on assessment plots, the lowest value for LBA was on transect 2 at Summit Lake with 0.42 m$^2$/ha, and the highest was at Preston Park on transect 2 with 11.05 m$^2$/ha. Numa Ridge assessment plots overall had the greatest number of live whitebark pine (33), the greatest number of dead whitebark pine (29) and the greatest number of seedlings per ha on any of the assessment plots (Table IV.1).

Transect 3 at Preston Park had only two living whitebark pine and no dead whitebark pine on assessment plots, with only 3% whitebark pine among canopy trees. No regeneration was found on six transects, including all of Summit Lake and the Two Medicine transects, and only two seedlings were found on all three transects at Preston Park (Table IV.1).

When comparing cone production with LBA, average canopy kill and DBH, I found that the greatest factor contributing to cone production was LBA, with Preston Park and Numa Ridge trees producing the greatest number of cones per ha as well as having the greatest LBA. Preston Park had a density of 203 cones/ha and an LBA of 15.6 m$^2$/ha and Numa Ridge came in second with 40 cones/ha and an LBA of 8.5 m$^2$/ha. These cone densities were calculated using the stand assessment plot method so that 2009 and 2010 could be combined.

**Comparing Nutcracker and Cone Counts on Stand Assessment Plots with Density Estimates from Distance Sampling**

I detected a total of 65 nutcrackers in 2009 and 2010, combined over a summed transect length of 5.25 km and 170 surveys (30 in 2009, 140 in 2010) (Table IV.3). Only 62 of these observations were used in the detection function modeling and density
estimates, because one observed cluster was a flyover and we could not determine the distance from the transect. Due to model selection uncertainty, I used model averaging and weighted AIC values to select a model. The model with the greatest probability of being the best was the Hazard + cosine model for nutcrackers. This model provided a density estimate, across all study areas, of 0.85 nutcrackers per hectare with a 95% confidence interval of 0.37-2.62 and a weighted AIC value of 0.37 (Table IV.4).

I detected a total of 1338 whitebark pine cones while using distance sampling in 2010 over a total transect length of 5.25 km. The uniform + simple polynomial model produced the best of fit model with a weighted AIC value of 0.51. This model gave a density estimate of 66.69 cones per hectare with a 95% confidence interval of 28.06-158.52 (Table IV.4).

For 2010, I compared the calculated density of cones per ha based on cone counts on stand assessment plots per transect with the cone density estimated by DISTANCE (Table IV.5). In 2010, no cones were detected at either Two Medicine or Numa Ridge by either method. No cones were counted in stand assessment plots at White Calf. However, cones were detected at White Calf using distance sampling (Table IV.5). At Preston Park, I found different numbers of cones especially for Transect 1 by estimating densities via the stand assessment plot method compared with estimates from distance sampling. There were no cones on the stand assessment plots for the first and third transects at Summit Lake, whereas I detected cones on all three transects using distance sampling.

**Comparing Raw Data from Distance Sampling with Model Estimates**

I collected raw counts of nutcrackers and cones using transect-based distance sampling. Program DISTANCE modeled a detection function that would account for any
individuals that we may have missed. This not only produced an estimated density for cones and nutcrackers, but it also gave us an estimate of N, or the number of nutcrackers or cones that would be found in the specified area. For this study, the specified area was along each non-strip transect of non-specified width. I compared these estimates of N with the raw counts of cones and nutcrackers that I collected in the field (Table IV.6). This was helpful for comparing methods. I could evaluate the effectiveness of raw individual number counts by determining whether those counts fell within the confidence interval produced in DISTANCE. These data are from 2010 observations for cones and for 2009 and 2010 combined for nutcrackers. The raw N for cones fell within the DISTANCE CI in only 10% of the compared samples. In 30% of compared samples, no cones were observed using either method. In 40% of the compared samples for nutcrackers, the raw observed value fell within the DISTANCE CI. In 30% of compared samples, no nutcrackers were observed using either method.

