The Ecology, Economics and Management of Biological Invasions

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Outline

- What is an alien invasive species?
- Spread of invasive species
- Identifying future invaders and vulnerable communities
- Impacts of alien invasive species
- Invasive species in Ghana
- Management of alien invasive species

What are alien invasive species?

What is an alien invasive species?

- An exotic species that becomes established in an ecosystem and threatens native biodiversity or has other negative ecological and economic impacts.
- A species that establishes a new range in which it proliferates, spreads and persists to the detriment of the environment.

What are alien invasive species?

- Biotic invaders have been variously referred to:
  - *aliens*, non-natives, *adventive*, *exotic, neophytes* (in the case of plants)*, introduced*, and *non-indigeneous* species

- An alien species is a species, subspecies or lower taxon occurring outside its natural range and dispersal potential
  - includes any part, gamete or propagule of such species that might survive and subsequently reproduce.

Invasion of *Lantana camara*

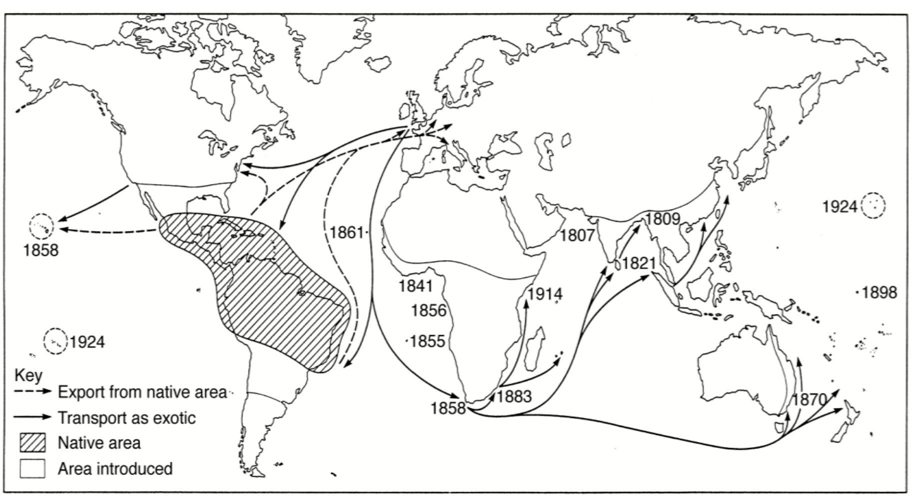


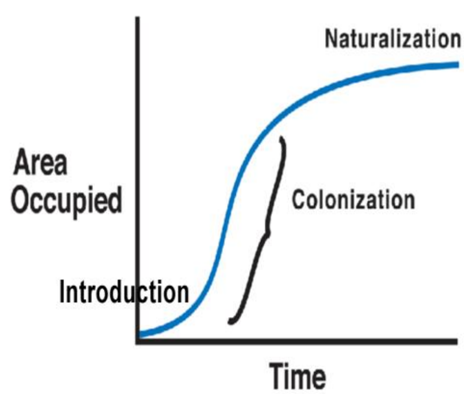
FIG. 1. Some invaders have widely separated new ranges, the products of repeated human dispersal and cultivation. For example, the shrub *Lantana camara* was carried transoceanically throughout the 19th and early 20th century to many subtropical and tropical locales where it has proliferated. Years refer to dates of introduction in widely separated locales (Cronk and Fuller 1995).

What are alien invasive species?

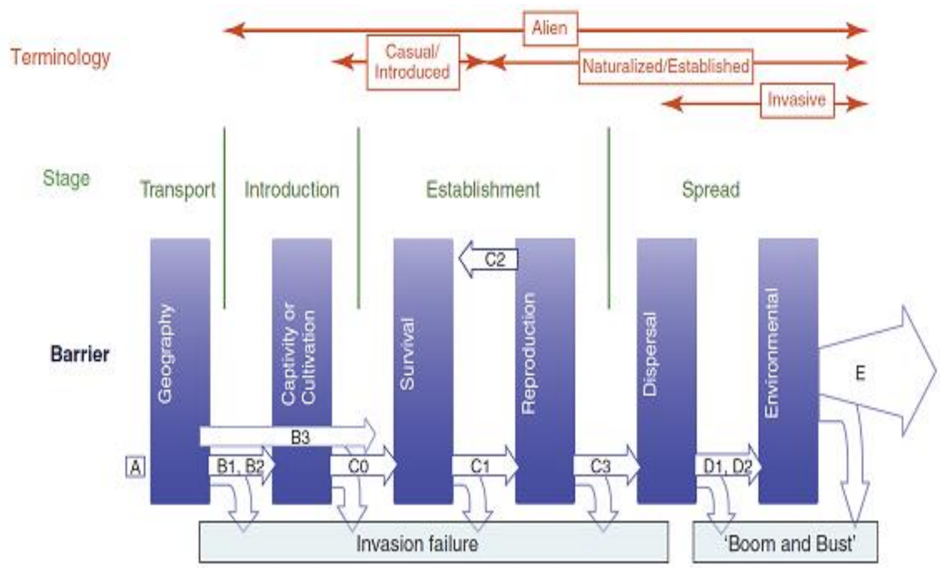
- Biotic invaders are the result of alteration in the distribution of the earth's biota brought about largely by human transport and commerce.
- Today, virtually every location on the planet from mountain peaks to remote oceanic islands has recently been invaded by species that originated elsewhere.
- Invasive species occur in all taxonomic groups from mammals to fungi to viruses.

