An Inquiry about Non-native Pinus contorta and Its Capability to Accelerate Disturbed Forest Restoration

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With increasing disturbance and degradation of tropical rainforests, estimates say that secondary forests now cover larger areas than old, undisturbed rainforest (Dent, DeWalt, & Deslow, 2013). Because tropical rainforests play an important role in regulating the carbon and water cycle (Davidson et al., 2013), the regrowth of secondary forests is essential to their performance of vital services to the global environment.

One cause of rainforest depletion is fire, both natural and human-induced to clear land for agricultural use. Although rainforests traditionally have high species diversity, most organisms have a low fire tolerance, save for large trees. As the forests disappear due to fire, as well as other causes, less vegetation survives to receive rainfall and return water into the atmosphere through transpiration. Instead, there is increased water runoff out of the remaining forest, carrying sediment containing important nutrients such as carbon and nitrogen. With less water reentering the atmosphere, droughts occur, and though other organisms can withstand water shortages, large trees cannot. Less rainfall also increases forest fire risk;drought, fire and depleting forests share a cyclic relationship. Rainforests are collectively the largest carbon sinks in the world, so as these ecosystems lose their ability to store carbon, the global climate feels the impact. (Davidson et al., 2013)

Speedy secondary forest regrowth is needed. Chiti, Grieco, Perugini, Rey, and Valentini (2013) tested carbon levels in the soil of undisturbed rainforest, secondary forest, single species tree plantations, and mixed species tree plantations (both constructed on previous rainforest land). The study found that although undisturbed forests had considerably higher carbon levels than any of the other sites, secondary forests reversed the soil carbon loss visible in plantations. This data shows that secondary forests start to inherit the same climate-regulating functions that undisturbed forests perform. Therefore, rainforest regrowth in depleted areas is beneficial to the global environment.

Taking fire into account, this growth could accelerate with the presence of organisms that respond well to fire. *Pinus contorta*, lodgepole pine trees, possess this special capability. These trees reproduce using serotinous pine cones, which typically only release their seeds after the waxy coating is exposed to extremely high temperatures, i.e. fire. Though native to North American boreal forests, these trees can survive and thrive well outside their native habitat, as commercial lumber plantations exist throughout the southern hemisphere (Richardson, Williams, & Hobbs, 1994). Would the presence of *P. contorta* cones along the edges of tropical rainforests influence the regrowth of secondary forests after burning events? Several possible outcomes exist. Circumstances such as shade intolerance and other unaccustomed circumstances could prevent the survival of this species. Conversely, they may flourish as the only fire-dependent organism in nearly desolate, burned forest and become invasive, thus reducing biodiversity. They may also positively contribute to forest regrowth, helping to replenish carbon while maintaining a high level of biodiversity. I will first consider *P. contorta* invadibility of various forest environments.

As mentioned, biodiversity is essential to the authenticity of the forest; an invasive species would be detrimental. Chiti et al. (2013) found that biodiversity positively correlated to higher soil carbon levels. Undisturbed rainforests had the highest soil carbon levels, followed by secondary forests, then agricultural land on sites of past forest. On farmland, mixed species tree plantations had noticeably higher carbon levels than single species plantations. Were *P. contorta* to invade secondary forests, it would fail as a solution to encourage species composition recovery.

Richardson et al. (1994) developed a widely accepted and cited model to predict pine invasions in various southern hemisphere environments. One pine examined in the research was a generic fire-dependent species with serotinous cones, equivalent to *P. contorta*. Environments modelled in the study were fire-prone shrubland, grassland, and temperate forest. Richardson et al. (1994) found that the fire-dependent species posed a high invasive potential in the shrubland and grassland environments, especially when fire served as a mechanism for reproduction. In temperate forests, however, this species had little success invading.

