



Long-Term Changes in the Dominance of Drought Tolerant Trees Reflect Climate Trends on a Micronesian Island

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Authors' contributions

This work was carried out in collaboration between all authors. Author YS designed the study, collected most of the data, performed the statistical analysis and wrote the protocol. Author MDA help design the study and wrote the first draft of the manuscript. Authors YS and AI managed the analyses of the study. Author AI formulated the species functional attributes. All authors read and approved the final manuscript.

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ABSTRACT

Background: The Ogasawara (Bonin) Islands of Micronesia lie in the western Pacific Ocean and are unique in terms of their isolation, climate, soils and diversity of rare plant species. We hypothesized that the vegetation on the islands will be a robust model system to study long-term climate change impacts on vegetation dynamics.

Methods: A large, long-term vegetation monitoring plot was established on Chichijima Island and measured in 1976 and 2017. It was located in an undisturbed dry forest area that contained many endemic and endangered species.

Results: During the 41 year study period, total basal area of tree species increased by 24.6% and

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was dominated by *Schima*, *Distylium* and *Pouteria*, whereas tree density declined by 30%. Tree genera exhibiting the largest increases in basal area were *Elaeocarpus*, *Ilex*, *Pandanus*, *Pouteria*, *Rhaphiolepis*, *Syzygium* and *Schima*. During the study period, the annual average (23.2°C), minimum and maximum temperatures increased by 0.5 to 0.8°C, respectively. The average annual precipitation was 1276 mm with severe droughts occurring in 1980, 1990 and 2016. The largest increases in the basal area were exhibited in trees species with wide functional distribution and attributes, including drought tolerance.

Conclusions: The results of this study suggest a link between the drought tolerance, species dominance and climate change at the study location. Our unique approach of linking functional attributes with long-term vegetation and climate change can serve as a model for other studies of global change impacts.

Keywords: *Vegetation dynamics; global warming; Bonin Islands; drought; endemic plants.*

1. INTRODUCTION

Climate-change effects on vegetation vary greatly depending on geographic and site locations IPCC [1]. They have been most pronounced in specialized or extreme locations where subtle changes in temperature or precipitation may be greatly magnified. However, vegetation change may lag due plant longevity, plasticity, and resilience, with long-lived trees being among the most recalcitrant. Moreover, climate change has not been uniform, but varies from region to region, thus affecting vegetation communities and attendant plants differently. Confounding things further, the individual elements of climate, including, temperature, precipitation, drought duration, relative humidity, growing season length, etc., can be interactive as well as vary independently of each other. Finally, natural and anthropogenic disturbances have impacted vegetation during the most recent period of climate change (past ≈150 yrs), some of which had profound and long-lasting effects. Thus, climate change has not acted alone in impacting vegetation. In total, present-day vegetation represents an amalgamation of all these phenomena to varying degrees and also by other genetic and environmental factors [2].

Scientific advances often take place when science of one field is merged with another. This type of interdisciplinary research involves the integration of different tools, skill sets, knowledge, and problem solving approaches from complementary disciplines to explore new areas of science. In recent years, research has expanded the knowledge of climate change, human impacts and land-use legacies by merging the fields of tree physiology and vegetation dynamics. This came forth from the realization that the distribution and dominance of each tree species corresponds to an

ecophysiological expression and that long-term change in forest composition is directly relatable to the underlying physiological attributes of component species. This analysis can provide a more robust assessment of the role and impacts of the most important drivers of forest dynamics, namely climate change and land-use history. To gain a sense of relative importance among the principal change factors, this research quantified the effects of climate change on 41 years of tree-census data in island vegetation in Micronesia, in the western Pacific Ocean. We employed a novel methodology in which tree ecophysiological and functional attributes were coupled with long-term changes in species composition and dominance and used for interpretation of global change impacts [3,4].