Spread of Alien Invasive Species

- Biological invasion is an irreversible, a multi-staged process:
  - comprises a number of phases and requires a species to overcome several barriers.
- Three main stages are generally recognized:
  - Introduction
  - Naturalization
  - Invasion



Phases of species invasion



Spread of Alien Invasive Species

- Introduction
  - The movement, by human agency, of a species, subspecies, or lower taxon (including any part, gametes or propagules) outside its native range.
  - a species overcomes a major *geographic barrier*.
  - A *casual* species may reproduce but fail to maintain its population over a longer period.
  - Also referred to as *establishment*, it is the most elusive of all the phases.
    - Populations are usually small at this stage.

Spread of Alien Invasive Species

- Introduction
  - Invaders most likely to fail at this stage.
    - unpredictable events like drought and diseases or lack of a minimum critical population size.

Introduction

- Two types of introduction
  - Deliberate
    - Gypsy moth (*Lymantria dispar*) deliberately introduced in eastern US to investigate its potential for silk production; causes massive defoliation of trees during periodic outbreaks.
  - Accidental
    - Zebra mussels (*Dreissena polymorpha*) introduced in 1980s to North America via ballast waters.

Spread of Alien Invasive Species

- Humans as agents of potential invasion
  - Humans have served as both accidental and deliberate dispersal agents.
    - Invasions have tracked the rise in human migration and commerce.
    - Human-driven introductions dwarf (in scope, frequency and impacts) the movement of organisms by natural forces.
  - Proportion of various types of organisms that have invaded as a result of accidental vs. deliberate introductions by humans vary among taxonomic groups.
    - Most plants and vertebrates invasions occur through deliberate introductions
    - Invertebrate animals and microbes invasions often result from accidental introductions.

Spread of Alien Invasive Species

- Naturalization
  - Begins when individuals overcome environmental and reproductive barriers, and survive.
  - A naturalized species establish a self-perpetuating population but do not necessarily invade ecosystems.
  - Persistence at a point does not depend on recurring, frequent re-immigration from the native range.

Spread of Alien Invasive Species

- Naturalization
  - Term used interchangeably with *colonization*.
  - Globally, more than 13,000 plant species are known to have become established outside their native ranges (van Kleunen et al., 2018).

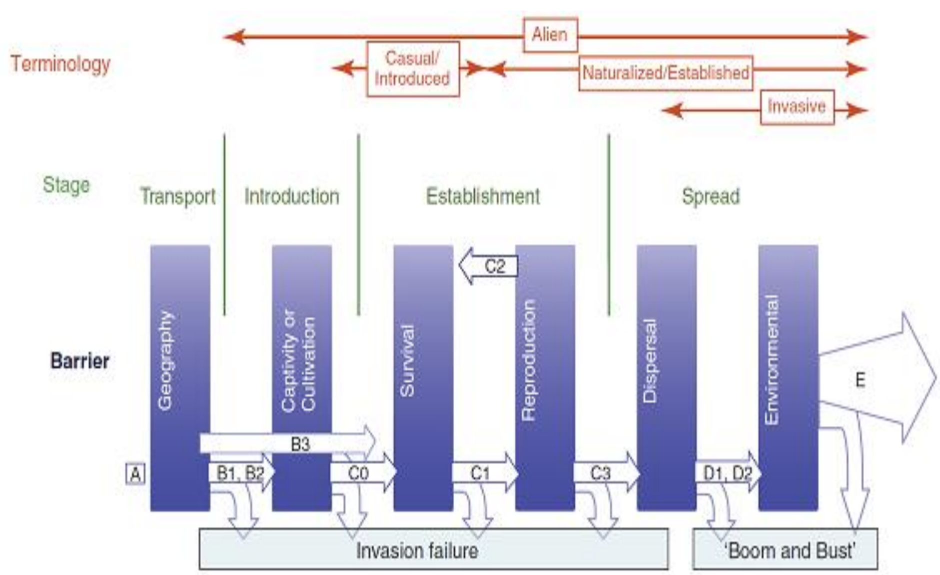
Spread of Alien Invasive Species

- Invasion
  - Introduced species overcome dispersal barriers and cope with the biotic and abiotic factors in the new locale.
  - Thus, the species is able to spread to new localities in their new range.
  - According to Williamson's "tens rule", only 10% of introduced species will make the transition from one stage to the next in the invasion process.

