The Impact of Archaeological Clearing on Secondary Succession in a Tropical Rainforest

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ABSTRACT

Disturbance events can often create an environment that allows invasive species to colonize, particularly on susceptible island ecosystems. An increasingly common form are anthropogenic disturbances, which are caused by human interactions with the environment. The 'Opunohu Valley on the island of Mo'orea, French Polynesia experiences continuous disturbance events in the form of forest clearing for archaeological excavations and mapping. This study examined whether archaeological clearing events increased the number of invasive plants during secondary regrowth by surveying four previously clear-cut archaeological sites for invasive vascular plants. There appeared to be no difference across treatments when looking at non-native species, but there was a difference in recent invaders. There was high variation between sites, indicating a possible confounding variable of previous habitation use or number of times cleared which varied across sites. The highest proportion of invasive species were found in a site that was repeatedly cleared for tourism purposes. Cleared archaeological sites overall had no effect on the invasion of non-native species, but may have helped distribute more recent invasive species. Thus, forest management organizations should take more precautions when conducting archaeological clearing and rebuilding prehistoric sites.

Keywords: Biological disturbance, Biological invasion, invasive species, forest clearing, archaeological excavation, tropical rainforest, Mo'orea

INTRODUCTION

Island ecosystems are extremely susceptible to disturbance events due to their isolation and limited size (Fosberg, 1963). Disturbances are defined as relatively discrete events in time that disrupt the ecosystem, community, or population structure and bring about a change in resources, substrate availability, or the physical environment (White & Pickett, 1985). Disturbance events are caused by abiotic, biotic, or anthropogenic factors. Islands, for example, are prone to non-living abiotic factors such as cyclones and floods and biotic factors such as disease (CPF, 2011). Forms of human habitat disturbance include forest clearing, infrastructure development, and agriculture (Hill *et al.*, 2005). After a disturbance occurs, it is common for the composition of the initial secondary growth vegetation to be different than the original vegetation inhabiting a location (Kotanen, 1997). Invasive species often colonize disturbed areas on island ecosystems due to their more generalist nature which allows them to occupy broader niche conditions (Mack *et al.*, 1998). Invasive species can be defined as either "species that [are] non-native to the ecosystem" or species that "cause economic or environmental harm or harm to human health" (ISAC, 2006). These invasive species can have devastating effects on native species and community structure (Sakai *et al.*, 2001). Therefore, it is important to minimize the spread of invasive species, and reducing the amount of human induced disturbances as much as possible may help mitigate the problem.

The island of Mo'orea, French Polynesia, has seen an influx of invasive species in disturbed areas (Hochrein, 2008). These invasive species can be native or introduced, however most are categorized by their ability to outcompete native species and alter traditional forest structure (Sakai *et al.*, 2001). For example, the invasive species *Miconia calvescens* is currently posing a risk to native flora in the forests of 'Opunohu Valley (Meyer, 1996). Species such as *M. calvescens* commonly displace native species and can grow in a variety of different habitats

(Starrs, 2010). And although the fern *Dicranopteris linearis* is native to Mo'orea, it can act as an aggressive invader in disturbed areas (Murdock, 1999). With the expansion of the human population and tourism on the island, invasive species have begun to colonize more areas on the island due to increased construction of roads and trails (Hochrein, 2008). Besides being disturbed areas themselves, these trails can act as pathways for invasive species to spread to more isolated disturbed areas that are easier to colonize (Hochrein, 2008).

