Assessment Of Plant Invasion And Forest Fires Linkage - A Case Study Of Lantana Camara

Neena Priyanka, P. K. Joshi

Abstract: Invasive species that alter fire regimes are widely recognized as some of the most important system-altering species on the planet. *Lantana camara*, a pervasive invasive species, is hypothesized to alter fire regimes to greater extent causing damage to ecosystem properties. Thus, to elucidate its relationship with fire, if any, study on species presence and fire occurrences were carried out in present study. Venn diagrams and distance matrix analysis were employed to discern relationship between the two. The study revealed that more than 75% of the fire occurrences overlapped with *Lantana camara* presence with overlapping percentage exceeding 50%. Also, these regions were characterized with open forest canopy and dense *Lantana camara* infestations. The distance matrices of fire occurrences and *Lantana camara* presence ascertained that around 63.33% of measured distances between the two varied between 0-15 km only in both national parks. This confirms that reported occurrences of fire were found to be in close vicinity of species presence. Also, due to *Lantana camara* close proximity to fire occurrences, propulsion of further fire by providing fuel loads cannot be ruled out. These empirical evidences to some extent support the hypothesis that fire may be driven under presence of invasive species such as *Lantana camara* and vice versa holds true. The information presented in this research along with further comprehension of the relationship dynamics will allow for better management of *Lantana camara* invasions that have major ecological, economic and societal implications.

Index Terms: Lantana camara, invasive, national parks, invasion, forest, fire.

1 INTRODUCTION

1.1 Invasion

Invasive species are recognized as threats and this problem is exacerbated as global trade and travel accelerates [1] and human-mediated disturbances increase [2]. The direct effects caused by invasive species include monopolizing the area they invade, resulting in homogeneity or being donors of limiting resources. Indirect effects comprises alteration of geomorphological processes such as disrupting soil stability [3], [4], colonizing open substrates [5], alteration of hydrological processes [6], alteration of biogeochemical cycles [7] and alteration of fire regime [8], [9] (Fig. 1).

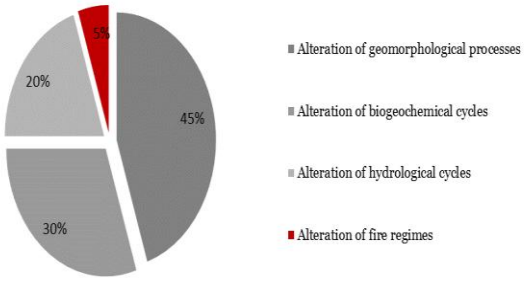

Fig. 1. Indirect effects of invasive species on ecosystem processes.

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Besides these, invasive species cause unprecedented losses to agriculture, forestry, and human health, are direct drivers of biodiversity loss and ecosystem change [10]. All these effects combined together changes native regimes beyond range of variation which has little prospect of irreversibility [11], [12]. One such transformation includes spectacular losses to extent and integrity of protected areas and wildlife sanctuaries as conservation, rehabilitation, and restoration of these areas are hampered immensely by invasive species [13]. Invasions to these areas indicate that the successful establishment of invaders is immensely dependent on various attributes and one such attribute is forest fire.

1.2 Forest Fire

The forest fires are defined on various parameters such as fire frequency, intensity, seasonality and extent of fire [14]. Fire frequency is defined as a measure of fire cycle i.e. “average time for fire to burn an area equal in size to given area of interest [15]. Fire frequency is also measured in terms of fire return interval i.e. average time before fire re-burns given area, also known as fire recurrence interval. Fire intensity is defined as “amount of heat released per unit of time” [16], [17]. Fire intensity measure is related to fire severity which is defined as “effect of this heat release on biotic and abiotic ecosystem properties”. Fire extent includes both size and spatial homogeneity of burning [18]. Fire type refers to the spread of wildfires varies based on the flammable material present and its vertical arrangement. It can be generally characterized as ground fire, surface fire and crown fire [15], [17]. Fire seasonality is defined as “annual window of fire activity and determined by fuel components level to ignite & spread fire” [19].

1.3 Feedback loops linking Fire and invasion

A typical forest fire cycle depends on spatio-temporal variations in topography, climate, fuel composition and levels (Brooks et al., 2004). Topography, climatic conditions, and native species from which litter is obtained acts as input for fire disturbances viz. widening fire regime, increasing frequency/seasonality, accelerating intensity, and altering its type. In turn, fire exerts its feedback mechanism limiting native biota and disrupting ecosystem properties. The scale at which

this variation occurs differs in time scale, topographic changes, regional climate shifts, and fuel condition change [20], [21] (Fig. 2).