Spread of Alien Invasive Species

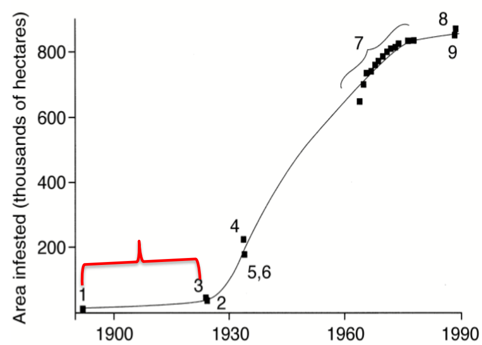
- Invasion
  - Consequently, only 1% of introduced species do become invasive.
  - E.g., 8.6% of naturalized species in Ghana are invasive (Ansong et al., 2019)

Phases of species invasion



Spread of Alien Invasive Species

- The Lag Phase
  - A time lag between introduction (establishment) and naturalization.
  - Population persists in low numbers in a fixed area.
  - Most extinctions of immigrant species occur during this phase.
  - Life/growth form of a species has significant effect on lag phase.



Invader populations in new ranges have been accelerating with pronounced "lag" and "log" phases of spread.

Spread of Alien Invasive Species

- The Lag Phase
  - Three categories of population lag recognized
    - *Inherent lag times* – caused by the nature of population growth and range expansion.
    - *Prolonged lag times* – caused by environmental factors. E.g., soil disturbance, climate change.
    - *Genetic lag times* – caused by genetic factors that improve fitness.

Spread of Alien Invasive Species

- The Lag Phase
  - A lag may result from several factors operating singly or in combination
    - Limits on the detection of a population's growth
      - Inability to detect small and isolated populations.
    - The number and arrangement of infestations of immigrants.
      - Invasion proceeds faster among many small and widely separated infestations or foci compared with a single larger one.
    - Natural selection among established species.
      - Selection pressures may destroy many of the established species.
    - Vagaries of environmental forces.

  - Clearly many species are able to overcome these factors and become established.

Identifying future invaders and vulnerable ecosystems

- What are the major determinants of invasiveness and invasibility?
  - Invasion success is influenced by several biotic and abiotic factors that reflect
    - Propagule pressure
    - Species attributes
    - Ecosystem properties

Propagule pressure

- The number of species added to a new locality.
- Two aspects:
  - Propagule size – the absolute or total number of individuals involved in any one release event.
  - Propagule number – the number of separate release events.
  - Propagule pressure increases as the number of releases and/or the number of individual released increase.
- This is an overwhelming factor in the success or failure of biological invasion.

Propagule pressure

- Quite intuitive—Probability of invasion increases with the initial population size and the number of introduction attempts.
  - Species introduced in larger numbers are more likely to become successful invaders
  - Habitats subjected to a greater seed rain or immigration rain from potential invaders are more likely to become invaded.
- Propagule pressure may confound other factors
  - Accounts for the high prevalence of invasive species near road sides, seaports and airports compared to nature reserves.
  - Large-flowered plants more common as invaders because they are disproportionately selected for imports by horticuralists compared to small-flowered plants.

Species Attributes
Which species are likely to invade?

- Many well-known invaders share certain traits that give them competitive advantage over native species or increase their potential to invade.
  - High reproductive capacity or growth rate
    - *Chromolaena odorata* produces over 6 million seeds annually—60-600 times more than that produced by related species.
    - Vigorous vegetative growth allows a species to spread when isolated and cannot be cross-pollinated. Also allows species to recover from disturbance more quickly through regeneration.

Species Attributes
Which species are likely to invade?

- Allelopathy as a competitive strategy
  - E.g., *Lantana camara* releases phytotoxins that inhibit the growth and regeneration of native species.
- Long-distance dispersal ability
  - Dispersal is an important barrier to species introduction
  - Species with short dispersal ranges often restricted to small areas.
  - Dispersal by humans is an important correlate of successful invasion.

Species Attributes

Which species are likely to invade?

- History of invasiveness or widespread distribution elsewhere
  - Perhaps the best predictor of invasiveness
- Other traits associated with invasive species include
  - Generalist resource use
  - High physiological tolerance
  - Asexual reproduction
  - Taxonomically distinctiveness from native species

Ecosystem Properties

Which habitats or ecosystems are likely to be invaded?

- Geographically isolated ecosystems
  - Evidenced by proliferation of oceanic islands by invaders. E.g., Hawaii, New Zealand.
  - Alien species richness on islands often equal to native plant richness, whereas on continents alien species typically constitute about 20% of native plant richness.
- Disturbed habitats or ecosystems
  - Changes in disturbance patterns increase the susceptibility of habitats to invasion
    - creating empty niches or "safe sites"
    - Disrupt species interaction
    - Increase colonization opportunity
    - Alters resource availability
    - Reduces competitiveness of native species
  - E.g., changes in fire regimes, hydrological cycles, nutrient levels, grazing, etc.

Ecosystem Properties

Which habitats or ecosystems are likely to be invaded?

- Resource availability
  - Fluctuations in resource availability control species invasion.
  - Increase use of limiting resource occuring at higher species richness can be a barrier to invasion.
- Enemy release hypothesis
  - New locales often without the natural enemies (predators, herbivores, pathogens, etc.) of the potential invaders.
  - The invader gains fitness advantage as it can reallocate resources from enemy defense to growth and reproduction.

Ecosystem Properties

Which habitats or ecosystems are likely to be invaded?

- Native species diversity
  - Some authors believe high native species diversity increases habitat resistance to invasion due to boost in competitive ability—biological resistance hypothesis.
  - Others hold the view that high native species richness facilitates invasion.
  - larger areas exhibit greater heterogeneity and tend to support both more native species and more invasive species.
  - This situation has been described as the “invasion paradox”

Impacts of Biological Invasions

- By definition, alien species are associated with negative ecological and economic impacts.