Mo'orea has a long history of human-induced disturbance events. Archaeological excavations have been used to uncover past environmental disturbances through the analysis of pollen grains and spores in sediment cores (Kirch, 2002). Excavations revealed that Pacific islands went through drastic ecological transitions after initial Polynesian settlement in 900AD (Kirch, 2002). In Mo'orea, the *Ma'ohi* (the ancestors of indigenous Polynesians) used slash and burn methods to clear the land where they built settlement structures, particularly in the 'Opunohu Valley (Kahn & Kirch, 2014). These structures were used for ceremonial, agricultural, and domestic purposes that corresponded with different introduced plants (Fyhrie, 2011). After European colonization, the valley was only used intermittently and there was vibrant secondary regrowth of Polynesian introduced species such as the Tahitian chestnut, or *Inocarpus fagiferus* (Kahn & Kirch, 2014; Starrs, 2010). There is little record of further disturbances in the valley until the start of archaeological research began in the 1920s. Since then, 'Opunohu Valley has been a popular site for archaeological excavations. Over the past 50 years, more than 300 *Ma'ohi* structures have been mapped by various archaeologists in 'Opunohu Valley (Kahn & Kirch, 2014). Ongoing projects to restore existing archaeological sites are also being undertaken by the French Ministry of Agriculture (Murphy, 2016). Although much can be learned from archaeological sites about the island's ecological history, very little is known about their immediate consequences on local ecosystems.

Archaeological research projects may act as disturbance events due to clear cutting done before mapping and excavation. Over the past two decades, increased tourism and interest in archaeological sites has prompted more forest clearing to make traditional habitation sites visible to the public (Murphy, 2016). Forest clearing may be allowing higher numbers of invasive species to inhabit the forest. It is possible that archaeological clearing is restricting native and traditional plants by allowing invasive species to propagate. A previous study done by Starrs (2010) found that there was no difference in the number of invasive species across various types of habitation sites, however the study only focused on one complex. This study will attempt to test the disturbance effect of archaeological clearing on secondary forest succession by determining if cleared archaeological sites show an increase in invasive plant vegetation.

METHODS

Sampling Sites

This study was conducted September- November 2016 in the Tupauruuru district of the 'Opunohu Valley in Mo'orea, French Polynesia (Fig. 1). Mo'orea is located 17 kilometers away from Tahiti and was formed by a geological hotspot 1.5-2.5 million years ago (Kahn & Kirch, 2014). The 'Opunohu Valley is in the interior of the island and the Tupauruuru district is the east side of the valley (Kahn & Kirch, 2014).

Four previously cleared archeological sites in the 'Opunohu Valley were sampled. Information on past clearing activities of sites was gathered using previous archaeological papers (Starrs, 2010; Kahn & Kirch, 2014; Fyrhie, 2011; Oakes, 1994) and consultations with experts P. Kirch, H. Murphy, and J. Kahn (Kirch, 2016; Kahn, 2016; Murphy, 2016). Each archaeological site had a previously identified paired control site within 50 m that had not been cleared within the past 20 years to prevent drastic differences in ecosystem conditions. Control sites were located with the help of J. Kahn (Kahn, 2016). All sites were located along a trail and therefore should have undergone the same amount of human disturbance post-clearing. The sites are as follows:

1. Site ScMo-171B was originally cleared by the *Ma'ohi* for domestic purposes around 230 years ago (Oakes, 1994). The site was cleared and excavated by Green and Descantes in the 60s and 90s and then by J. Kahn in 2000 and cleared again in October 2016 (Kahn, 2016; Oakes, 1994). Surveying was done before the clearing in October 2016. Ten quadrats were taken at both the site and its control location (described below).
2. Site ScMo-106B was first cleared for ceremonial purposes and a *marae* or sacred site typically with an altar, which was built in the late 17th century (Sharp *et al*., 2010). In 2006, J. Kahn cleared the site, but did not excavate it (Kahn, 2016).
3. Site ScMo-106H was also cleared for ceremonial purposes in the 17th century (Sharp, *et. al.*, 2010). The *marae* was excavated and rebuilt by the French Ministry of Agriculture in 2002 (Eddowes, 2016). The interior of the *marae* was continuously cleared from then until 2009 but has not been cleared since (Kahn, 2016).
4. An agricultural terrace site Southeast of site ScMo-171B was most likely cleared by the *Ma'ohi* for taro cultivation (Fyhrie, 2011). It was last cleared in March 2016 by J. Kahn (Kahn, 2016).

