

Article

Response of the Invasive Grass *Imperata cylindrica* to Disturbance in the Southeastern Forests, USA

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Abstract: *Imperata cylindrica* is an invasive plant species that threatens diversity and forest productivity in southeastern ecosystems. We examined the effects of disturbance events, particularly fire and hurricane/salvage harvesting, to determine the effects on *I. cylindrica* abundance in longleaf pine (*Pinus palustris*) forests in the Florida panhandle. Areas that were burned or had greater biomass removal following a hurricane had a greater number of *I. cylindrica* patches and larger patch size. These results highlight the importance of disturbance events on expanding invasive species populations in this region and are likely applicable for other invasive species as well. Monitoring and treatment should follow disturbance events to ensure that invasive species populations do not exceed unmanageable levels.

Keywords: *Imperata cylindrica*; fire; hurricane; salvage logging

1. Introduction

Imperata cylindrica (L.) Beauv. (cogongrass) is an aggressive, C₄ perennial grass that has invaded nearly 500,000 ha in the southeastern United States [1]. Native to Asia, the species was introduced to the United States multiple times, both accidentally and intentionally, in the first part of the 20th

century [2]. The species performs well on droughty, nutrient poor soils and it was initially intended as a forage crop, but high silica content when the plant matures makes it unpalatable to livestock [2,3]. It was also used for soil stabilization along road banks and mined lands, but unintended spread into adjacent areas led to placement of the species on the Federal noxious weed list and it is now considered one of the worst weeds in the world [4]. The grass can decrease native species plant biodiversity [5] and alter nutrient availability [6,7]. *Imperata cylindrica* is a problem particularly in young pine plantations in the southeastern United States. In a study of survival, growth and productivity of *Pinus taeda* L. (loblolly pine) seedlings established in a cutover area infested with *I. cylindrica*, Daneshgar *et al.* [8] reported a 35% reduction in survival and a 63% reduction in height of *P. taeda* seedlings 27 months after establishment in plots where *I. cylindrica* was allowed to persist.

Imperata cylindrica spreads both vegetatively and via seeds making it difficult to control. Typically, long distance dispersal is attributed to seed, and once established, patches expand primarily through rhizomes [9,10]. However, long-distance spread is also believed to occur via rhizomes through transportation of equipment and machinery and regeneration with rhizomes can occur from less than 0.1 g of material, which is smaller than a grain of rice [11]. There are several hypotheses as to what makes it so invasive, including that it has few natural enemies in invaded areas, that it is a successful competitor for nutrients, and its ability to produce allelopathic chemicals (phytotoxic compounds) [12].