1.1 The Specific Objectives of This Research

1. Characterize the ecophysiological attributes (drought and shade tolerance and successional status) of the major tree species in the Ogasawara (Bonin) Islands of Micronesia.
2. Use long-term (41 year) records of tree census and climate and land-use data to determine changes in each category.
3. Relate species changes to the corresponding changes in ecophysiological expression.
4. Determine the causal factors for the change in species and ecophysiology, with a special emphasis of changing drought resistance and vulnerability in Micronesian forests.

2. STUDY SITE AND METHODS

The Bonin Islands (Ogasawara-gunto in Japanese) are located about 1000 km south of

Tokyo in the Pacific Ocean. Since 2011, the islands have been listed in the World Natural Heritage sites to conserve the specific ecosystems. The islands are divided into three clusters, Mukojima, Chichijima, and Hahajimaretto (island groups) from north to south (Fig. 1). The basal rocks of the Islands were formed by submarine volcanic activity in the Tertiary. Boninite, a kind of andesite characterized by rich magnesium oxide, chromium, and silica dioxide content, is spread widely. Volcanic breccia covers the boninitelava in some places [5]. The Islands are almost completely surrounded by sea cliffs 50-100 m high. Land with low relief (hilly land) occurs on higher regions above the sea cliffs [6]. A permanent plot used in this study was set on a mountain plateau (230 m a.s.l.) called Chuosan- higashidaira. This area is dominated by *Distylium-Schima* dry forest and scrub, 3-8m high, which is typical vegetation on thin-soiled dry habitat in the Bonin Islands [7]. It includes many endemic species, half of which are designated as endangered species by Japanese Government. *Distylium lepidotum* is the most dominant species, followed by *Schima mertensiana*, *Pouteria obovata*, *Syzygium buxifolium* and *Pandanus boninensis* as subdominants (Table 1). The forest has the highest species diversity of all forest types in the Bonin Islands. The forest where the permanent quadrat was located is unique because many endemic and endangered species remain collectively.

The study site belongs to a national forest. The area was appointed as Forest Reserve by Forestry Agency in 1972 and it was changed to Forest Ecosystem Protection Area in 2007. It has also been included in the sanctuary for endemic animals and insects established in 2003. In addition, this area is incorporated into the World Natural Heritage area in 2011, so the study site has not received direct human impacts at least these 41 years.

The climate is subtropical and maritime (Fig. 2). The annual mean temperature is 22.9°C and has a small temperature range. The annual precipitation averages 1200 mm, including rainy seasons in May-June and October- November and the dry season in midsummer (Fig. 3). The location of the Chichijima Meteorological Observatory is 27.1N, 142.2E at 3 m a.s.l.

A permanent plot (30 mx30 m) was established in 1976 and was investigated using the following

procedure in 1976, 1986, 1997, 2007 and 2017. The plot was divided into 36 sub-plots (5 m x 5 m) which was used as an investigation unit. Each tree in the forest layer (≥ 2 m in height) was measured for diameter at 1.2 m in height for basal area calculations. The density of all trees in the plot, regardless of height (including seedlings and saplings), were recorded in each subplot. Statistical differences in the sub-plot data between 1976 and 2017 was accomplished using T-tests at $p < .05$.

3. RESULTS AND DISCUSSION

Between 1976 and 2017, total basal area of tree species increased by 24.6% and was dominated by *Schima*, *Distylium* and *Pouteria*, (Table 1). During this time, trees declined from 970 to 678 individuals per 900 m². In terms of individual species, tree genera exhibiting the largest increases in basal area from 1976 to 2017 were *Elaeocarpus*, *Ilex*, *Pandanus*, *Pouteria*, *Rhaphiolepis*, *Syzygium*, and *Schima*. Those exhibiting a significant decline in basal area are *Distylium* and *Myrsine*. Tree genera showing the largest decrease in density over the study period were *Distylium*, *Evodia*, *Gardenia*, *Ilex*, *Myrsine* and *Pouteria*. Many trees had increased basal area despite a decline in density.