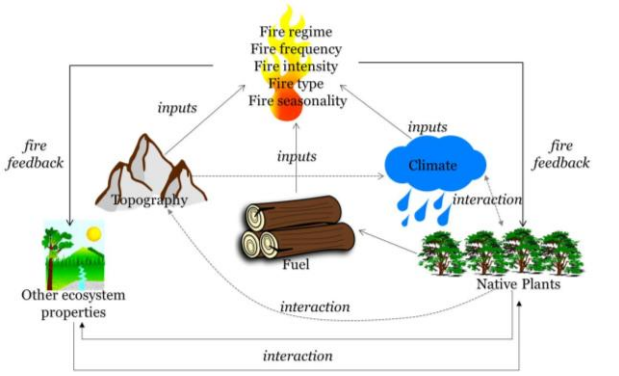

Fig. 2. Fire regime cycle before invasion – simple interaction.

In ecosystem, fire characteristics and change in fuel that aggravate fire are intricately linked through feedback mechanism [17]. The new fire regime opens up forest canopy, increases desiccation of forest and makes the environs further susceptible to fire. This also creates opportunities for colonization or expansion by invasive species by facilitating habitat that could not be previously dominated due to intensive dominance of native flora. Mostly, invaders can adapt and persists in altered landscapes and rapidly spread in disturbed regime [22]. In addition, invaders also alter fire characteristics and thrive well under altered environs. Fuel properties are altered directly by accumulation of invasive plants or indirectly by change in the volume and composition of native flora [17]. The process involves eliminating native flora through competition or allelopathic interactions (Fig. 3).

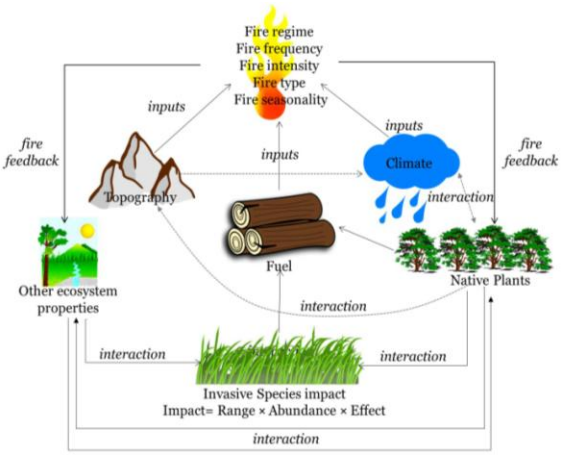

Fig. 3. Fire regime cycle before invasion – complex interaction.

There are various hypothesis regarding relationships between invasion and fires. A majority of researchers postulate that existence of invasive species under altered natural conditions is dependent on fires [23]. Numerous other studies have proposed that invasive species facilitates fire while others conform anthropogenic disturbances as main facilitator of fire in pristine forests. These views however has no concrete experimental proof and research is still in its stage of infancy. The intent of literature review is to understand the fire and invasive species relationship dynamics.

2 Literature Review

In various field based research, the findings suggests that there exists relationship between the characteristics of fire and growth characteristics of the invasive [24], [25], [26], [27]. Researchers D'Antonio & Vitousek, and Brooks & Pyke demonstrated conversions of native communities to exotic annual grass under the influence of fire-invasion cycle [28], [29]. Buell et al., in their study on invasive reported that higher fuel load increases fire frequency and intensity [30]. Caling and Adams in their study on effects of bulldozing and wildfire on plant species richness showed that invasive germination and growth are rapid after fire [31]. Rossiter et al. in his study reported increase in fire frequency with spread of invasive species [32]. Dodson and Fiedler confirmed that alien species abundance increases with increasing fire intensity [33]. Paschke et al. revealed that invasive species have reduced the fire-return intervals after displacing native flora [34]. Gomez-Gonzalez et al. in their sampling study showed that anthropogenic fires favored more for the establishment of invaders than by the native communities [35]. A series of experiments and surveys by Srinivasn ascertained positive correlation between fire frequencies and invasive spread [36]. Studies by Catford et al. indicate that disturbance levels such as those provided by fire maximizes invaded communities by altering native diversity [37]. Most field based research supports invasive and fire linkages. The field based are however confronted with certain limitations such as not being a viable option for large study area. Thus, to overcome these limitations, technologies such as remote sensing, GIS and modeling methods have emerged as powerful techniques to develop simple, feasible, and repeatable methodology to assess invasive species and fire dynamics at the landscape level. This complements site-specific assessment methodologies, since manual effort and cost of experimentation will increase drastically in large study area. Also, till date spatial-temporal assessment of invasive species and fire relationship is a formidable task. Geospatial studies have been employed in estimating extent of invasion [38], [39] and fire occurrences in invaded land [40]. However, there are only a few studies which have employed geospatial techniques to elucidate relationship between the two. One such study was conducted by Pino et al. where GIS tools were employed to highlight relationship between fire and invasive species [41]. The association of invasive presence with fire was explored by means of stepwise regression models applied on the axes obtained from principal component analysis (PCA). Research by Bradley and Mustard, who employed remote sensing techniques, demonstrated that Bromus tectorum (Cheatgrass) presence leads to increased fire frequency due to higher fuel loads and thereby reducing native biological diversity [42]. Steven analyzed digital aerial photographs and illustrated fire frequency correlation with the Brazilian pepper invasion [43]. Stohlgren et al. employed video mapping system for rapid evaluation of invasive species and fire occurrences data [44]. The results confirmed increasing spread of invasive as compared to native in fire disturbed transects. In a study by Silverman, habitat suitability models were developed to predict responses of three invasive species viz. Linnaria dalmatica,