- Measurable and significant changes to ecosystem properties such as species composition and ecosystem functioning.

When do environmental impacts of IAS become significant?

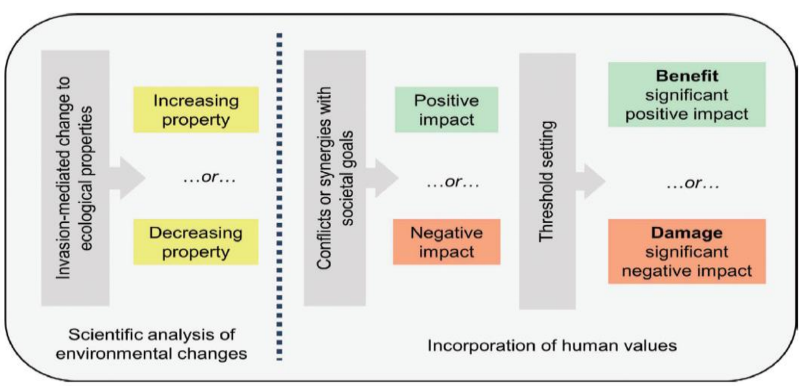


Figure 1. From environmental changes to environmental damages by invasive alien plants. In an assessment approach, invasion-mediated changes become environmental damages or benefits when human values are incorporated. Human values matter in selecting relevant assessment endpoints and categories of impact, in distinguishing mere changes in ecological properties from negative or positive impacts, and in setting thresholds that separate impacts from significant impacts. Only significant negative impacts represent damage or harm (after Bartz et al. 2010).

Bartz and Kowarik, 2019

Impacts of Biological Invasions

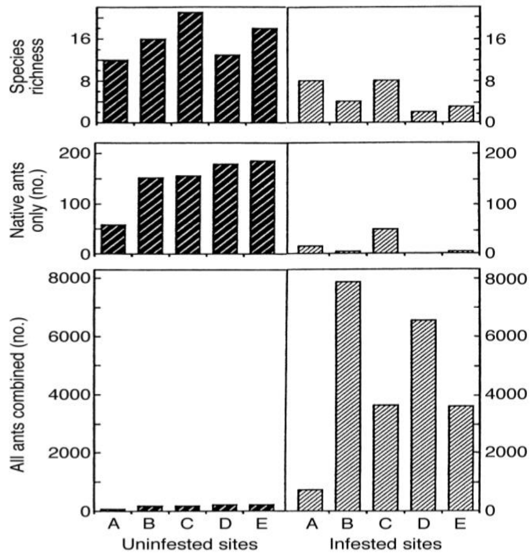
- The adverse ecological consequences of biotic invasions can be grouped into three:
  - Drivers of extinction
  - Modifiers of ecosystem processes
  - Modifers of evolution.

Impacts of Biological Invasions

- Drivers of extinction
  - At a global scale, alien invasions are contributing to a decline in species diversity and homogenization of the Earth's biota.
  - Alien invasive species reduces native species diversity, contributing to their extinction.
    - Introduction of Nile perch (*Lantes niloticus*) in East Africa's Lake Victoria contributed to the extinction of about 200 native cichlid fish.
    - Chestnut blight in America nearly caused the extermination of the American chestnut (*Castanea dentata*)

Ecological impacts of invasions

- Invasion of Brazilian ant in Texas causes a change in native ants composition



Mack *et al*. 2000

Ecological impacts of invasions

- Invasive species may also alter ecosystem processes such as nutrient cycling, fire regimes, hydrological cycles, siltation, etc.
- By altering the environment, invasive species may facilitate further invasion or prevent reestablishment of native species.
- However, these impacts are less widely acknowledge.

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Broussonetia papyrifera controls nutrient return to soil to facilitate its invasion in a tropical forest of Ghana

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Abstract

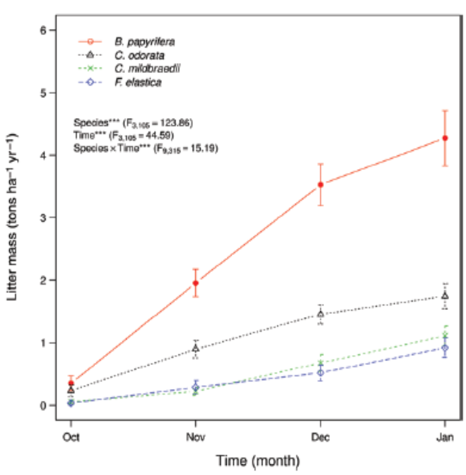
Aims
Non-native invasive plants can alter soil chemistry through litter production and decomposition to facilitate their invasion. However, the important roles of these underlying processes in plant invasion remain poorly understood, particularly in tropical forest ecosystems. Here, we compared litter production, quality and decomposition of two invasive species (*Broussonetia papyrifera* and *Cedrela odorata*) and two co-occurring native species (*Celtis mildbraedii* and *Funtumia elastica*), and soil properties under them to elucidate their roles in the invasion of a tropical forest in Ghana.