During the study period, the annual average (23.2°C), minimum and maximum temperatures increased by about 0.5 to 0.8°C (Fig. 2). The average annual precipitation was 1276 mm and included large annual fluctuations as a result of periodic typhoons and droughts (Fig. 3). There were severe droughts in 1980, 1990 and 2016 when May through October precipitation declined to 300 mm or less. In contrast, typhoons in 1989, 1997 and 2005 delivered exceptionally high annual rainfall amounts (> 1650 mm), coupled with high wind. In 1983, a big typhoon hit Ogasawara and resulted in much disturbance to the plot area, although rainfall amounts were not exceptionally high.

When linking forest dynamics to changes in ecophysiological attributes of the study species, the largest increases in the basal area of *Schima*, *Pouteria*, *Rhaphiolepis*, *Syzygium* and *Pandanus* represent an increase in species with wide functional distribution, including drought tolerance. Disentangling disturbance versus climate change effects on vegetation and assigning importance is challenging due to a number of reasons, including spatiotemporal differences (e.g., disturbance can have

Table 1. The name, distribution, maximum height, basal area (cm²) and number of individuals > 2 m height surveyed in 1976 and 2017 in the 30 x 30 m² study plot on Chichijima Island, Micronesia. Basal area and number of individuals data in 2017 with an asterisk are significantly different (p< .05) from that in 1976

Scientific name	Distribution	Max. height (m)	Functional type	Basal area (1976)	Basal area (2017)	#ind. (1976)	#ind. (2017)
<i>Clinostigma savoryanum</i>	Endemic	10	Relatively Wet	2	489*	2	4
<i>Distylium lepidotum</i>	Endemic	10	Drought tolerance	7457	5962*	199	133*
<i>Elaeocarpus photiniifolius</i>	Endemic	15	Relatively Wet	139	493*	14	10
<i>Evodia nishimurae</i>	Endemic(Rare)	6-4	Relatively Wet	1232	1692	17	10*
<i>Gardenia boninensis</i>	Endemic(Rare)	4-1	Semi-canopy tree	30	113*	21	12*
<i>Geniostoma fagraeoides</i>	Endemic(Rare)	6-2	Relatively Wet	144	0*	3	0*
<i>Hibiscus glaber</i>	Endemic	16	Wide range, Drought tolerant	508	450	22	15*
<i>Ilex matanoana</i>	Endemic(Rare)	6-4	Relatively Wet	1574	2186*	41	29*
<i>Juniperus taxifolia</i>	Endemic	5	Drought tolerant	43	64	1	1
<i>Ligustrum micranthum</i>	Endemic	6-4	Wide range, Drought tolerant	139	268*	87	41*
<i>Machilus boninensis</i>	Endemic	8-5	Relatively Wet	86	193*	37	28
<i>Myrsine maximowiczii</i>	Endemic(Rare)	6-5	Relatively Wet	1885	1153*	44	22*
<i>Neolitsea boninensis</i>	Endemic	8-5	Relatively Wet	5	54*	5	10
<i>Pandanus boniensis</i>	Endemic	8-3	Wide range, Drought tolerant	1939	2893*	53	48
<i>Pinus lichuensis</i>	Invasive	20	Drought tolerant	55	36	7	2
<i>Pouteria obovata</i>	Broad area	15	Wide range, Drought tolerant	4269	6083*	120	57*
<i>Psychotria homalosperma</i>	Endemic(Rare)	8-5	Relatively Wet	942	562	16	8*
<i>Rhaphiolepis indica</i>	Broad area	10	Wide range from wet to dry	273	494*	44	32
<i>Syzygium cleyerifolium</i>	Endemic	10	Wide range from wet to dry	1952	3683*	122	104
<i>Schima mertensiana</i>	Endemic	15	Wide range, Drought tolerant	8874	12288*	97	89
<i>Wikstroemia pseudoretusa</i>	Endemic	4-1.5	Drought tolerant	134	303	12	21
Total				31679	39468*	970	678*