Survey Methods

Within each of the eight-total archaeological and control sites, a 10 x 10 m grid was created and a random number sequence generator was used to determine 30 random quadrat numbers which were then surveyed. An examination of each 1 m^2 quadrat, constructed from pvc pipe, was then done. All the visible vascular plants were recorded with the number of individuals per species within each quadrat. For any unknown species, a picture or sample of the plant was taken and later identified. Non-vascular plants such as bryophytes and liverworts were not recorded. Each plant species was categorized with the help of the Mo'orea Digital Flora Project (Murdock, 1999) using two definitions of "invasive species". The first definition of invasive was defined as "non-native species" and included all introduced vegetation. Species naturalized by prehistoric Polynesians such as *I. fagiferus* was considered "non-native" while non-introduced species such as ferns and *Hibiscus tiliaceus* were considered "native". The second categorized only species that "caused economic or environmental harm" as "invasive". Local authorities and community leaders such as the Ministry of Agricultural and H. Murphy determined these (Murphy, 2016). Quadrats that yielded no plants were disregarded so as not to influence data results. See figure 2 for a complete list of species and their categorization as non-native or invasive.

Statistical Analysis

Statistical analysis' was done for "non-invasive", "native", "invasive" and "non-native" categorizations of plants. For each category, the proportion of individuals per quadrat in cleared treated sites was compared to the undisturbed control sites using a nested ANOVA test in the program "R" (R Core Team, 2016). The relationship between sites was also analyzed using the same method.

RESULTS

Individual Site Findings

In both the control and treatment plots of Site 1, Tahitian Chestnut *(I. fagifer*) was the most abundant species. The control site had 95 total individuals and 6 different species were found. Out of the 95 individuals, 6.3% were determined to be native and 1.1% were invasive. The treated site had 12 less total individuals and 1 more species than the control site. The composition of vegetation was 14.5% native and 18.1% invasive.

Site 2's treated plot survey revealed 13 different species with Basket Grass *(Oplismenus compositus*). Out of the 125 total species, 31.2% were native an 36% were invasive. The control site only had 5 different speicies and *I. fagifer* was the most abundant. There were no invasive species found and 10.4% of the 173 total individuals were native.

The treated plot of Site 3 has 126 total individuals, of which 25.2% were native and 42.1% were invasive. There were 10 different species found and the African Tulip (*Spathodea campanulate*) had the highest density. The control site had 31 more individuals and was comprised of 27.8% native species and 5.6% invasive species. *Inocarpus fagifer* was the most abundant out of the 8 species found.

Site 4 had the most individuals and species diversity of all other sites. Both the control and treated areas were most abundant in ferns. The treated site had 297 individuals, 28.6% of which were native and 29.3% were invasive. There were 16 species found here, the most of any other site. 201 individuals and 13 species were found in the control site. It had the highest percentage of native growth at 40.2% and of the 201 individuals, 17.9% were invasive.

Statistical Analysis

Four nested ANOVA tests were completed to compare the prevelance of invasive species and non-native species. For the number of individuals per species per site, see Figure 2.

When comparing the proportion of non-invasive individuals across treatments, there was no difference found, while a difference was found across sites (ANOVA: $F_{(3,198)}$, $p < 0.01$). Site 4 had a significant interaction and had a lower proportion of non-invasive species when compared to the other 3 sites. At Site 2, the proportion of non-invasive vegetation was lower in the treated plot than the control plot (Fig. 3).

There was also no difference between treatment types when comparing the proportion of native vegetation, but was different between sites (ANOVA: $F_{(3,198)}$, $p < 0.01$). Site 4 had a higher proportion of native individuals when compared to the other sites (TukeyHSD post-hoc comparisons= $p<0.05$). Only Site 2 saw a higher proportion of native species on the treated plot than on the control plot (Fig. 4).