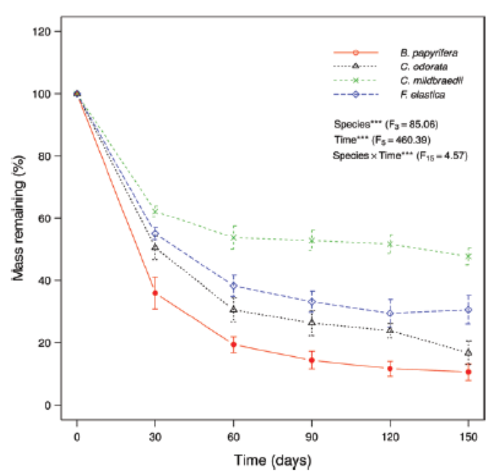
Methods
Leaf litter production rates were determined using 36 mesh traps installed in the study area, while litter quality and soil physico-chemical properties were determined using standard protocols. A 6-month decomposition experiment using the litterbag technique was conducted to compare the decomposition rates of the species.

January; the other species produced … er the same period. In the litterbag expe… d the lowest mass remaining (11–36% … – 51%), *F. elastica* (31–55%) and *C. mildbraedii* (48–62%) in that order. *Broussonetia papyrifera* had the highest nitrogen (3.91%) and phosphorus (0.24%) but lowest lignin (12.20%) concentrations and the lowest C:N (10.87) ratio, indicating higher litter quality compared to the other species. Soil under *B. paprifera* was richest in phosphorus and nitrogen compared to the other species. Overall, our results indicate that the production of more nutrient-rich and rapidly decomposing leaf litter by *B. papyrifera* may constitute an important positive feedback mechanism driving its invasion and impacts in this tropical forest.

Keywords: leaf litter quality, decomposition, Opro River Forest Reserve, paper mulberry invasion, soil nutrient input, *Cedrela*

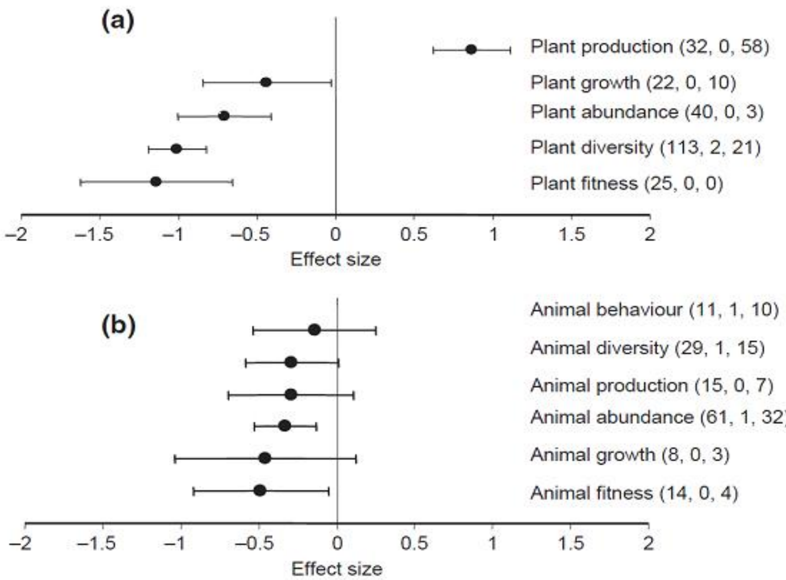
Litter Production and Decomposition of *Broussonetia papyrifera* in Ghana





Anning et al. (2018)

Ecological impacts of invasions



Vilà et al. (2011)

Ecological impacts of invasions

- The most profound impact of alien invasive species may be their effect on evolution, which occurs through:
  - Evolutionary diversification of alien species in their new locales. Invaders drift genetically
  - Evolutionary adaptation of native species to the altered ecological conditions.
  - Hybridization.

Table 1. Examples of ecosystem and community transformations by invasive consumer populations