Cirsium vulgare and Carduus nutans to fire in three National Parks [45]. The results are indicative of positive relationship between fire and invasive species, however, the intensity of relationship varied with varying species. Study carried out by Young et al. affirms relationship between invasive species and fire by modeling a number of invasive species [46]. In this study, weighted fire history polygons of fires (suppression, prescribed, and fire use) and invasive species occurrences were used to discern relationship between the two. Literature review thus divulges an ample range of methods employed for studying invasive species and fire relationship, but there is little indication which method is superior because very few of reported methods have been validated for their accuracy, and so far, no comparative studies have focused on *Lantana camara* invasion potential and fire occurrences relationship. Thus, the objective of current study is to provide empirical evidence on relationship between fire occurrences and *Lantana camara* invasion, if any.

3 Materials And Methods

For the purpose of working out relationship with fire occurrences, the study was conducted in two phases. Phase-I involved deducing fire and invasive relationship aspects in various research through online electronic database searches. This was carried out to demonstrate the nature of relationship that exists from time immemorial between invasive presence and fire occurrences. Phase II involved determination of relationship between *Lantana camara* and fire occurrences through field studies and visual interpretations. For this the steps mentioned below were carried out:

- Occurrences records: *Lantana camara* occurrence records were collected from Jim Corbett and Rajaji National Parks. These datasets were brought into spatial domain. Fire occurrence historical records were collated from park officials' handbook and from Firemapper which contains digital data of fire records.
- Fire occurrence and *Lantana camara* presence were buffered to 1 km to normalize exact presence location and to correct for deviation in data collection arising from the fact that the fire data were provided based on crude estimation.
- Venn diagrams were used to depict all possible nature of logical relations between fire and *Lantana camara* occurrences. However, Venn diagrams do not generally contain information on the relative or absolute sizes (cardinality) of sets; i.e. they are simply schematic diagrams. In the present study, in a two-set Venn diagram, one circle represent potential occurrences of fire (F), while the other represent potential presence of *Lantana camara* (L). The area intersected by both circle represent the region where both of these are recorded.
- To quantify the distance between fire and *Lantana camara* occurrences distance matrices were calculated. Distance matrix is an ordination method that is well suited to data that are non-normal or are on arbitrary, discontinuous scales. The calculations are based on an n χ n distance matrix calculated from the n χ p-dimensional main matrix, where n is the number of rows and p is the number of columns in the main matrix.

4 Results and Discussions

4.1 Electronic Database Searches

On using search keywords combinations such as "invasive species and fire", "fire management and invasive species", "invasion and fire ecology" and "fire and plant invasion" in Google search engine, a list of 575 peer-reviewed and online publications were retrieved. These publications focused upon various aspects of plant invasion and fire ecology. Amongst these, publications dealing only with invasive plant species and fire ecology were screened and kept aside by reading the title and abstract. A systematic search for empirical case studies discerning relationship of plant invasion and fire were performed. From these selected publications, reference section were screened to further identify publications matching the above stated search criterion. A total of 88 publications dealing with plant invasion and fire relationship were identified and studied (Fig. 4).