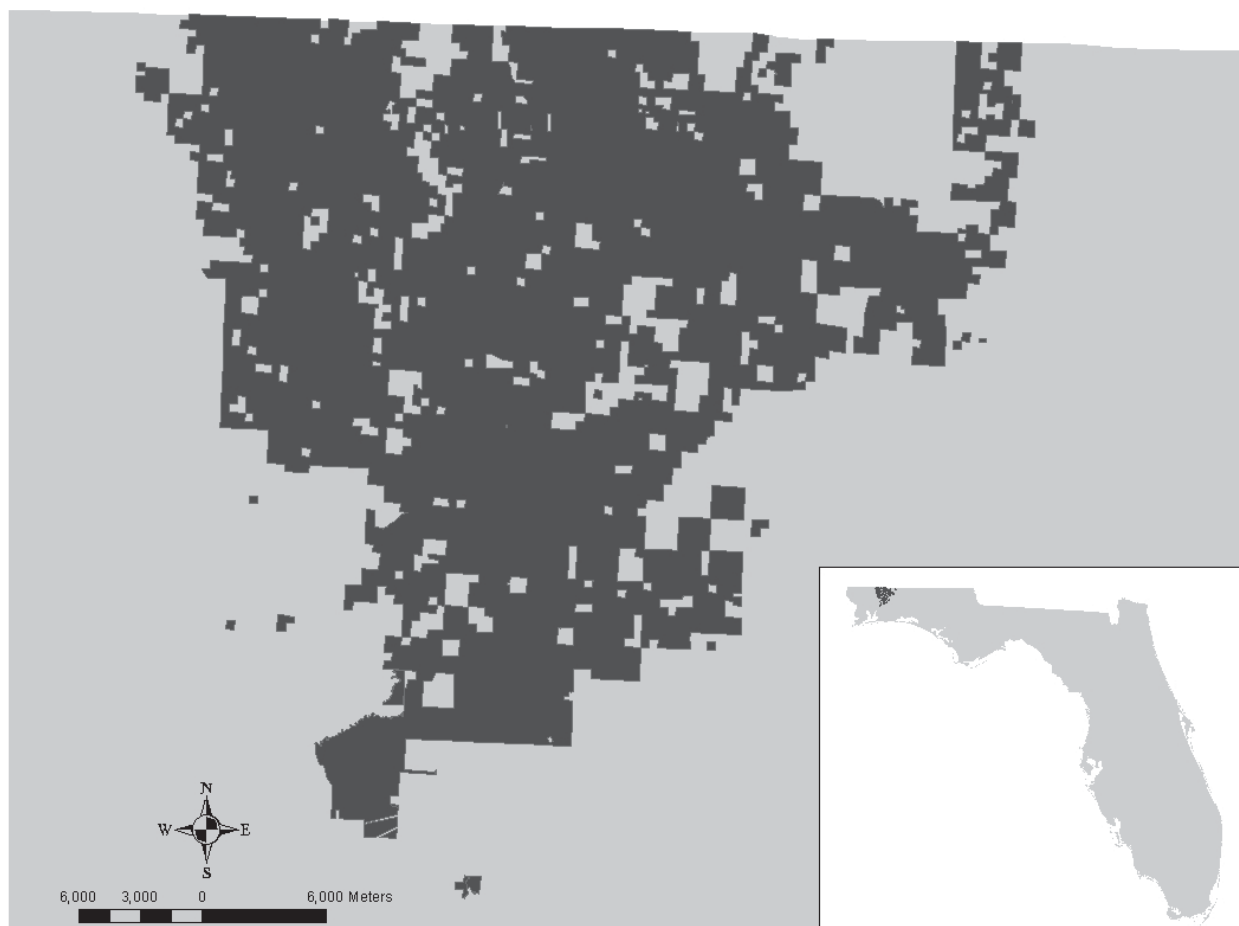
In natural settings, it is believed that *I. cylindrica* first becomes established along roads and trails [13,14]. In addition, the species has the ability to become established in small forest gaps and a low light compensation point allows it to persist as small patches in shaded forest understories [10,15]. Several studies indicate that fire increases the abundance and dominance of *I. cylindrica* in forested areas, even in fire-dependent ecosystems. For example, both Lippincott [16] and Yager [17] reported increased abundance of *I. cylindrica* following burning in southern pine ecosystems in the southeastern United States. However, these studies have only tested the relationship between *I. cylindrica* and fire at the plot level. The objective of this study was to investigate the effects of disturbance, both fire and overstory removal, on a larger landscape level by using Geographic Information Systems (GIS) data to explore the relationship between *I. cylindrica* populations and disturbance. Based on the results from previous studies, we hypothesize that *I. cylindrica* will be more abundant in burned areas and areas where overstory was removed.