Unlike the other ANOVAs, the proportion of invasive individuals was different between treatments as well as sites (ANOVA: $F_{(3,198)}$, $p < 0.01$). There was high variation between sites. The only significant difference between control and treatment was found in Site 3 and seemed to have a significant effect (TukeyHSD post-hoc comparisons= $p<0.05$). Site 3 was also the only sight with a higher proportion of invasive plants in the treated plot (Fig. 5).

When comparing the proportion of non-native individuals, there was no difference across treatment types (ANOVA: $F_{(3,198)}, p < 0.01$). Site 2 was the only sight that had a lower proportion of non-native vegetation in the treated plot than the control plot (TukeyHSD post-hoc comparisons= p<0.05). Site 4 had a lower proportion of non-native species compared to the rest of sites (TukeyHSD post-hoc comparisons= p<0.05) (Fig. 6).

DISCUSSION

Treated sites appeared to have a higher proportion of invasive individuals, but overall for non-invasive and native plants there was no difference across treatments. This means archeaological clearing seems to have no effect on non-native invaders, but increases the number of recently inroduced invaders. There seemed to be no effect of archaelogical clearing on the proportion of non-native plants as well. The greatest difference was seen between sites, meaning that past land use may have played a large role in forest recovery structure. This was seen in a Fyhrie's study (2011) as well, which determined that prehistoric *Ma'ohi* aboriculture created a lasting change in forest structure.

It is possible that there are multiple factors altering the results of the data. For example, illegal clearing activities for easier forest access have been rampant in many areas of the forest close to archaeological sites. The complex ScMo-106 is believed to be a popular site for clearing activities (Kahn, 2016). It is possible that the control location for Site 3 (Sc-Mo 106H) was cleared earlier in 2016 (Eddowes, 2016). ScMo-106H also has a significantly different clearing history than the other 3 sites. Since the treated site, the *marae*, was continuously cleared from 2000 until 2009 (Kahn, 2016), it experienced repeated disturbance events. This may have caused the influx of invasive species seen in Figure 5. There was also a statistically significant difference between site 3 and the other sites in regards to invasive species.

From personal observation, it appears that cleared areas for trails see more invasive species than areas of archaeological focus. This follows what Hochrein (2008) found: that many forest trails act as pathways for invasive species. This implies there is a method used by archaeological clearing differing from the trail clearing that prevents further spread of invasive species. There could also be a difference in disturbance patterns resulting from more human interaction within trails. Since Site 3 saw repeated clearing, much like trails do, it is possible that the number of times an area is cleared helps determine its susceptibility to invaders.

Although Starrs (2010) found that there was no difference in the number of invasive species across various types of sites. Their findings contrast with the results of this study significantly. Since Starrs' study site (Sc-Mo 124) was at a higher elevation and farther from trails, it was subject to less human interaction, therefore less prone to invasive species. However, personal observation of site SC-Mo 124 six years later showed a high number of invasive species compared to nearby forest growth. This could indicate a recent invasive species event.

More recent clearing events after 2006, appeared to have much more invasive species. This may indicate a more recent introduction of invasive species, causing a higher number within these sites. If sites were cleared during a period of heavy invasive introduction, it may have allowed more to propagate initially. Sites that were cleared earlier may have experienced more native and naturalized secondary regrowth and could have prevented heavy invasive species intrusion. There also seemed to be a widespread knowledge among local communities about the threat of

M. calvescens and ongoing efforts to remove it from the forest, which could have reduced the numbers of the invasive species in surveys.

Although further research should be done to verify the results of this study, the implications of forest clearing seem to be significant. If forest clearing events do encourage the spread of recently introduced invaders, more precautions should be taken when clearing areas of archaeological interest. Archaeological sites that are rebuilt and cleared continuously should be weeded regularly and watched for invasive species. Forest management organizations should put limits on clearing archaeological sites or have a dedicated team to eradicate invasive threats after clearing is done. Illegal clearing activities should also be monitored. Clearing should only be undertaken for immediate excavation purposes to reduce the number of times an area is cleared. Rebuilt pre-historic architecture for tourism purposes should be kept to a minimum or restricted to the edge of forests to prevent further edge effects from occurring deeper in the forest.