No cones were detected using distance sampling at Numa Ridge or Two Medicine. At White Calf, 198 (CI: 132-297) cones per ha were estimated by DISTANCE compared to the 9 that we actually counted. Of the three transects at Preston Park, two cone counts fell within the DISTANCE confidence interval, and no cone counts at Summit Lake fell within the DISTANCE confidence interval.

**Cone Production vs. Nutcracker Observations**

Raw numbers of nutcrackers sighted on transects (and not the estimates from distance sampling) were used to calculate total number of observation hours where one or more nutcrackers were observed, and added to the scatterplot in Fig. 4b in Barringer et al. (2012) (Fig. IV.3).
There is an order of magnitude difference in the number of cones/ha for some of the data points in each study, because both the McKinney et al. (2009) and Barringer et al. (2012) studies included regions with healthier whitebark pine communities. For example, the greatest number of cones/ha found in this current study per ha was 470, whereas the greatest numbers of cones/ha in the McKinney et al. (2009) and Barringer et al. (2012) studies were 4573 and 4050, respectively. The average proportion of hours resulting in one or more nutcracker observations also varied greatly between this study and the others. The average proportion for this study was 0.128 (SD 0.179) and for McKinney et al. (2009) and Barringer et al. (2012), the average proportions were 0.489 (SD 0.394) and 0.451 (SD 0.379), respectively.
Figures and Tables

**Table IV.1. Transect stand assessment plot variables.** Percentages, canopy kill class, and DBH based on means of both stand assessment plots per transect. Live basal area (LBA), total number of dead and live WBP, and regeneration (no. of seedlings per transect) numbers were based on sums across both stand assessment plots of each transect. There were no recent MPB infestations in our study areas.

<table>
<thead>
<tr>
<th>Park</th>
<th>Study Area</th>
<th>Transect</th>
<th>Avg dbh cm, (SD)</th>
<th>Percent live trees with blister rust</th>
<th>Avg canopy kill class</th>
<th>LBA m²/ha</th>
<th>Total no. dead WBP</th>
<th>Total no. live WBP</th>
<th>Percent WBP in overstory</th>
<th>No. seedlings/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNP</td>
<td>Numa Ridge</td>
<td>1</td>
<td>11.4 (7.3)</td>
<td>75</td>
<td>4.6</td>
<td>0.181/1.81</td>
<td>16</td>
<td>16</td>
<td>13</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10.9 (4.6)</td>
<td>76</td>
<td>6</td>
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<td>29</td>
<td>33</td>
<td>30</td>
<td>330</td>
</tr>
<tr>
<td></td>
<td>Preston Park</td>
<td>1</td>
<td>30.5 (12.1)</td>
<td>50</td>
<td>5.5</td>
<td>0.183/1.83</td>
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<td>34.2 (11.9)</td>
<td>80</td>
<td>5.2</td>
<td>1.105/11.05</td>
<td>17</td>
<td>10</td>
<td>3</td>
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<td></td>
<td>3</td>
<td>36.6 (27.3)</td>
<td>50</td>
<td>3</td>
<td>0.269/2.69</td>
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<td>2</td>
<td>3</td>
<td>0</td>
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<tr>
<td></td>
<td>Two Medicine</td>
<td>1</td>
<td>37.4 (13.6)</td>
<td>67</td>
<td>4</td>
<td>0.487/4.87</td>
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<td>3</td>
<td>3</td>
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</tr>
<tr>
<td></td>
<td>White Calf</td>
<td>1</td>
<td>6.5 (3.2)</td>
<td>75</td>
<td>2.3</td>
<td>0.048/0.48</td>
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<td>12</td>
<td>100</td>
<td>40</td>
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<tr>
<td>WLNP</td>
<td>Summit Lake</td>
<td>1</td>
<td>15.8 (11.3)</td>
<td>55</td>
<td>2.4</td>
<td>0.294/2.94</td>
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<td>11</td>
<td>15</td>
<td>0</td>
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<td></td>
<td>2</td>
<td>32.6 (32.6)</td>
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<td></td>
<td>3</td>
<td>18.5 (13.4)</td>
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<td>4</td>
<td>8</td>
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Figure IV.1. Average dbh per study area. This boxplot shows the median dbh, upper (25% of the data are greater than this value) and lower (25% of the data are less than this value) quartiles, maximum and minimum dbh values and outliers for dbh in each study area.
Table IV.2. Wilcoxon rank sum test. Post hoc analyses of differences in median dbh among study areas. Results show a significant difference in dbh among all study areas with the exception of two comparisons: Summit Lake vs. Numa Ridge and Two Medicine vs. Preston Park. The Kruskal-Wallis rank sum test comparing all study areas resulted in $p=2.2e-16$, chi-squared value of 81.1 and four degrees of freedom, indicating significant differences in the median dbh among study areas.