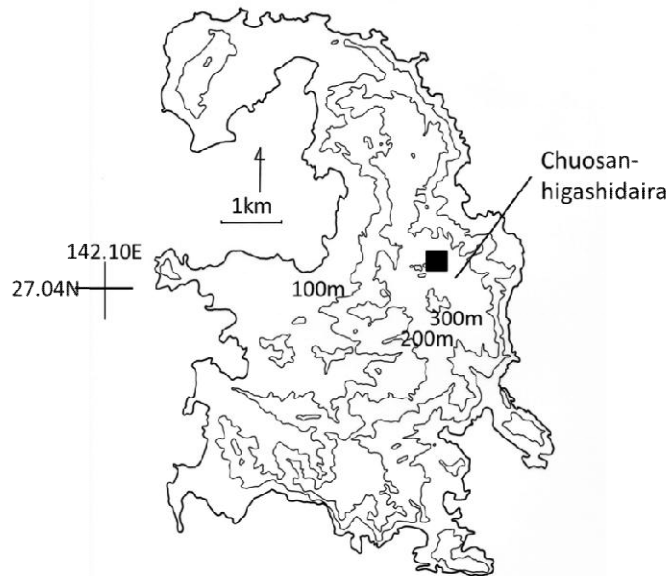


Fig. 1. Location of the study site on Chichijima Island, Ogasawara, Micronesia

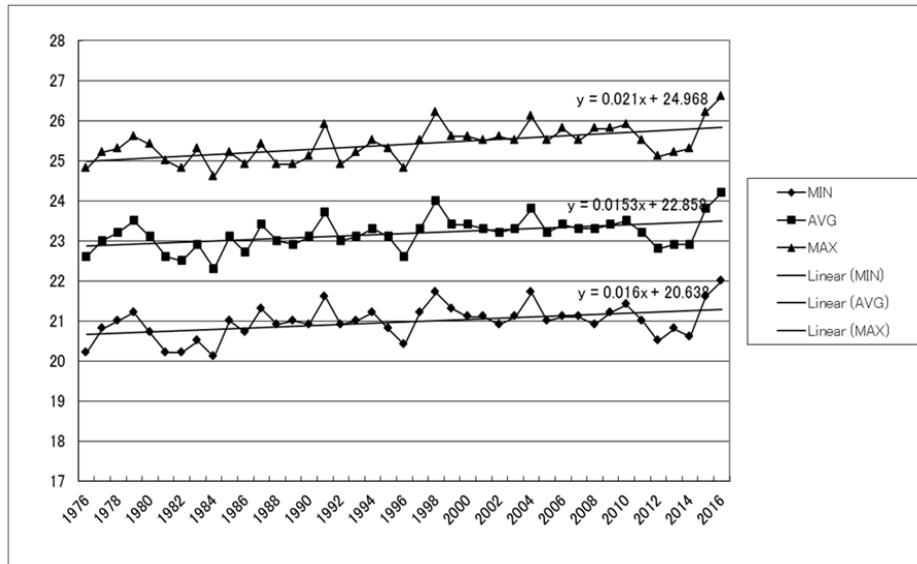


Fig. 2. Mean annual minimum, maximum and average temperature (°C) on Chichijima Island between 1976 and 2016

immediate, dramatic, and long-term impacts whereas climate changes plays out more subtly over longer time scales due to ecological inertia and time-lags). Nevertheless, the results of this research shows on increase dominance of drought tolerant trees species coupled with an increase in moderate to severe droughts and increase in temperature during the 41 year study period.

All tree species (excluding *Hibiscus*) that grow a wide range from the dry ridges to the wet valleys (*Ligustrum*, *Pandanus*, *Pouteria*, *Rhaphiolepis*, *Syzygium* and *Schima*) significantly increased their basal areas in the permanent plot during the last 41 years. The yearly variations of climate and the frequent disturbance caused by large typhoons resulted in fluctuations in resources, such as light and water and nutrients in soil.