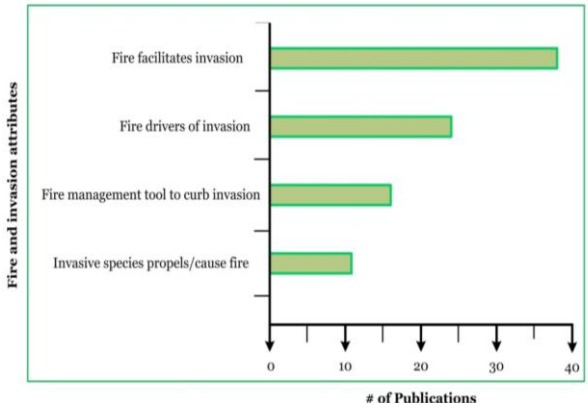

Fig. 4. Most studied fire and invasion attributes.

In all these research, fire is considered as the driver and even facilitator of plant invasion and vice versa. Thus, this ascertains the hypothesis that there exist relationship between fire occurrences and invasive species presence. The literature search also reveals that the spread of invasive is accelerated under fire influence as fire tends to open ecological niches by altering stable native communities [47], [48], [15], [49], [50]. This phenomenon is called as habitat porosity (Fig. 5). In Fig. 5, area a shows source population of invasive species, area b depicts opening of niches to invasive species under the influence of forest fires and lastly area c illustrates most of the natives have been replaced by invasive species. The process is still underway by fire to create further habitat porosity by displacing all natives. Thus, it is evident from pertinent discussion that fire influence all three types of barrier to the invasion i.e. dispersal, abiotic factors, and competition and is totally responsible for habitat porosity.

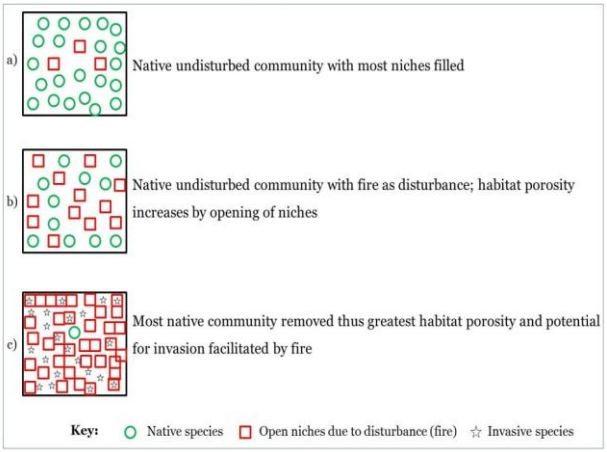

Fig. 5. A diagram depicting habitat porosity caused due to fire resulting in invasion.

Electronic database search results further disclose that fire accelerate dispersion of invasive species at all stages of invasion. The plant invasion is a four tier process (Fig. 6) viz. introduction, colonization, naturalization and invasion.

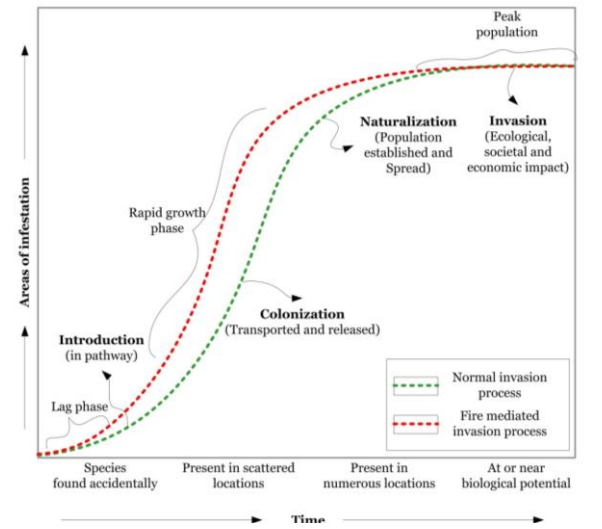

Fig.6. Invasion process: Normal and fire mediated.

Invasive when brought accidentally or intentionally to the site are not detected and therefore flourish unhindered. This constitutes the introduction phase of invasion process. During this phase, population of invaders may fail to establish due to events such as drought, flood and diseases or because of a lack of a minimum critical population size necessary for the population to genetically maintain itself. Colonization phase of invasion process is characterized by exponential rise in population of invasive species. During this explosive growth phase, invasive species become apparent. It is thought to depend more on biological factors than environmental, though both are essential in due course of time. Following this, the species become naturalized in new landscapes and on successful establishment in native communities; dispersal of new progenies is carried out. At the stage of invasion, species begin to exert its effects and impacts in its new establishment and cause damages to socio-economic and environmental infrastructure (Fig. 6). In a fire mediated process of invasion, the introduction phase is completed faster by invasive species is faster as fire opens up spaces by eliminating natives, reduces competitors and provide resources for their germination and growth. The process of fire-mediated invasion slows down in colonization phase because by this time the native species too begin to grow along with aliens and compete for plant resources. The curve of fire mediated invasion finally merges with the curve of normal naturalization phase of invasion because at this stage distinction cannot be made whether the community is developed under fire influence or under normal invasion process (Fig. 6).