Two important conclusions come from Richardson et al. (1994), along with other considerations. First, grassland and shrubland are low-diversity environments comparable to newly burned rainforest. *P. contorta* may invade preliminary secondary forests, inhibiting authentic forest regrowth. Secondly, in favor of the null effect, *P. contorta* seeds are unlikely invaders of dense forest. Sunlight is key for the success of *P. contorta*, so saplings that were unable to find a gap in the crowded forest, whose canopy received most of the sunlight, would die. This trend is similarly found in rainforests, where large tree survival depends on a sufficient opening in the forest canopy for sunlight to reach the floor. *P. contorta* pine cones existing within the abundance of life in an undisturbed forest may occasionally succeed, but overall will have no impact on community structure and diversity. Though grassland, shrubland, and temperate forest environments are relatable to certain stages of rainforest, they are not an exact replica. Richardson et al. (1994) noted that higher latitudes fare favorably when implicating pine invasions, so one must consider the likelihood of *P. contorta* surviving near the equator. While lodgepole pines have adapted to a wide range of temperatures, from -57ºC in mountain regions to over 38ºC on the California coast, the lowest known native habitat is still over 30ºN. Though *P. contorta* is an opportunistic species, this still puts survivability into question. The next study will analyze an exotic tree invasive to tropical forests. I will consider the qualities that facilitated invasion.

Brown, Scatena, and Gurevitch (2006) studied the prevalence of *Syzygium jambos*, a fruiting tree non-native to the tropics that has successfully invaded parts of Puerto Rican rainforests. Results found a negative correlation between forest age and *S. jambos* dominance. *S. jambos* were able to colonize in undisturbed forest, but were dominant in secondary forests. In one area with data dating back to 1936, when farmers abandoned the land, *S. jambos* established a dominant population that has significantly reduced plant diversity compared to nearby undisturbed forest.

Though *S. jambos* successfully invaded secondary forests, it may have some essential adaptive characteristics that *P. contorta* does not. As a fruiting tree, *S. jambos* has a market for distribution with birds and other animal species (Brown et

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al., 2006). *P. contorta* can only use wind as a means of seed dispersal (Richardson et al., 1994). Furthermore, the ability of *S. jambos* to tolerate low levels of sunlight, combined with wide distribution, has allowed some survival in undisturbed forests (Brown et al., 2006). The Richardson et al. (1994) model predicted that serotinous cones in shaded, dense forests would die if they failed to find a gap in the canopy.

This, however, leads to another consideration. Richardson et al. (1994) reported that pine trees with serotinous cones typically release about 10% of their seeds even without the influence of fire or other high temperature. Accounting for the nearly 17,000 seeds that an adult *P. contorta* can produce per year, one can infer that an established *P. contorta* stand is a viable competitor in any environment. Obviously, the comparison between undisturbed and secondary forests is not black and white. There are stages of growth and sunlight intensity as degraded forests develop to resemble undisturbed forests. The next section will account for important community structure changes in growing secondary forests and assess the viability of *P. contorta* as a result of these natural trends.

Dent et al. (2013) examined the correlation between species and functional makeup of rainforests with the age of the forest, investigating forests from 20 years to over 500 years old. They found that the shade tolerance of non-canopy vegetation species increased over time in rainforests. As the canopy increasingly receives more sunlight, lower level organisms must adapt to survive with less light. As a result, vegetation that relies on sunlight would most likely die at the seedling stage. This is typical for large trees in rainforests and also *P. contorta* in their natural habitat, but it warrants considering the presence of *P. contorta* in the canopy. Typical rainforest canopies range from 20 to 40 m in height, with an emergent layer sometimes reaching up to 80 m. *P. contorta* can grow to 50 m in height, which would put an adult stand above the typical canopy height. Pair this with the 17,000 seeds an adult *P. contorta* can produce, plus the 10% seed release rate without fire, and possibly, one adult stand in a dense forest may have an extreme impact on the environment.

As a whole, the goal of *P. contorta* pine cone introduction to edges of tropical forests would be to accelerate regrowth of future burned areas whilst maintaining a high level of biodiversity. Faster regrowth accelerates the reuptake of carbon into the soil and reentry of water into the atmosphere through transpiring vegetation in the growing secondary forests. After assessing many variables to rainforest and *P. contorta* function, a few conclusions and many considerations result. High biodiversity levels in undisturbed forests, paired with the shade intolerance of *P. contorta*, would probably inhibit considerable spread of the pine without forest disturbance. Following a disturbance event such as fire, however, *P. contorta* may take over as the only fire-dependent species with a high likelihood of invading low-diversity environments. One should note that *P. contorta* has a higher chance of survival in areas of regrowth that are free of human influence, as *P. contorta* saplings could be easily cut by attendant farmers. *P. contorta* seed dispersal would be an interesting and unique experiment overall.

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