2. Experimental Section

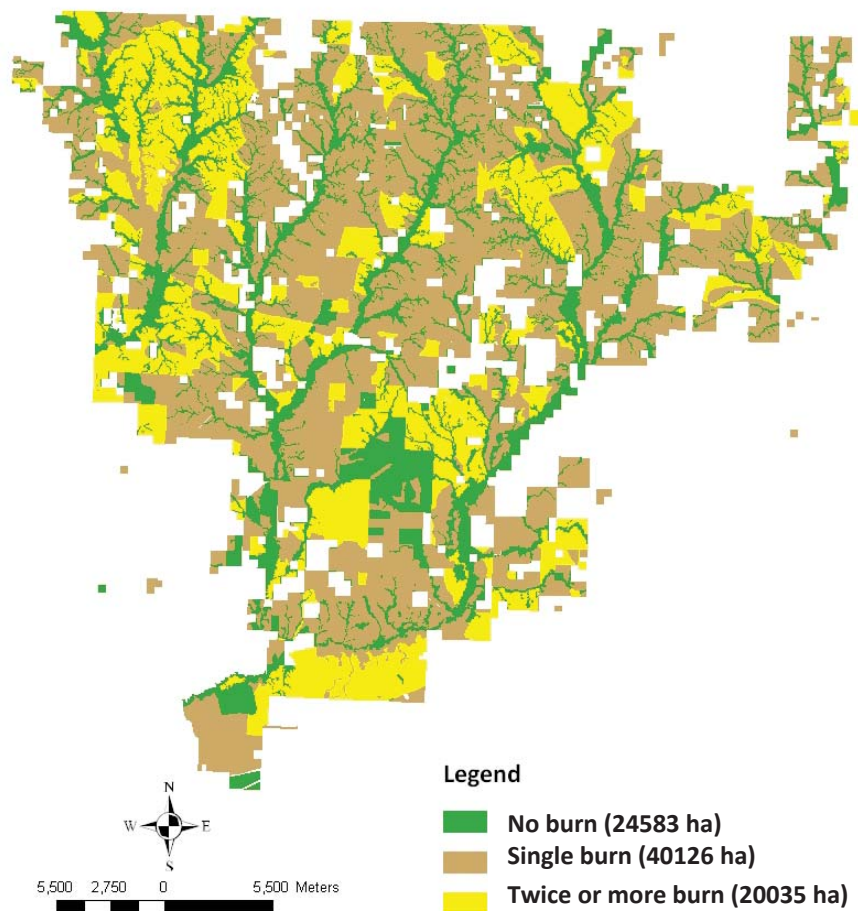
Blackwater River State Forest (BRSF) encompasses approximately 84,000 ha in the Florida panhandle (Figure 1). It is adjacent to Conecuh National Forest and Eglin Air Force Base, making it part of one of the largest contiguous areas of longleaf pine/wiregrass ecosystem in the world. This system, which once dominated the southeastern United States, has been reduced to less than 95% of its original area. Due to this reduction, many of the species of flora and fauna found within the longleaf pine/wiregrass ecosystem are classified as endangered or threatened. In BRSF, upland areas are dominated by a *Pinus palustris* (longleaf pine), *P. elliotii* (slash pine), and *Quercus* (oak) species overstory, and a *Gentiana pennelliana* (wiregrass)–*Serenia repens* (saw palmetto) understory. Bottomland areas are dominated by hardwood species such as *Quercus nigra* (water oak), *Magnolia virginiana* (sweetbay) and *Cyrillaria cerniflora* (titi). Mean annual temperature is 19.2 °C

and mean annual precipitation is 168 cm. Elevation throughout BRSF ranges from 3 m to 88 m and soils are primarily comprised of loamy to fine-loamy ultisols.

Figure 1. Map depicting Blackwater River State Forest and location within the Florida panhandle.



We used BRSF records to determine disturbance and *I. cylindrica* abundance within the area. Between 1983 and 2007 there were 60,161 ha (71% of total area) burned in BRSF (Figure 2). Approximately 67% (40,126 ha) of the burned area had only burned once, while 33% (20,035 ha) of the burned area had burned two or more times. Two hurricanes, Ivan and Dennis, caused considerable damage to BRSF in 2004 and 2005, respectively (Figure 3A). Salvage harvesting was conducted following hurricane Ivan in 2005 to remove downed or damaged wood and ranged from approximately 4500–9000 kg ha⁻¹ (Figure 3B,C). Patches of *I. cylindrica* have been marked throughout BRSF. Each known patch of the invasive grass has a GPS location that gives UTM coordinates and the patch size. Overall, there 384 known patches of *I. cylindrica* that cover 30 ha within BRSF (Figure 4). We conducted an overlay analysis to determine the relationship between burning, hurricane/overstory removal, and *I. cylindrica* abundance within BRSF. Using this data we determined patterns of invasion based on burn frequency and biomass removal.

Figure 2. Location of burned and unburned areas within Blackwater River State Forest.

3. Results and Discussion

Most of the areas within BRSF infested with *I. cylindrica* are within burned areas, as compared to unburned areas (87% versus 13%, respectively). Fifty three *I. cylindrica* patches covering 4 ha are in unburned areas, 228 *I. cylindrica* patches covering 17 ha are in single burn areas, and 103 patches covering 9 ha are in areas that had burned two times or more in BRSF. After calculating % invasion (% invasion = infested area of burn class/total area of burn class), we determined *I. cylindrica* was more than twice as likely to occur in burned areas compared to unburned areas (Figure 5).