4.2 Venn relationship diagram

Phase II results involve illustrating fire and *Lantana camara* relationship using Venn diagrams. Venn diagrams intersection theory was used to test whether occurrences of fire were in vicinity of *Lantana camara* presence. The plotted fire occurrences were mostly aligned in peripheral regions of both national parks. In both of these parks more than 75% of fire occurrences overlapped with *Lantana camara* infestation distribution with overlapping percentage exceeding 50%. Also, these fire regions are characterized with open forest canopy and dense *Lantana camara* infestation. In Jim Corbett National Park, 4 out of 5 reported fire occurrences, showed higher overlap with *Lantana camara* presence (Fig. 7).

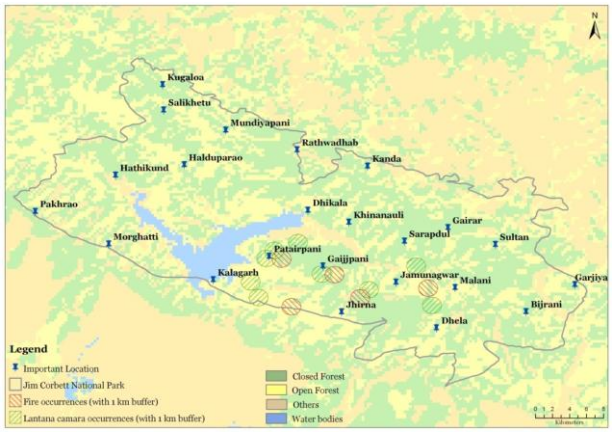

Fig.7. Fire and *Lantana camara* relationship Venn diagram of Jim Corbett National Park.

In Rajaji National Park (Fig. 8), fire occurrences showed similar interaction with *Lantana camara* but the proportion of interaction was higher than Jim Corbett National Park. Further most of the fire and *Lantana camara* occurrences were associated with open forest type. These trivial empirical evidences ascertain the proposed theory that fire occurrences and presence of *Lantana camara* do have close affinity which may likely together be able to cause adverse impact on ecosystem properties.

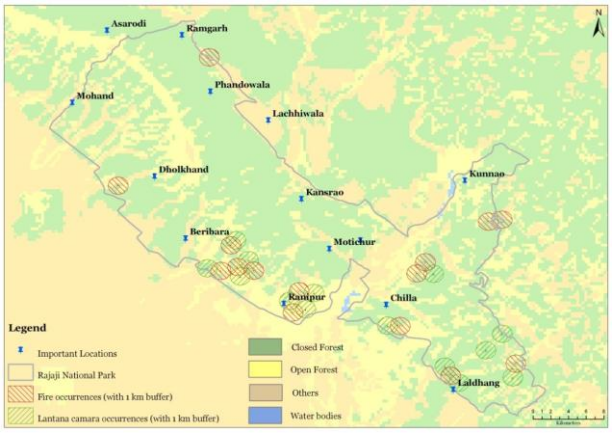

Fig.8. Fire and *Lantana camara* relationship Venn diagram of Rajaji National Park.

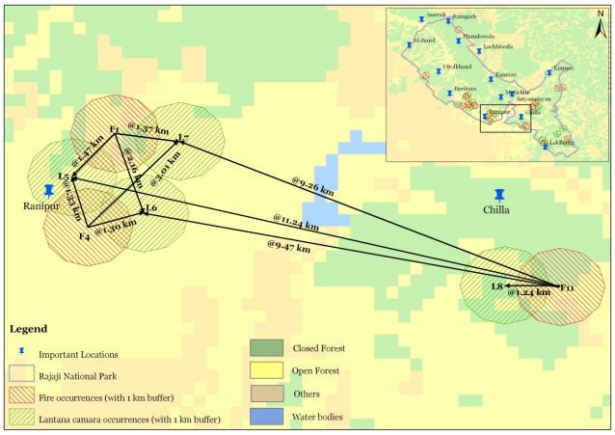

Fig.10. Fire and *Lantana camara* distance relationship diagram of Rajaji National Park.

Further, distance matrices between fire occurrences and *Lantana camara* presence were computed. This provided quantitative estimation that most of the fire occurrences were in close proximity to *Lantana camara*. The average distance between the two was 8.16 km and 16.56 km in Jim Corbett and Rajaji National Parks, respectively (Fig. 9 and 10). None of the distance measures between *Lantana camara* presence and fire occurrences exceed beyond 50 km.