Species	Transformation	Refs
Introduced herbivores		
Gypsy moth (*Lymantria dispar*)	Nutrient pulses to forest floor, altering soil organic matter dynamics	[83]
Hemlock woolly adelgid (*Adelges tsugae*)	Hemlock replacement by species producing higher quality litter that stimulates nutrient cycling	[83]
Black-tailed deer (*Odocoileus hemionus columbianus* and red deer (*Cervus elaphus*)	Replacement of understory plants by plants producing poor-quality litter, altering nutrient cycling and the soil food web	[84]
	Decline in understory vegetation dramatically reducing arthropods and songbirds	[64]
North American beaver (*Castor canadensis*)	Change in watershed hydrology and nutrient cycling, transforming forests into meadows	[85]
Rabbitfish (*Siganus* spp.)	Reduction of habitat complexity and species richness, and alteration of food webs	[86]
Introduced predators		
Yellow crazy ant (*Anoplolepis gracilipes*)	Dramatic reduction of red crab population, increasing tree seedling density, and reduction of litter decomposition	[87]
Ship rat (*Rattus rattus*), Norway rat (*Rattus norvegicus*), and Arctic fox (*Vulpes lagopus*)	Predation on seabirds thwarting nutrient transfer from ocean to land. Rats change belowground community, nutrient cycling, and decomposition	[88]
	Foxes change soil fertility and transform grasslands to shrub- and forb-dominated ecosystems	[89]
Rainbow trout (*Oncorhynchus mykiss*)	Usurping terrestrial insects falling into streams, causing native char to shift to foraging for insects feeding on bottom algae, increasing algal biomass, decreasing insect emergence and spider populations	[90]
Nile perch (*Lates niloticus*)	Driving over 150 native fish species to extinction, including many phytoplanktivores and detritivores, favoring increased algal blooms and submersed vegetation, and massively increased prawn populations; perch fisheries attracted more humans, further exacerbating eutrophication	[91]
Belowground invasions		
Root pathogenic fungi and oomycetes (notably *Armillaria* and *Phytophthora* spp.)	Causing massive tree death in Australia and California with wide-ranging impacts above- and belowground	[92]
Earthworms	In deglaciated parts of North America lacking native worms, causing loss of organic matter, nutrient mineralization, enhanced plant invasion, loss of rare native species, and altered soil invertebrate communities	[65]
Predatory flatworm (*Arthurdendyus triangulatus*)	In British islands and Faroe islands, depleting lumbricid earthworm populations, reducing soil porosity and drainage, increasing waterlogging, increasing domination by *Juncus*, and reducing mole density	[93]
Invasive bivalves	Providing shelter and substrate, altering sediment chemistry, grain size, and organic matter content by sediment reworking, and increasing light penetration by filter feeding	[94]
Sphaeroma quoyanum (isopod)	In California, creating galleries that reduce sediment stability and increase erosion, ultimately converting saltmarshes to mudflats	[95]

Simberloff et al., 2013

Economic impacts of invasions

- Economic impacts may be separated into damages and costs of control.
- Damages include
  - Damage to infrastructure, crops, pasture, livestock, etc.
  - Damage to ecosystem services
- Annual economic costs of alien invasive species has been estimated at $120 billion in the USA alone (Pimentel et al., 2000).

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Alien Plant Species Invasion in Ghana

- The spread of invasive alien plants is an age-old phenomenon in Ghana.
- Major waterbodies in the country have been impacted by invasive species. E.g., Volta Lake, Barekese Dam, Brimsu Water Works, etc.
- A tentative list of 30 plant invasive species has been produced by the CSIR (2002)
- 191 naturalized; 25 invasive plant species in Ghana (Ansong et al, 2019).

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Alien Plant Species Invasion in Ghana

Diversity and distribution of invasive weeds in Ashanti Region, Ghana

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Abstract

Weed invasion presents a serious threat to Ghana's agriculture, forestry and economy, hydropower generation and drinking water supply systems. This notwithstanding, information on the diversity, modes of introduction, spread and impacts of invasive weeds is scanty. This study sought to determine the diversity and distribution of invasive weed species in the humid forest environment of Ashanti Region, Ghana. The study involved field surveys, species identification and sample collections extending from March, 2003 to February, 2004. A total of 43 species belonging to nineteen families, 41 genera and six life/growth forms were identified in five different habitats namely: cultivated, degraded, aquatic, ruderal and forested. Degraded habitat recorded the highest species richness of 31 species while cultivated and forested had the least numbers of 24 and 22 species respectively. Statistical analysis of the distribution of species in these habitats however, did not show any significant differences ($P > 0.05$), suggesting the susceptibility of most ecosystems in the region to weed invasion. The dominant invasive weeds were *Chromolaena odorata* (L.) King & Robinson (12.71%), *Centrosema pubescens* Benth. (10.42%) and *Rottboellia cochinchinensis* (Lour.) Clayton (6.39%). The results revealed the growing menace of alien weed invasion in the region and the country as a whole.

Key words: abundance, Ashanti, distribution, forest, invasive weeds

Résumé

L'invasion des mauvaises herbes pose une menace sérieuse pour l'agriculture ghanéenne, pour la foresterie et l'économie, et pour les systèmes hydroélectriques et d'alimentation en eau potable. Malgré cela, on dispose de peu d'informations sur la diversité, les modes d'introduction, la dispersion et l'impact des plantes envahissantes. Cette étude a cherché à déterminer la diversité et la distribution des espèces de plantes envahissantes dans l'environnement forestier humide de la région d'Ashanti, au Ghana. Cette étude, qui a duré de mars 2003 à février 2004, comprenait des recherches sur le terrain, l'identification d'espèces et la récolte d'échantillons. On a identifié un total de 43 espèces appartenant à 19 familles, 41 genres et six stades de croissance ont été identifiés dans cinq habitats différents, à savoir des habitats cultivé, dégradé, aquatique, rural et forestier. L'habitat dégradé comptait la plus grande richesse avec 31 espèces, alors que les habitats cultivés et forestiers étaient les moins riches avec 24 et 22 espèces respectivement. L'analyse statistique de la distribution des espèces dans ces habitats n'a cependant pas montré de différences significatives ($P > 0.05$), ce qui fait présumer que la plupart des écosystèmes de la région sont susceptibles de se faire envahir par les mauvaises herbes. Les plantes envahissantes dominantes sont *Chromolaena odorata* (L.) King & Robinson (12.71%), *Centrosema pubescens* Benth. (10.42%) et *Rottboellia cochinchinensis* (Lour.) Clayton (6.39%). Les résultats révèlent la menace croissante que représente l'invasion de plantes exotiques dans la région et dans l'ensemble du pays.