<table>
<thead>
<tr>
<th>Study Area Comparison</th>
<th>W</th>
<th>p-value</th>
<th>Median comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preston Park-Numa</td>
<td>3793</td>
<td>&lt; 2.2e-16</td>
<td>PP &gt; NR</td>
</tr>
<tr>
<td>Summit Lake-Numa</td>
<td>1338.5</td>
<td>0.07795</td>
<td>SL = NR</td>
</tr>
<tr>
<td>Two Medicine-Numa</td>
<td>462</td>
<td>0.000295</td>
<td>TM &gt; NR</td>
</tr>
<tr>
<td>White Calf-Numa</td>
<td>261.5</td>
<td>0.002599</td>
<td>WC &gt; NR</td>
</tr>
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<td>Summit Lake-Preston Park</td>
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<td>SL &lt; PP</td>
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<td>Two Medicine-Preston Park</td>
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<td>White Calf-Preston Park</td>
<td>14</td>
<td>6.97E-07</td>
<td>WC &lt; PP</td>
</tr>
<tr>
<td>Two Medicine-Summit Lake</td>
<td>97</td>
<td>0.01565</td>
<td>TM &gt; SL</td>
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<tr>
<td>White Calf-Two Medicine</td>
<td>0</td>
<td>0.000323</td>
<td>WC &lt; TM</td>
</tr>
</tbody>
</table>

Figure IV.2. Comparing stand assessment variables across study areas. Percentages of healthy, live whitebark pine (WPB), live, blister rust infected WBP and dead WBP.
Table IV.3. Numbers of Clark’s nutcrackers observed during distance sampling in 2009 and 2010, with combined cone counts from stand assessment plots for 2010. Nutcracker surveys were conducted three times per transect from July through September in 2009 (one survey each visit) and 14 times per transect in 2010 (two surveys per visit). The numbers of nutcrackers observed in 2010 are reported per visit, with observations only occurring during one survey per visit. Cone counts were conducted three times. Number shown is survey with greatest count.

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Transect</th>
<th>2009</th>
<th></th>
<th>2010</th>
<th></th>
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<td>Total No. NC</td>
<td>Total No. Cones</td>
<td>Visit No. (2 surveys/visit)</td>
<td>Total No. NC</td>
<td>Total No. Cones</td>
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<td></td>
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<td>Summit Lake</td>
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<td>1</td>
<td>0</td>
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<td></td>
<td>0</td>
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<td>4</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>9</td>
</tr>
</tbody>
</table>
Table IV.4. Models used in Program DISTANCE to estimate density for nutcrackers and cones in Waterton-Glacier International Peace Park. Models are ordered by increasing ΔAIC, the difference in AIC between a given model and the most parsimonious model. The AIC value for hazard + cosine model (nutcrackers) was 233.91 and the AIC value for uniform + simple model was 612.96 (cones). Due to model selection uncertainty, model averaging was used to determine which model best fit the data. AIC weights are given for each model. Density is given in number of objects/ha.