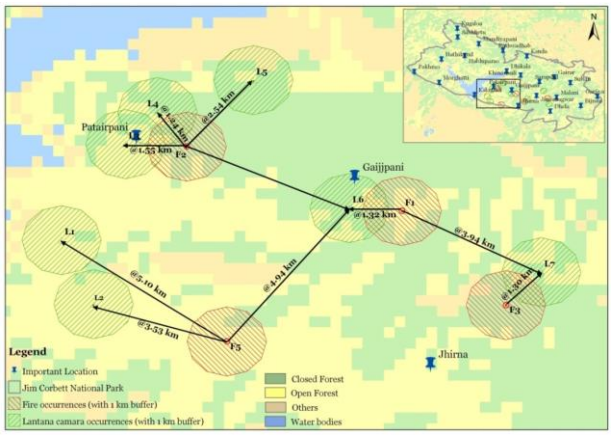

Fig.9. Fire and *Lantana camara* distance relationship diagram of Jim Corbett National Park.

The hypothesis assumed in this study that whether or not there exists any relationship between fire and *Lantana camara* occurrences is thus proven by the visual and quantitative estimation that there is considerable overlap of fire regime and *Lantana camara* distribution and hence there is possibility that fire may be provoked by the species or that fire cause distribution of species. Even though the research methodology were not designed to conduct field sampling and plot analysis experiments to ascertain relationship between fire and invasive species growth, the deduced relationship results itself is indicative of the fact that forest fires does occur in close vicinity of *Lantana camara* and thus may promote its further facilitation and henceforth antagonistic effects on native biota. The vice versa may hold true as well i.e. *Lantana camara* may provide fuel load and accelerate fire.

5 Conclusion

Comparatively little is known about most invasive plants in India and their relationship to forest fire. The above explained research is the best empirical study depicting overlapping regime of invasive distribution and fire regimes in National Parks, although the research is still anecdotal. Current studies suggest that forest fire and *Lantana camara* tends to occur in close vicinity to each other. Thus, former may exert influence on facilitating *Lantana camara* and later in turn may support its further spread by providing fuel loads. In many ecosystems, the dense growth tendency and flammable tissue of *Lantana camara* create continuous drier fuels that are lacking in uninvaded communities. This could significantly exacerbate problems of alteration in fire regime. Thus, work is required in this direction to accommodate plausible trajectories in invasive species and fire relationship frameworks in their planning and management. Further scientific evaluation is necessary to accurately identify mechanisms that lead to these changes. Future research should evaluate progression path of fire and its relationship to invasive species to guide management efforts to conserve and restore native biota from invasion. Enhancing the understanding to address capacity building and educational transformation in the field of invasion ecology and fire management will present an important step forward in maintaining ecosystem sustainability.

References

[1] T.S. Hoffmeister, L.E.M. Vet, A. Biere, K. Holsinger and J. Filser, “Ecological and evolutionary consequences of biological invasion and habitat fragmentation,” *Ecosystems*, vol.8, no.6, pp. 657-667, 2005.

[2] Z. Zhang, Y. Xie and Y. Wu, “Human disturbance, climate and biodiversity determine biological invasion at a regional scale,” *Integrative Zoology*, vol. 1, pp. 130-138, 2006.

[3] R.L. Hill and A.A. Seawright,” The status of lantana in New Zealand,” *Proc. of the 36th N.Z. Weed and Pest Control Conference*, pp. 38–40, 1983.

[4] J.E. Byers, S. Reichard, J.M. Randall, I.M. Parker,

C.S. Smith and W.M. Lonsdale, “Directing research to reduce the impacts of nonindigeneous species,” *Conservation Biology*, vol. 16, pp. 630-640, 2002.

[5] C.M. D’Antonio, *Fire, plant invasions, and global changes. Invasive species in a changing world*, H. Mooney and R.J. Hobbs, eds., Island Press: Washington D.C., pp. 65–95, 2000.

[6] D.M. Richardson, N. Allsopp, C.M. D’Antonio, S.J. Milton and M. Rejmanek, “Plant invasions—the role of mutualisms,” *Biological Review*, vol. 77, pp. 65–93, 2000.

[7] R. Nathan and H.C.M. Landau, “Spatial patterns of seed dispersal, their determinants and consequences for recruitment,” *Trends in Ecological Evolution*, vol. 15, pp. 278-285, 2000.

[8] S.T.A. Pickett and P.S. White, *The Ecology of Natural Disturbance and Patch Dynamics*, Academic Press: London, pp. 111-158, 1985.