Introduction

The spread of invasive alien plants is an age-old phenomenon in Ghana, and as in many others countries, constitutes a major threat to biological diversity. Invasive species have been partly responsible for reducing the original stretch of tropical forest in the country by about 90% (Council for Scientific and Industrial Research: CSIR, 2002). According to Poku & Agyakwa (2002),

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Alien Plant Species Invasion in Ghana

- Major invasive plant species in Ghana include
  - *Eichhornia crasipes*
  - *Gliricidium sepium*
  - *Leucaena leucocephala*
  - *Chromolaena odorata*
  - *Ceratophyllum demersum*
  - *Lantana camara*
  - *Limnocharis flava*
  - *Broussonetia papyrifera*
  - *Typha latifolia*

About 43 alien plant species have become established in several ecosystems in Ashanti Region Ghana (Anning and Yeboah-Gyan, 2007)

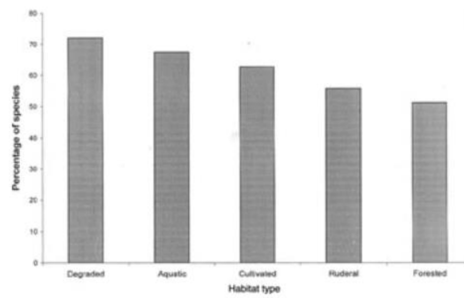

Fig 2 Invasibility of different habitats within the study area

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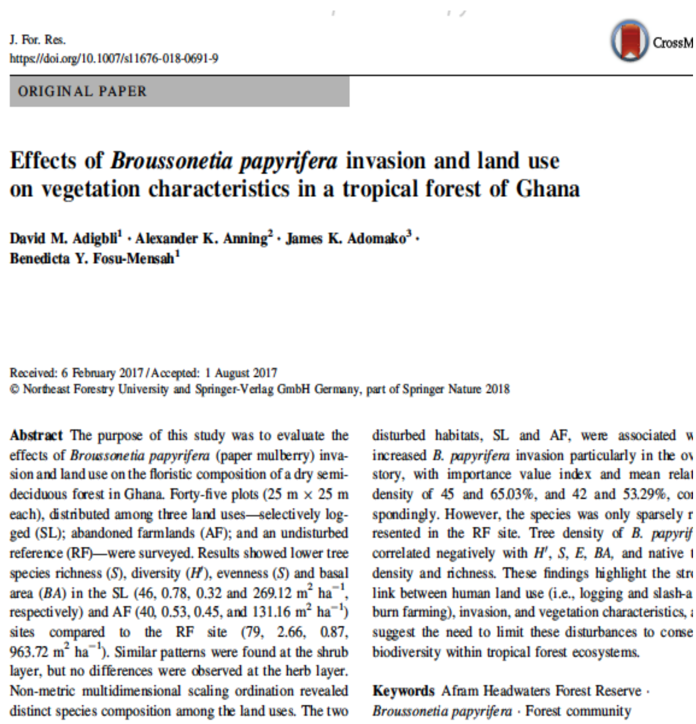
Aquatic invasion of the Barekese dam

Alien Plant Species Invasion in Ghana



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ORIGINAL PAPER

Effects of *Broussonetia papyrifera* invasion and land use on vegetation characteristics in a tropical forest of Ghana

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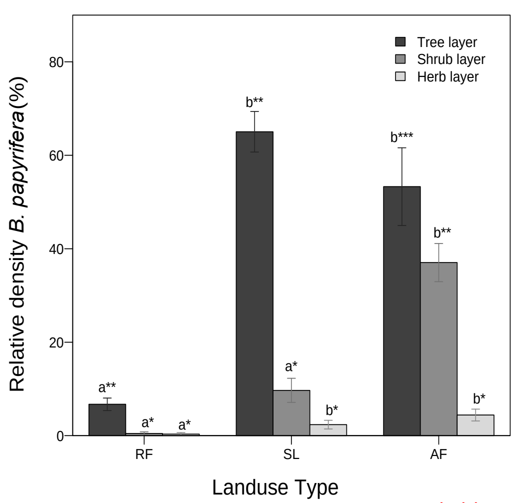
Abstract The purpose of this study was to evaluate the effects of *Broussonetia papyrifera* (paper mulberry) invasion and land use on the floristic composition of a dry semi-deciduous forest in Ghana. Forty-five plots (25 m × 25 m each), distributed among three land uses—selectively logged (SL); abandoned farmlands (AF); and an undisturbed reference (RF)—were surveyed. Results showed lower tree species richness (*S*), diversity (*H'*), evenness (*S*) and basal area (*BA*) in the SL (46, 0.78, 0.32 and 269.12 m^2 ha^{-1}, respectively) and AF (40, 0.53, 0.45, and 131.16 m^2 ha^{-1}) sites compared to the RF site (79, 2.66, 0.87, 963.72 m^2 ha^{-1}). Similar patterns were found at the shrub layer, but no differences were observed at the herb layer. Non-metric multidimensional scaling ordination revealed distinct species composition among the land uses. The two disturbed habitats, SL and AF, were associated w increased *B. papyrifera* invasion particularly in the ov story, with importance value index and mean relat density of 45 and 65.03%, and 42 and 53.29%, co spondingly. However, the species was only sparsely r resented in the RF site. Tree density of *B. papyrif* correlated negatively with *H'*, *S*, *E*, *BA*, and native density and richness. These findings highlight the str link between human land use (i.e., logging and slash-a burn farming), invasion, and vegetation characteristics, suggest the need to limit these disturbances to conse biodiversity within tropical forest ecosystems.