Archaeological clearing is a common practice around the globe and in areas highly susceptible to invasive species such as islands, it is important to take precautions to prevent invasive species from inhabiting an area. Since invasive species can be extremely detrimental to local ecosystems, preventing disturbances that help introduce and spread them should be a top priority.

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Figure 1. Map of the study site in ‘Opunohu Valley in the context of Mo’orea, French Polynesia and the Society Islands archipelago. The study area was located in the Tupauruuru district of the ‘Opunohu Valley. This map was originally from Starrs (2010).

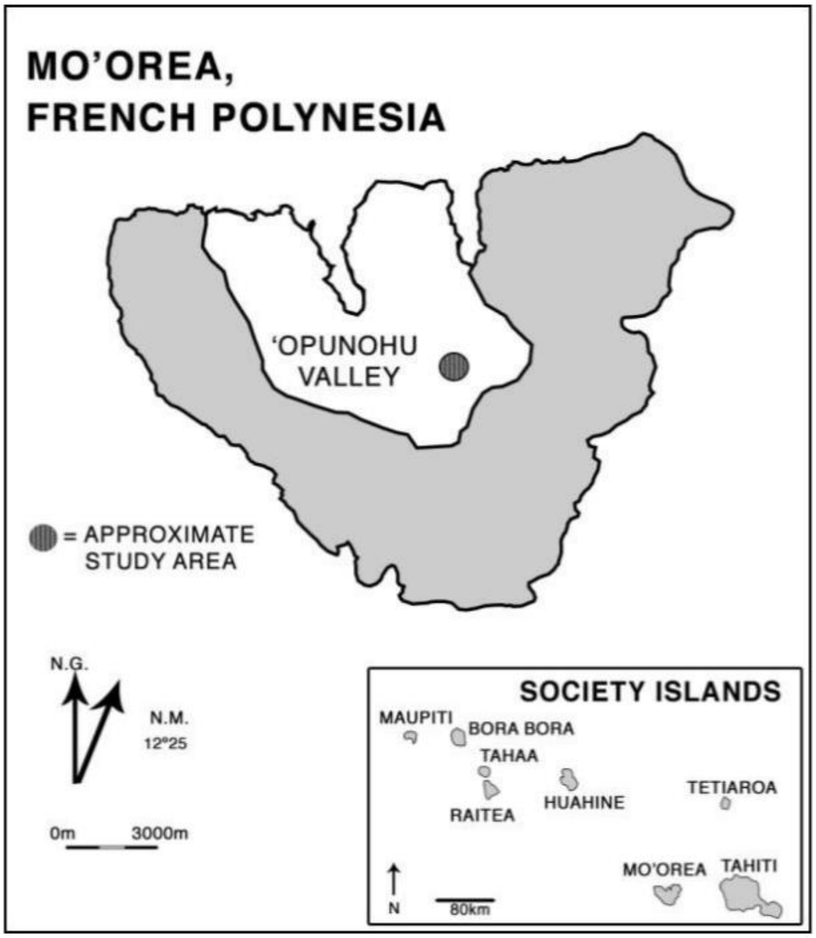

Figure 2. This chart shows the number of individuals per species found at each site as well as how each species was categorized for analysis.