[9] S.T. Knick, D.S. Dobkin, J.T. Rotenberry, M.A. Schroeder, W.M. Vander Haegen and C.V. Riper III, “Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats,” *Condor*, vol. 105, pp. 611-634, 2003.

[10] United Nations. “Convention on Biological Diversity,” http://www.cbd.int/doc/legal/cbd-en.pdf. 1992.

[11] J. Levine and C.M. D’Antonio, “Elton revisited: a review of evidence linking diversity and invasibility,” *Oikos*, vol. 87, pp. 15–26, 1999.

[12] M. Vila and I. Ibanez, “Plant invasions in the landscape,” *Landscape Ecology*, vol. 26, pp. 461-472, 2011.

[13] J.G. Pausas and J.E. Keeley, “A burning story: the role of fire in the history of life,” *BioScience*, vol. 59, pp. 593–601, 2009.

[14] E.A. Johnson, K. Miyanishi and J.M.H. Weir, “Wildfires in the western Canadian boreal forest: landscape patterns and ecosystem management,” *Journal of Vegetation Science*, vol. 9, pp. 603-610, 1998.

[15] G.R. McPherson, D.D. Wade and C.B. Phillips, “Glossary of wildland fire management terms used in the United States,” *Society of American Foresters*, vol.138, pp. 90-95, 1990.

[16] P.M. Vitousek, C.M. D’Antonio, C.M. Loope, and R. Westbrooks, “Biological invasions as global environmental change,”*Ammons Scientific*, vol. 84, pp. 468-478, 1996.

[17] M.L. Brooks, C.M. D’Antonio, D.M. Richardson, J. Grace, J.J. Keeley, J.M. DiTomaso, R. Hobb, M. Pellant and D. Pyke, “Effects of invasive alien plants on fire regime,” *BioScience*, vol. 54, pp. 677-688, 2004.

[18] W.J. Reed and E.A. Johnson, “Statistical methods for estimating historical fire frequency from multiple fire-scar data,” *Canadian Journal of Forest Research*, vol. 34, pp. 2306-2313, 2004.

[19] S.R. Abella, E.C. Engel, C.L. Lund and J.E. Spencer, “Early post-fire plant establishment on a Mojave Desert burn,” *Madroño*, vol. 56, pp. 137-148, 2009.

[20] W.C. Bessie and R. Johnson, “The relative importance of fuels and weather on fire behaviour in subalpine forests,” *Ecology*, vol. 76, pp. 747-762, 1995.

[21] J.W. Williams, S.T. Jackson and J.E. Kutzbach, “Projected distributions of novel and disappearing climates by 2100 AD,” *Proc. of the National Academy of Sciences of USA*, vol. 104, pp. 5738-5742, 2007.

[22] J. Pollet and P.N Omi, “Effect of thinning and prescribed burning on wildfire severity in ponderosa pine forests,” *International Journal of Wildland Fire*, vol. 11, pp. 1-10, 2002.

[23] A. Gromtsev , “Natural disturbance dynamics in the boreal forests of European Russia: a review,” *Silva Fennica*, vol. 36, no. 1, pp. 41–55, 2002.

[24] R.J. Hobbs and L.F. Huenneke, “Disturbance, diversity and invasion: implications for conservation,” *Conservation Biology*, vol. 6, pp. 324-337, 1992.

[25] T.R. Allen and J.A. Kupfer,” Application of spherical statistics to change vector analysis of Landsat data: Southern appalachian spruce - Fir forests,” *Remote Sensing of Environment*, vol. 74, pp. 482-493, 2000.

[26] M.C. Andersen, H. Adams, B. Hope and M. Powell, “Risk Assessment for Invasive Species,” *Risk Analysis*, vol. 24, no. 4, pp. 787-793, 2004.

[27] K.M. Goodwin and R.L. Sheley, “What to do when fires fuel weeds,” *Rangelands*, vol. 23, pp. 15-21, 2001.

[28] C.M. D’Antonio and P.M. Vitousek, “Biological invasions by exotic grasses, the grass/fire cycle, and global change,” *Annual Review of Ecology and Systematics*, vol. 23, pp. 63–87, 1992.

[29] M.L. Brooks and D.A. Pyke, *Invasive Plants and Fire in the Deserts of North America*, Allen Press: DTPro System, 2001.

[30] A.C. Buell, A.J. Pickart and J.D. Stuart, “Introduction

history and invasion patterns of Ammophila arenaria on the north coast of California," *Conservation Biology*, vol. 9, pp. 1587–1593, 1995.