Within BRSF, a greater number of patches and hectares of *I. cylindrica* occur in the areas that are also closest in distance to the paths of Hurricanes Ivan and Dennis (Figure 6). Greater blowdown occurred in the western portion of BRSF during Hurricane Ivan in 2004, and subsequently there was greater biomass removal in this area in 2005 (Figure 3). We observed a linear relationship ($r^2 = 0.35$) between biomass removed using salvage harvesting following Hurricane Ivan in 2004 and *I. cylindrica* invasion in harvested stands.

Figure 3. Map of Blackwater River State Forest depicting paths of Hurricanes Ivan and Dennis (A), biomass removal following Hurricane Ivan in 2005 (B) and Euclidian distance from Ivan overlaid on the biomass removal map (C).

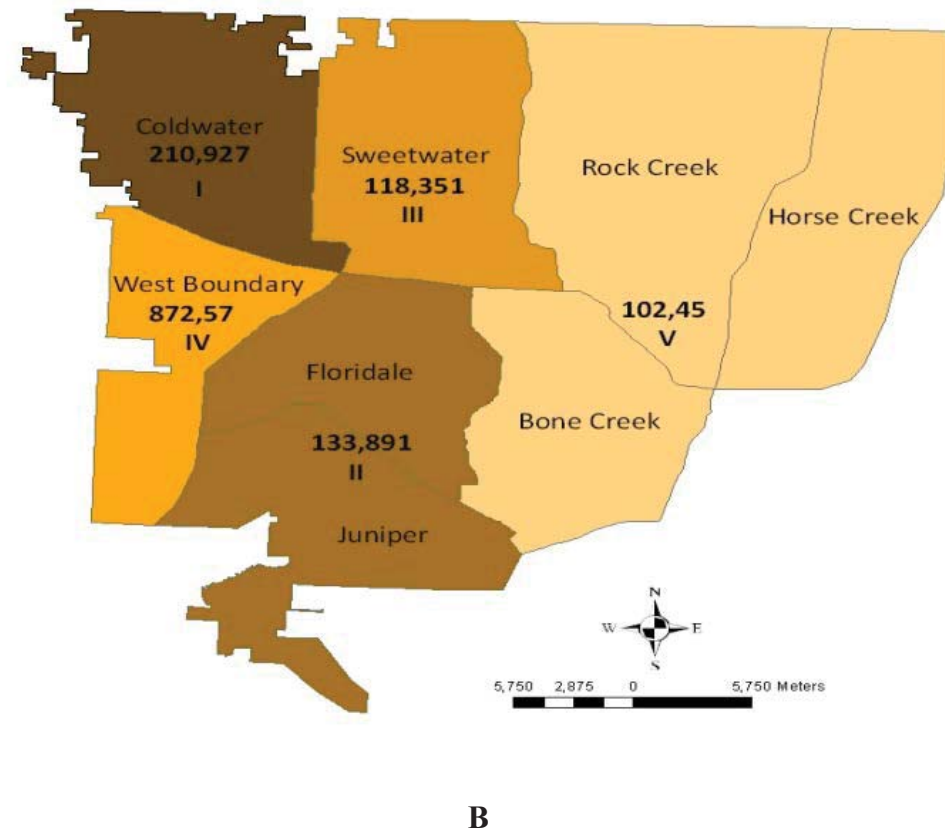
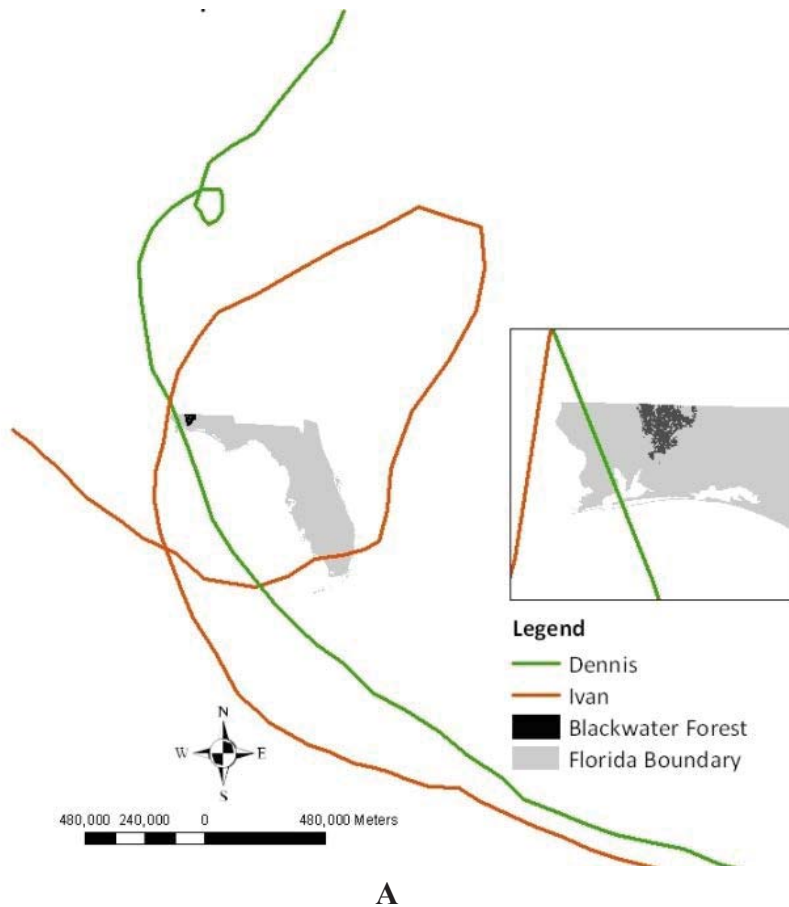
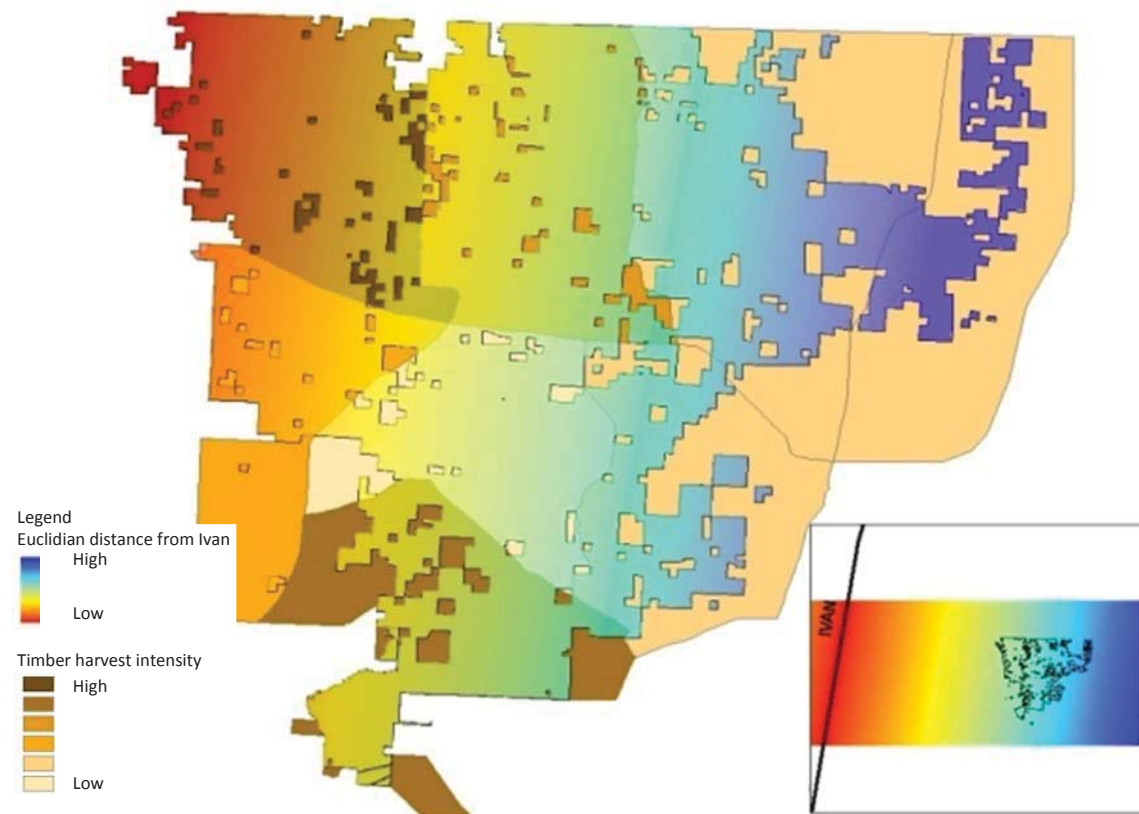


Figure 3. Cont.