<table>
<thead>
<tr>
<th>Object</th>
<th>Model</th>
<th>No. of parameters</th>
<th>ΔAIC</th>
<th>AIC Weight</th>
<th>D (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutcrackers</td>
<td>Hazard + cosine</td>
<td>2</td>
<td>0.00</td>
<td>0.37</td>
<td>0.85 (0.37-2.62)</td>
</tr>
<tr>
<td></td>
<td>Uniform + cosine</td>
<td>2</td>
<td>1.04</td>
<td>0.22</td>
<td>0.73 (0.42-2.06)</td>
</tr>
<tr>
<td></td>
<td>Uniform + simple</td>
<td>2</td>
<td>1.07</td>
<td>0.22</td>
<td>0.67 (0.43-2.22)</td>
</tr>
<tr>
<td></td>
<td>Half normal + cosine</td>
<td>2</td>
<td>1.26</td>
<td>0.20</td>
<td>0.78 (0.39-1.86)</td>
</tr>
<tr>
<td>Cones</td>
<td>Uniform + simple</td>
<td>2</td>
<td>0.00</td>
<td>0.51</td>
<td>66.69 (28.06-158.52)</td>
</tr>
<tr>
<td></td>
<td>Half normal + cosine</td>
<td>1</td>
<td>1.52</td>
<td>0.24</td>
<td>66.01 (27.71-157.27)</td>
</tr>
<tr>
<td></td>
<td>Uniform + cosine</td>
<td>1</td>
<td>1.81</td>
<td>0.20</td>
<td>62.26 (26.24-147.78)</td>
</tr>
<tr>
<td></td>
<td>Hazard + cosine</td>
<td>2</td>
<td>4.85</td>
<td>0.05</td>
<td>66.83 (27.80-160.65)</td>
</tr>
</tbody>
</table>
Table IV.5. Cone density estimate method comparison. The stand assessment method was used in both 2009 and 2010. Distance was used to estimate densities in 2010 alone. The stand assessment method for density estimate does not include a confidence interval (CI), which DISTANCE provides. In 30% of compared density estimates no cones were observed using either method and in only 10% of compared density estimates did the stand assessment method density estimate fall within the DISTANCE CI.

<table>
<thead>
<tr>
<th>Site</th>
<th>Transect</th>
<th>Cone density (No./ha) Stand assessment method</th>
<th>Cone density (No./ha) DISTANCE (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WC</td>
<td>1</td>
<td>0</td>
<td>27.54 (18.38-41.27)</td>
</tr>
<tr>
<td>NR</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PP</td>
<td>1</td>
<td>470</td>
<td>75.42 (50.33-113.01)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>90</td>
<td>146.90 (98.03-220.13)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20</td>
<td>10.20 (6.81-15.29)</td>
</tr>
<tr>
<td>SL</td>
<td>1</td>
<td>0</td>
<td>13.77 (9.19-20.64)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>50</td>
<td>41.0 (27.57-61.91)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>9.18 (6.13-13.76)</td>
</tr>
</tbody>
</table>
### Table IV.6. Comparison of N (estimate of number of objects in the specified area) and the number of observations for cones and nutcrackers made while on each distance sampling transect in Waterton-Glacier International Peace Park.

Using DISTANCE to estimate N gives a confidence interval which indicates the probability that the true population mean lies within the range of the sample mean. Using raw observation numbers alone removes this indication of the reliability of the cone and nutcracker observation estimates.