Species	Common Name	Introduced	Invasive	1. Treated	1. Control	2. Treated	2. Control	3. Treated	3. Control	4. Treated	4. Control
Inocarpus fagifer	Tahitian Chestnut	x		2	2	4	3	4	2	3	2
	Seedling	x		52	51	21	142	24	80	3	36
Miconia calvescens	Miconia/ "Purple Plague"	x	x	9	0	1	0	2	0	14	0
Multiple	Weeds	x	x	4	0	0	0	0	0	1	2
Multiple	Ferns			11	6	37	13	23	31	82	73
Zingiber zerumbet	Shampoo Ginger	x		2	31	0	5	0	0	77	34
Angiopteris evecta	Giant Tree Fern			1	0	2	0	1	3	1	4
Psidium guajava	Guava	x	x	2	0	0	0	0	0	0	0
Cordalyne fruticosa	Ti	x		0	1	1	0	1	1	7	6
Annona muricata	Soursop	x	x	0	1	0	0	1	2	3	3
Syzygium malaccense	Malay Apple	x		0	3	4	5	2	1	0	0
Oplismenus compositus	Basket Grass	x	x	0	0	40	0	2	0	67	14
Colocasia esculenta	Taro	x		0	0	5	0	0	0	31	0
Dypsis madagascariensis	Palm	x	x	0	0	2	0	1	5	0	0
Passiflora quadrangularis	Giant Granadilla	x	x	0	0	2	0	0	0	0	0
Syzygium jambos	Rose-Apple	x		0	0	1	0	0	0	0	0
Terminalia cattapa	Tropical Almond	x		0	0	3	0	0	0	0	1
Cananga odorata	Cananga	x		0	0	2	0	0	0	2	0
Hibiscus tiliaceus	Hibiscus			0	0	0	5	0	1	1	2
Spathodea campanulate	African Tulip	x	x	0	0	0	0	34	0	2	17
Aleurites moluccana	Candlenut	x		0	0	0	0	0	0	1	2
Neonauclea fosteri	Mara	x		0	0	0	0	0	0	1	0
Geophila repens	Tohetupou			0	0	0	0	0	0	1	2
TOTAL INDIVIDUALS				83	95	125	173	95	126	297	201

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Figure 3. This box plot shows the proportion of non-invasive individuals to total individuals per quadrat across all 4 sites and their paired control site. Control data is represented by a red outlined boxplot while the treated plot is outlined in blue.

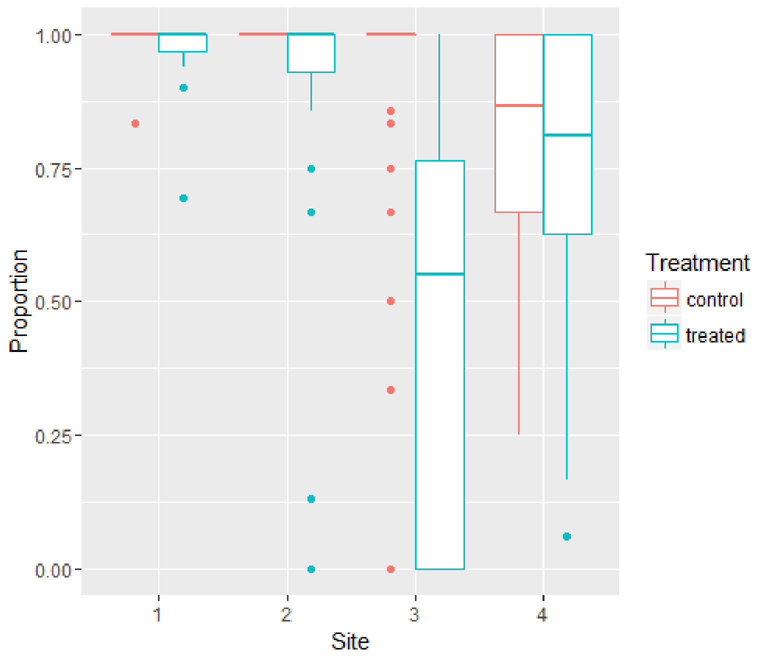

Figure 4. The proportion of native vegetation per quadrat in each site is represented here similar to Figure 3.