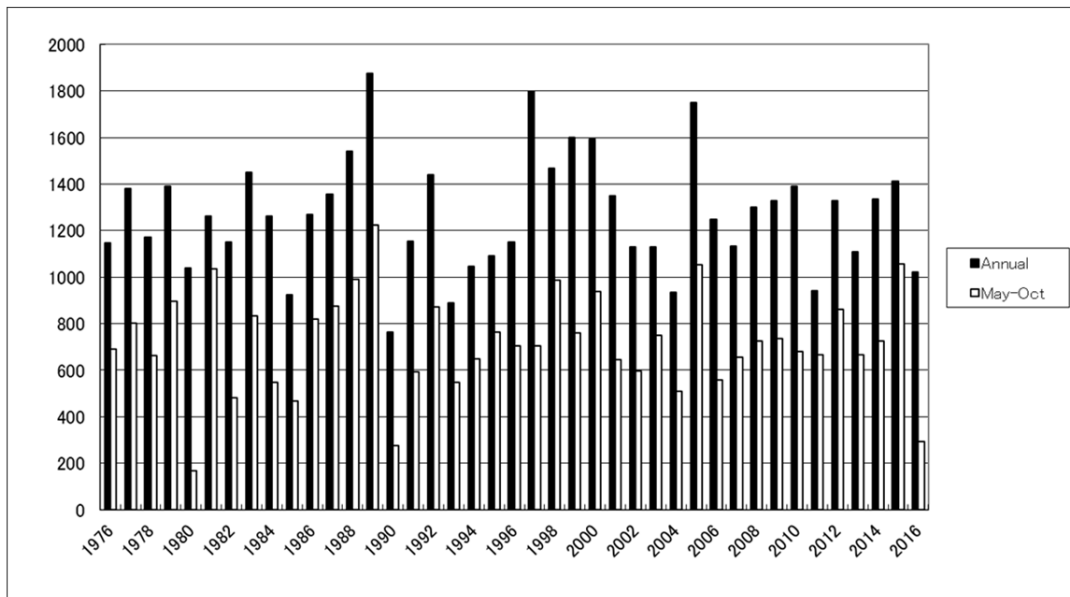


Fig. 3. Annual and May-October precipitation (mm) on Chichijima Island between 1976 and 2016

According to the potted seedling experiments, variation in light, water and nitrogen availability enhances photosynthesis and resultant growth in the specific tree species [8,9,10]. Tree species that grow a wide range of abiotic conditions often can adjust to fluctuations in the environment, resulting in their increase in the dry rides in the islands under climate change conditions.

Distylium, the most dominant species with drought tolerance in this forest, decreased both basal area and individuals in these 41 years. The reason is that this species can endure usual dry climate but it dies of unusually severe drought more easily than other drought tolerant species [11]. Among six rare species which require relatively wet condition, *Geniostoma*, *Myrsine* and *Psychotria* decreased both basal area and individuals during the study period. *Evodia*, *Gardenia* and *Ilex* increased the basal area but they decreased the number of individuals greatly. Therefore, the increase in basal area may not continue long into the future. It can be said that rare species are disappearing from the study site.

The diverse forests of Asia are a reflection of a multitude of ecological settings, climatic conditions, and human interventions and are ideal for this proposed research, mainly due to their vulnerability to climate change and anthropogenic disturbances (IPCC 2014). Much

has been conjectured about the impacts of future climate change on vegetation, yet few have directly assessed the relative importance of climate vs. human-based disturbances as currently expressed in vegetation, particularly in Asia. We conducted this study for a better understanding of the role of climate-disturbance interactions in the vegetation dynamics for a remote and understudied region of the world. Human populations and their role as a disturbing agent in ecosystems have also changed dramatically along with the recent changes in climate [12]. Comprehending past and future impacts of climate change on vegetation requires a more complete understanding of the human-climate-vegetation dynamic. Future research that utilizes the scientific convergence of tree physiology with long-term tree survey data, as outlined in this papers, in other locations and with other disciplines should greatly increase the understanding the global change impacts was we move further into the 21st century.

4. CONCLUSIONS

The results of this study suggest a link between wide functional attributes, drought tolerance, species dominance and climate change at the study location. Our unique approach of linking ecophysiological attributes with long-term vegetation and climate change can serve as a model for other studies of global change impacts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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