<table>
<thead>
<tr>
<th>Site</th>
<th>Transect</th>
<th>N DISTANCE Cones (95% CI)</th>
<th>No. Observations Cones</th>
<th>N DISTANCE Nutcrackers</th>
<th>No. Observations Nutcrackers</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WC</td>
<td>1</td>
<td>198 (132-297)</td>
<td>9</td>
<td>11 (4-28)</td>
<td>12</td>
</tr>
<tr>
<td>NR</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>22 (8-55)</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PP</td>
<td>1</td>
<td>759 (507-1138)</td>
<td>651</td>
<td>5 (2-14)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1056 (705-1583)</td>
<td>622</td>
<td>27 (10-69)</td>
<td>6</td>
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<tr>
<td></td>
<td>3</td>
<td>66 (44-99)</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SL</td>
<td>1</td>
<td>99 (66-148)</td>
<td>9</td>
<td>16 (6-42)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>297 (198-445)</td>
<td>25</td>
<td>27 (10-69)</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>66 (44-99)</td>
<td>17</td>
<td>16 (6-42)</td>
<td>10</td>
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</tbody>
</table>
Figure IV.3. **Cone and nutcracker observations.** Proportion of observation hours resulting in an observation of one or more Clark’s nutcracker as related to average density of whitebark pine cones on survey plots sampled in this study (triangles) combined with those sampled in McKinney et al. (2009) (circles) and Barringer et al. (2012) (squares). Of 20 data points for this study, seven points overlap with zero nutcrackers and zero cones.
CHAPTER V
DISCUSSION

The objectives in this study were to determine: 1) if nutcrackers occur in whitebark pine communities in the Water-Glacier International Peace Park and at what density, 2) how or if nutcracker densities vary with whitebark pine cone production, 3) how cone production varies with whitebark pine prevalence and health in Waterton-Glacier International Peace Park, and 4) whether the relationship between the likelihood of nutcracker visitation and whitebark pine cone density is similar to those results found in McKinney et al. (2009) and Barringer et al. (2012). In addition, I developed a protocol for counting both nutcrackers and whitebark pine cones using a line transect-based distance sampling method, which may standardize the collection of whitebark pine cone and Clark’s nutcracker information for use in restoration strategies. I addressed study objectives by gathering information on whitebark pine communities and stand health, along with cone and nutcracker densities.

Nutcracker Occurrence and Density in Whitebark Pine Communities in the Park

Nutcrackers did occur in most of the whitebark pine communities that I surveyed, but unpredictably and usually with low numbers. To put this in perspective, of the 30 distance sampling surveys conducted on transects in 2009, nutcrackers were sighted in only 6 surveys or 20%. Of the 140 surveys conducted in 2010, nutcrackers were sighted in only 9 of these surveys or 6.4%. I generated an overall density estimate across all study areas of 0.85 nutcrackers per ha with a 95% confidence interval of 0.37-2.62. There are no comparable distance sampling data for nutcrackers in the literature for comparison,
but based on previous assessments using other techniques (McKinney et al. 2009, Barringer et al. 2012), these numbers seem low.

Distance sampling proved useful in Waterton-Glacier International Peace Park, since the bird densities were low and study areas varied in their accessibility, forest density, forest type, and topography. In general, distance sampling works well for populations which have low density and for sampling large areas quickly; double counting of birds is a minor issue (Gregory et al. 2005). Density estimates from standard distance sampling are superior to raw count data, because distance sampling corrects for decreasing detection probability with increasing observation distance, while raw count data do not (Gregory et al. 2005, Bächler and Liechti 2007, Diefenbach et al. 2007). I note that the population estimate for nutcrackers in the Waterton-Glacier International Peace Park is relative, because I cannot verify the assumption that all objects on the transect line were detected. Nevertheless, the use of this method achieves an estimate closer to true density than raw bird count data (Bächler and Liechti 2007). Lorenz and Sullivan 2010 tested the reliability of four survey techniques (standard point counts, playback point counts, line transects, and Breeding Bird Survey) from July through November in 2007 and 2009. They found detection rates of nutcrackers to be low and variable for all survey types. They were unable to estimate population size or assess the accuracy of their survey methods. This was attributed to the fact that the birds have large home ranges, they do not regularly sing or call, and their numbers may be too low for reliable detection. For this study, I used a distance sampling method that had not been previously used to estimate nutcracker densities. The advantage to this method is that it uses a detection probability function to estimate densities. This was useful in Waterton-
Glacier International Peace Park as the bird densities were low and study areas varied in their accessibility and landscape. Put simply, it was more difficult to detect nutcrackers in some study areas than in others. The detection probability function compensates for this. This method is useful for populations which have lower density, it is efficient with regard to covering ground quickly and increasing the number of birds recorded, and double counting of birds is a minor issue (Gregory et al. 2004).