C

Figure 4. Map of Blackwater River State Forest showing the location (A) and size (B) of known *Imperata cylindrica* patches.

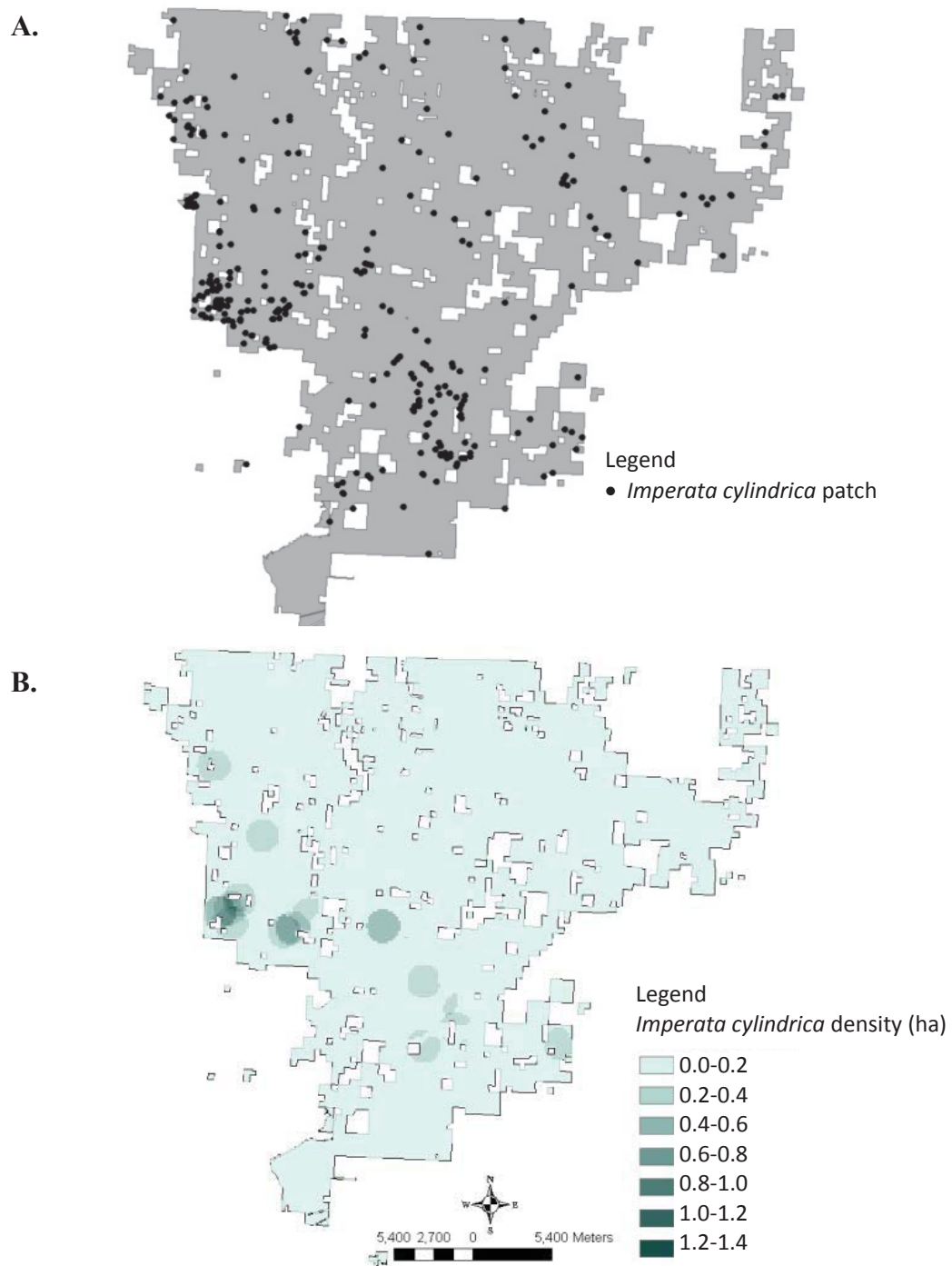


Figure 5. Relationship between *Imperata cylindrica* % invasion and burn frequency in Blackwater River State Forest.