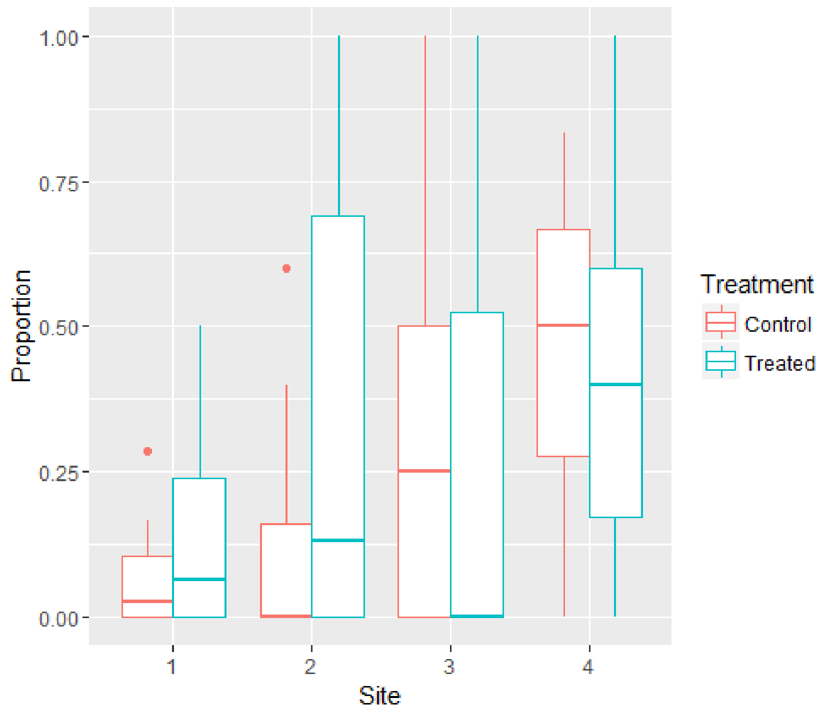

Figure 5. The proportion of invasive individuals per quadrat is represented across sites and treatments.

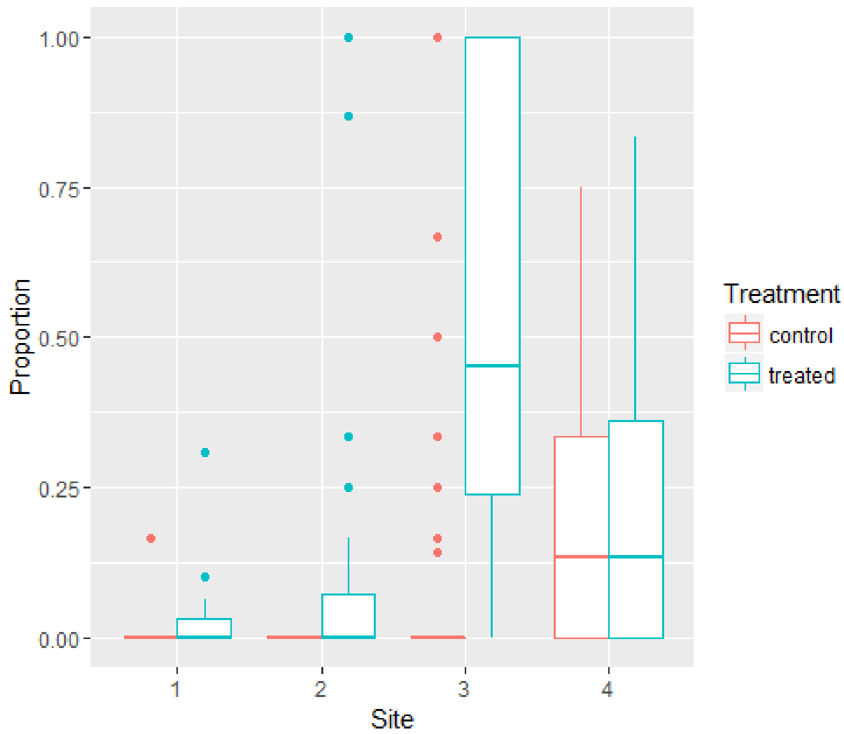

Figure 6. This boxplot represents the proportion of non-native vegetation per quadrat across sites and treatments