This justification can be extended as well to estimations of cone density. Using distance sampling as well as stand assessment plots to estimate cone density has provided an opportunity to compare methods within the same study. Tables IV.5 and IV.6 compare density and N estimates for cones. The stand assessment method for density estimate does not include a confidence interval (CI), which DISTANCE provides. In 30% of compared density estimates, no cones were observed using either method and in only 10% of compared density estimates or one case did the stand assessment method density estimate fall within the DISTANCE CI. Additionally, the raw distance sampling N for cones fell within the DISTANCE confidence interval in only 10% of the compared samples or one case. In 30% of compared samples, no cones were observed using either method. In 40% of the compared samples for nutcrackers, the raw observed value fell within the DISTANCE CI. In 30% of compared samples, no nutcrackers were observed using either method. I conclude that using distance sampling would provide a more accurate estimate of cone production and nutcracker densities, as opposed to extrapolating cone and nutcracker observations with the use of other count methods.
**Nutcracker Densities and Whitebark Pine Cone Production**

For restoration efforts to be successful, the vector of regeneration for the whitebark pine must be present; that is, there must be sufficient numbers of nutcrackers to propagate the species naturally. McKinney et al. (2009) proposed 1000 cones/ha would be needed to insure attracting and maintaining nutcrackers in whitebark pine communities at the time of seed dispersal. When cone production fell below ~ 130 cones/ha, the likelihood of nutcracker occurrence became “negligible,” according to their model (Fig. 3, McKinney et al. 2009). They also estimated that whitebark pine stands with a live basal area of 5.0 m$^2$/ha will be able to produce 1000 cones/ha in high cone production years. They found that the frequency of nutcracker occurrence at their sites was strongly associated with the number of available cones and that both nutcracker occurrence and cone production were negatively correlated with whitebark pine mortality and positively correlated with whitebark pine live basal area. Barringer et al. (2012) also indicated that 1000 cones/ha would result in a high likelihood (above 0.75) of nutcracker occurrence within a stand. However, they also found that nutcrackers could be observed in stands at any level of cone production, suggesting that the birds “cruise” stands to assess cone availability. The results presented here, as well as the conclusions of Barringer et al. (2012), suggest that nutcrackers visit whitebark pine stands at all levels of cone production, even well below 130 cones/ha, but the likelihood of nutcracker visitation increases as cone production increases.

I found nutcrackers harvesting seeds for the first time in early to mid-August in 2010, as the cone crop was slow to mature due to deep, lingering snowpack that year. It was at this time that we started observing what we interpreted as caching behavior by
nutcrackers on White Calf Mountain. However, from late June through late August, nutcrackers could be heard in lower elevation habitat while we moved up into higher elevation and whitebark pine. In fact, nutcrackers were observed feeding on subalpine fir seeds and spruce budworm on several occasions. This may indicate that nutcrackers are and will continue to utilize other food resources as they wait for whitebark pine seeds to ripen.