[31] T.M. Caling and R. Adams, "Ecological impacts of fire suppression operations in a small vegetation remnant", *Australian Bushfire Conference on InFlammable Australia: the Fire Regimes and Biodiversity of a Continent*, Albury, New South Wales, Australia, pp. 110-134, 1999.

[32] N.A. Rossiter, S.A. Setterfield, M.M. Douglas and L.B. Hutley, "Testing the grassfire cycle: alien grass invasion in the tropical savannas of northern Australia," *Diversity and Distribution*, vol. 9, pp. 169-184, 2003.

[33] E.K. Dodson and C.E. Fiedler, "Impacts of restoration treatments on alien plant invasion in Pinus ponderosa forests, Montana, USA," *Journal of Applied Ecology*, vol. 43, pp. 887–897, 2006.

[34] M.W. Paschke, P.J. Meiman, W.H. Romme and C.S. Brown, "Using native annual plant species to suppress weedy invasive species in post-fire habitats," Prepared for Colorado State University, July 2007.

[35] S. Gomez-Gonzalez, C. Torres-Dıaz, G. Valencia, P. Torres-Morales, L.A. Cavieres and J.G. Pausas, "Anthropogenic fires increase alien and native annual species in the Chilean coastal matorral," *Diversity and Distributions*, vol. 17, pp. 58–67, 2011.

[36] M.P. Srinivasan, "The ecology of disturbances and global change in the montane grassland of the Nilgiris, South India," PhD dissertation, University of Kentucky, Lexington, 2011. http://uknowledge.uky.edu/gradschool_diss/213

[37] J.A. Catford, C.C. Daehlerb, H.T. Murphy, A.W. Sheppardd, B.D. Hardesty and D.A. Westcottc. "The intermediate disturbance hypothesis and plant invasions: Implications for species richness and management," *Evolution and Systematics*, vol. 14, pp. 231– 241, 2012.

[38] J.E. Luther, S.E. Franklin, J. Hudak and J.P. Meades, "Forecasting the susceptibility and vulnerability of balsam fir stands to insect defoliation with Landsat Thematic Mapper data," *Remote Sensing of Environment*, vol. 59, pp. 77-91, 1997.

[39] H.T. Ripley, *Mapping invasive species*, *Hyperspectral Data International:* Inc Halifax, Canada, pp. 15-67, 2006.

[40] M.L. Floyd, W.H. Romme and D.D. Hanna, "Historical and recent fire regimes in piñon–juniper woodlands on Mesa Verde, Colorado, USA," *Forest Ecology and Management*, vol. 198, pp. 269–289, 2004.

[41] J. Pino, X. Font, ´J. Carbo, M. Jove and L. Pallares, "Large-scale correlates of alien plant invasion in Catalonia (NE of Spain)," *Biological Conservation*, vol. 122, pp. 339-350, 2005.

[42] B.A. Bradley and J.F. Mustard, "Characterizing the Landscape Dynamics of an Invasive Plant and Risk of Invasion Using Remote Sensing," *Ecological Applications*, vol. 16, pp. 1132-1147, 2006.

[43] J. Stevens, "The role of fire disturbance in the invasion of South Florida pine savannas by Brazilian pepper," MSc. Dissertation, The University of Vermont, United States, Oct. 2008.

[44] T.J. Stohlgren, C. Jarnevich, G.W. Chong and P.H. Evangelista, "Scale and plant invasions: a theory of biotic acceptance," *Preslia*, vol. 78, pp. 405-426, 2006.

[45] J. Silverman, "Incorporating the disturbance process of fire into invasive species habitat suitability models," MSc. Dissertation, Colorado State University, Colorado, May 2008.

[46] E.K. Young, C. Caldwell, L. Abbott, "Early Detection of Invasive Plant Species on Holloman Air Force Base, New Mexico," Prepared for Holloman Air Force Base, 2009.

[47] C.S. Elton, 1958. *The ecology of invasions by animals and plants*, Methuen: London, 1958.

[48] R.J. Hobbs and L. Atkins, "Fire-related dynamics of a Banksia woodland in south-western Western Australia," *Australian Journal of Botany*, vol. 38, pp. 97-110, 1990.

[49] D. Simberloff, "How much information on population biology is needed to manage introduced species?," *Conservation Biology*, vol. 17, pp. 83–92, 2003. doi:10.1046/j.1523-1739.2003.02028.x.

[50] E.K. Young, T.S. Schrader, K.G. Boykin, C. Caldwell and G.W. Roemer, "Early Detection of Invasive Species in Big Bend National Park: Remote Sensing and GIS Strategies," Prepared for U.S. Geological Survey Status & Trends of Biological Resources Program, Beltsville, MD, May 2007.