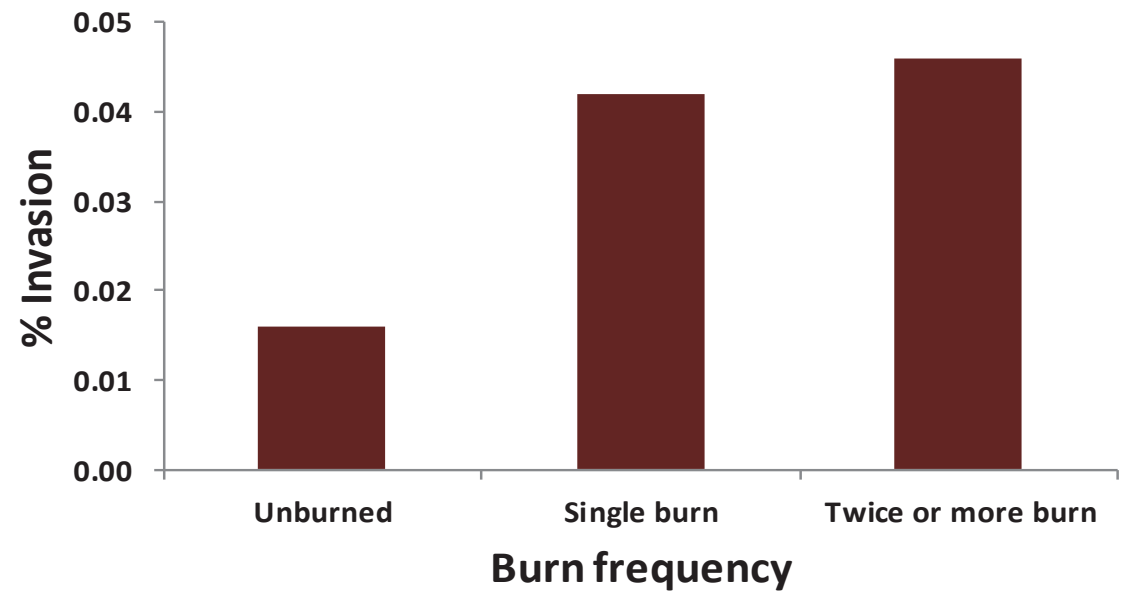
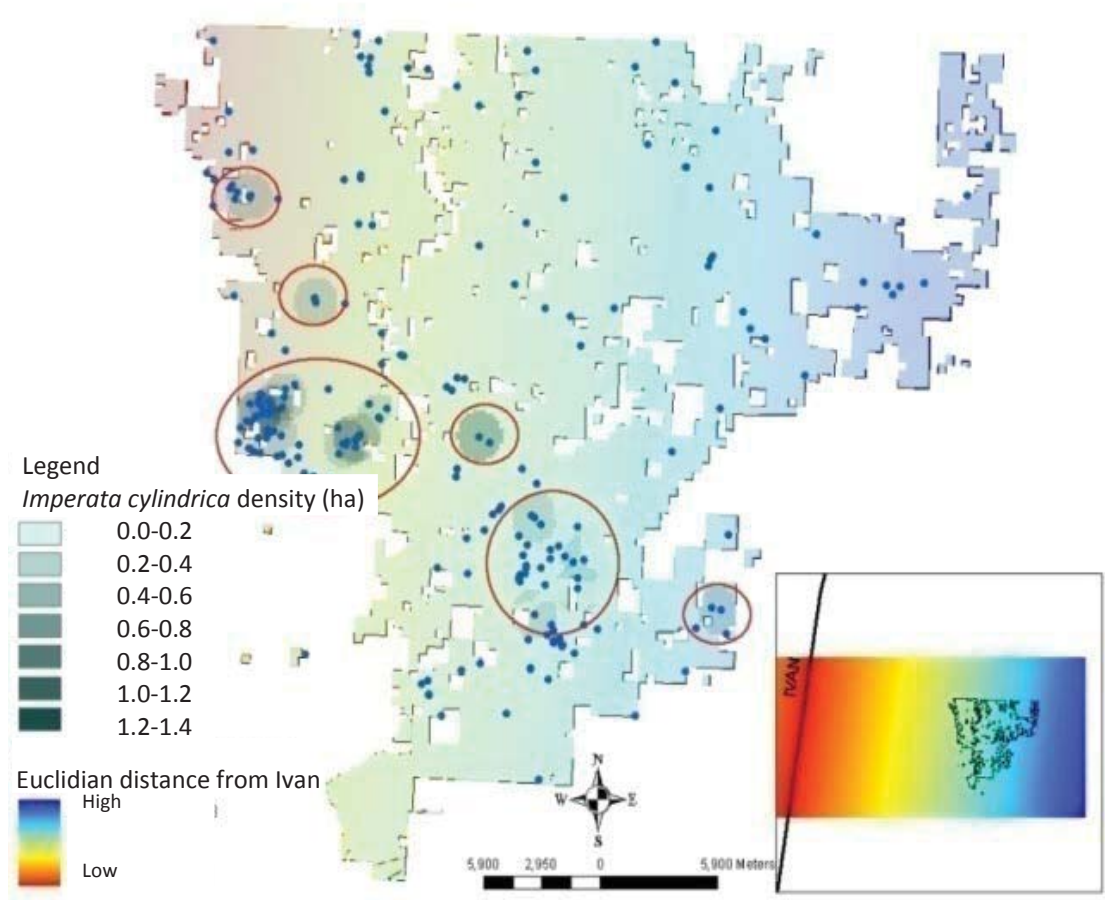