**Whitebark Pine Prevalence and Health**

Blister rust infection percentages per transect ranged from 54.3% (Summit Lake) to 75.5% (Numa Ridge). The highest average category of canopy kill for whitebark pine occurred on Numa Ridge (6.0, or 46-55%) while the lowest average canopy kill class was found at White Calf (2.3, or 6-15%). Numa Ridge assessment plots overall had the greatest number of live whitebark pine (33), and the greatest number of dead whitebark pine (29). This is concerning as Numa Ridge has the greatest density, yet one of the highest rates of infection. And with 9 out of 10 transects having an over 50% blister rust infection rate, it is clear that the situation is dire within the park. The highest density of cones was found, using distance sampling, at Preston Park, with 146.90 cones/ha on transect 2. This transect also had the single highest blister rust infection at 80%. When comparing cone production DBH, canopy kill and LBA, I found that Two Medicine had the greatest average DBH at 37.4 cm but no cones were observed. In addition, Two Medicine had an average canopy kill of only 26-35%. Comparing that to Summit Lake, which had the same canopy kill and an average DBH of 20.2, I found that this study area had 23 cones/ha. Each of these study areas had low LBA at 4.9 m$^2$/ha and 4.1 m$^2$/ha respectively. Generally, I would have expected cones/ha to coincide with greater DBH
and lower canopy kill, or damage due to blister rust (McKinney and Tornback 2007). White Calf, with the lowest canopy kill at 6-15% had less than 1 cone/ha. However, this site had the lowest average DBH at 6.5 cm. The only study area that followed trends which may be expected for increased cone production was Preston Park, which had 203 cones/ha with an average DBH of 33.1 cm and the highest LBA at 15.6 m²/ha. However, Preston Park did have one of the highest average canopy kill percentages (Fig.IV.3). These findings clearly show the threat of blister rust within the park, with Preston Park being of particular concern as it appears to have the highest cone production, largest, most mature trees and the highest infection rate of all 10 transects.

**Comparing with Previous Studies**

Whitebark pine cone production and nutcracker occurrence appeared to be sporadic and comparatively low on all transects in both years of this study, especially in relation to cone production observed in other ecosystems with more reliable occurrence of nutcrackers (McKinney et al. 2009, Barringer et al. 2012). It is possible that we may have been working in generally low cone production years, since the cone production per living whitebark pine appeared low. According to Crone et al. 2011, spatial variation in mast seeding could reflect differences in site productivity, differences in seed utilization by generalist seed consumers versus attracting specialist seed dispersers, or due to pathogen infection.

Alternatively, the numbers of dead trees, low live basal area, and extent of canopy kill from blister rust, and high blister infection levels indicate that these communities as a whole are in serious decline and high cone production years are unlikely.
The Barringer et al. (2012) study reports a mean of 24 cones/ha for the “north,” which comprised study areas in the Waterton-Glacier International Peace Park. The distance sampling density estimate of whitebark pine cones that I obtained for study areas and all transects in Waterton-Glacier International Peace Park was 66.7 cones per hectare with a 95% confidence interval of 28.06-158.52 cones per hectare. Both studies are consistent in reporting low cone production for the Waterton-Glacier International Peace Park over the period of the two studies combined, 2008 through 2010.

Management Implications of this Study

Summarizing the implications of our results, Fig. IV.4 above indicates that higher levels of cone production generate more reliable occurrences of Clark’s nutcrackers. This in turn results in more reliable seed dispersal. Overall, it appears that cone production, seed dispersal, and subsequent regeneration are not dependable in the Waterton-Glacier International Peace Park. With low cone production, and low nutcracker densities, there is clearly a reduction in natural regeneration and the outlook for the future is bleak. Without restoration efforts within the park, whitebark pine will likely continue to decline over time. This study and McKinney et al. (2009) and Barringer et al. (2012) together indicate that whitebark pine communities in the Northern Divide Ecosystem, and particularly in the Waterton-Glacier International Peace Park, are seriously in decline and at risk of extirpation without management intervention.
REFERENCES


Bachler, E., Liechti, F., 2007. On the importance of $g(0)$ for estimating bird population densities with standard distance-sampling: implications from a telemetry study and a literature review. Ibis 149, 693-700.