Keywords Afram Headwaters Forest Reserve · *Broussonetia papyrifera* · Forest community

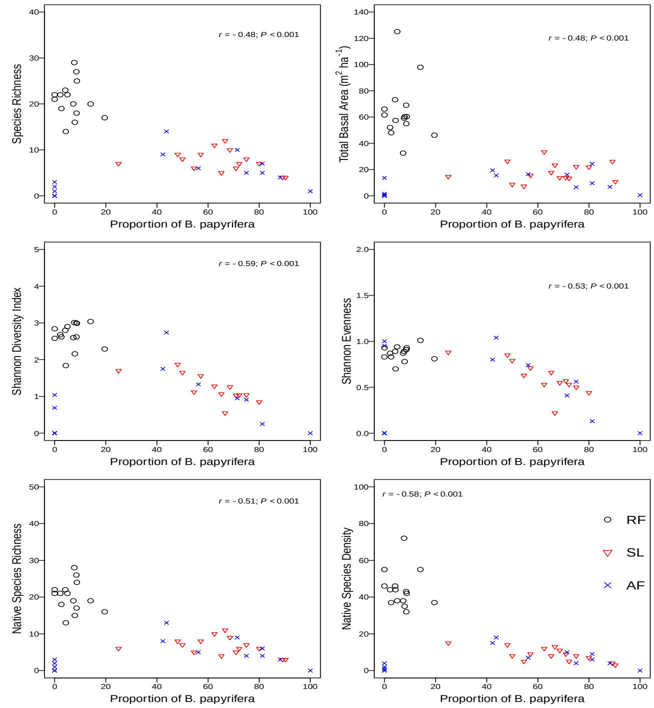
Alien Plant Species Invasion in Ghana

- *Broussonetia papyrifera* invasion in the AHWFR



Adigbli et al. (*2019*)

Correlation Analyses of *B. papyrifera* with some diversity metrics



Adigbli et al. (2019)

Management of Biological Invasion

- Management of alien species invasion is necessary to reduce their impact and prevent further introduction.

Management of biological invasion

The success of management depends on several factors:

Management prospects	Availability of effective and practicable methods (Cacho et al. 2006, Panetta and Timmins 2004)
	Availability of personnel and financial resources within the required time frame (Child et al. 2001, Panetta 2009)
	Size of (potentially) infested area (Rejmánek and Pitcairn 2002, Woldendorp and Bomford 2004)
	Number, detectability, accessibility of infestations (Cunningham et al. 2004, Harris and Timmins 2009)
	Species traits or characteristics that might impede management (Simberloff 2003, Panetta 2009)
	Unwanted management effects (Carroll et al. 2001, Pearson et al. 2016)
	Restorability of affected resources (Jäger and Kowarik 2010, Panetta et al. 2019)
	Cooperativeness of landowners (Gardener et al. 2010)

Bartz and Kowarik, 2019

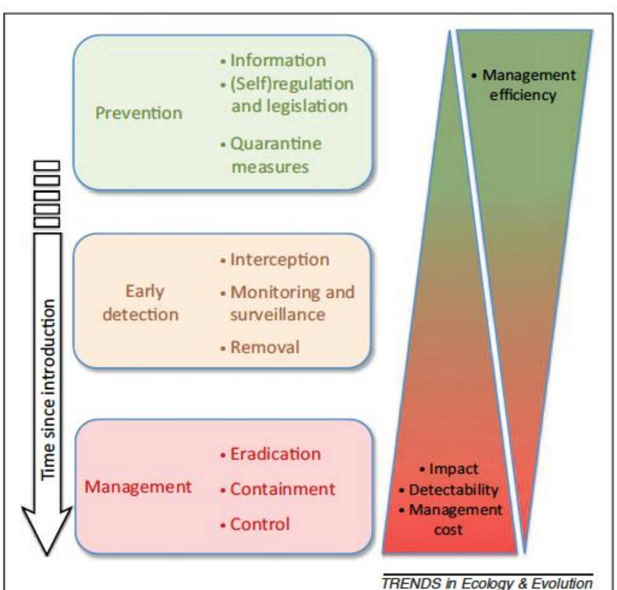


Figure 1. Management strategy against invasive species. The optimal strategy evolves with time since introduction, with management efficiency decreasing and management costs increasing with time since introduction.

Optimal management changes with time since introduction

Simberloff et al., 2013

Management of species invasion

- Prevention is the most effective management method.
  - Quarantine and screening procedures can reduce accidental and unwanted deliberate introductions.
- Once species have become introduced and invasive, the goal becomes control, containment or eradication.
- Strategies include chemical, mechanical and biological controls.