Figure 6. Overlay map of *Imperata cylindrica* density and Euclidian distance from hurricane Ivan in Blackwater River State Forest.



One of the reasons the *I. cylindrica* is thought to be so invasive is because it will become established along roads or trails where it receives full sunlight and expand from these areas into other areas that have an open canopy [14]. This is a characteristic shared by other invasive plants as well [18]. It also has the ability to tolerate low light levels and linger in small, isolated patches in undisturbed forests and expand in size once the area is disturbed [12]. Our results indicate that disturbance, both from fire and windthrow/harvesting increases the size and frequency of *I. cylindrica* patches across the landscape (Figures 5 and 6). This supports results from Lippincott [16] and Yager *et al.* [17] which observed *I. cylindrica* expansion following disturbance from fire in plot level experiments.

After expansion occurs following disturbance, *I. cylindrica* may be particularly difficult to manage in southeastern forests. Although the longleaf pine/wiregrass ecosystem relies on fire and historically burned every 1–10 years, once *I. cylindrica* invades an area it can alter the fire behavior within an ecosystem [19]. Lippincott [16] observed greater mortality of *P. palustris* saplings in areas invaded with *I. cylindrica* compared to areas that had native vegetation. The author reported a change in fire behavior that resulted in increased maximum temperatures which was attributed to greater fine fuels where *I. cylindrica* was present. Holzmüller and Jose [12] also observed increased fire intensity and *P. palustris* mortality in areas invaded with *I. cylindrica* in central Florida. Alteration of a fire regime is not unique to *I. cylindrica*. D’Antonio and Vitousek [20] reviewed multiple examples of invasive grasses that have altered the fire regimes across the globe. In general these invasions facilitated a positive feedback cycle that increased fire frequency due to increased fine fuels. A review by Brooks *et al.* [21] highlighted how the alteration of a fire regime by invasive plants can also have other ecosystem effects such as loss of wildlife habitat, facilitating invasion for other exotic species, and alteration watershed function.

While several studies have explored the relationship between *I. cylindrica* and fire, research testing *I. cylindrica* expansion following overstory removal from hurricane damage or salvage logging is not as available. However, several examples demonstrate that *I. cylindrica* control is a problem in areas where the overstory has been removed [22]. Other studies of exotic grass invasion indicate that overstory removal, particularly salvage logging following disturbance, can increase abundance of exotic species [23–25].

4. Conclusions

It is probable that expansion of existing populations alone cannot account for increased *I. cylindrica* abundance following disturbance from fire and overstory removal in BRSF. Additional spread may have come from windblown seed or propagule movement from machinery during harvest. Nevertheless there is a clear relationship between *I. cylindrica* abundance and disturbance at BRSF. This relationship is applicable across the southeastern United States in other areas where *I. cylindrica* is present, and is likely applicable in other ecosystems affected by exotic grass invasion. Treatment of *I. cylindrica* can be difficult and often requires an integrated management approach that is more than a single herbicide treatment [15,22,26]. This paper calls to attention the importance of monitoring and treating areas prior to disturbance, as well as, monitoring areas immediately following burning, hurricanes, or overstory removal to ensure that invasive populations do not exceed manageable levels.

Acknowledgments

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Conflict of Interest

The authors declare no conflict of interest.

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