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Contrasting Effects of Intensive Cultivation and Paddy Field Abandonment on the Invasion of *Ludwigia grandiflora* (Michx.) Greuter & Burdet in the Lowlands of Manokwari, Indonesia

Pengaruh Kontras Lahan Sawah Intensif dan Lahan Bekas Sawah terhadap Invasi *Ludwigia grandiflora* (Michx.) Greuter & Burdet di Dataran Rendah Manokwari, Indonesia

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Abstrak

Tumbuhan invasif *Ludwigia grandiflora* (Michx.) Greuter & Burdet merupakan ancaman serius bagi ekosistem lahan basah tropis, khususnya lahan bekas sawah yang ditinggalkan. Potensi invasi tumbuhan ini merupakan hasil interaksi antara kapasitas regeneratif melalui jumlah individu, produksi biji, cadangan biji dalam tanah, dan laju perkecambahan. Penelitian ini bertujuan untuk menganalisis kelimpahan individu, potensi cadangan biji, serta laju perkecambahan *L. grandiflora* pada dua tipe penggunaan lahan, yaitu sawah yang digunakan secara intensif dan lahan bekas sawah yang telah ditinggalkan selama lima tahun, di Distrik Sidey, Kabupaten Manokwari, Papua Barat. Kelimpahan diukur menggunakan metode kuadran, sedangkan potensi cadangan biji dan laju perkecambahan dianalisis melalui perhitungan jumlah biji per kapsul serta metode *seedling emergence* pada dua kedalaman tanah. Hasil penelitian menunjukkan bahwa kelimpahan *L. grandiflora* pada lahan sawah intensif berkisar antara 80–160 individu/m^2, sedangkan pada lahan bekas sawah berkisar antara 50–90 individu/m^2. Uji Welch t-test memperlihatkan bahwa kelimpahan *L. grandiflora* antar kedua lahan yang diteliti berbeda nyata ($p<0,05$), begitu juga dengan jumlah biji per kapsul secara signifikan lebih tinggi pada lahan sawah intensif ($p<0,05$). Sebaliknya, lahan bekas sawah memiliki cadangan biji dalam tanah dan tingkat perkecambahan yang lebih tinggi ($p<0,05$) dibandingkan lahan sawah intensif. Sampel tanah pada kedalaman yang lebih dalam menunjukkan laju dan daya perkecambahan *L. grandiflora* yang lebih rendah serta waktu perkecambahan yang lebih lama dibandingkan tanah permukaan. Kelimpahan, produksi biji, cadangan biji tanah, dan laju perkecambahan dapat menjadi indikasi awal tumbuhan invasif *L. grandiflora*. Temuan ini mengindikasikan bahwa aktivitas pertanian, khususnya pemupukan, berperan penting dalam meningkatkan potensi invasi *L. grandiflora* di ekosistem sawah dataran rendah.

Kata kunci: residu pemupukan, gulma, kelimpahan, potensi cadangan biji, perkecambahan

Abstract

The invasive plant Ludwigia grandiflora (Michx.) Greuter & Burdet poses a serious threat to tropical wetland ecosystems, particularly abandoned paddy fields. The invasive potential of this plant results from the interaction between its regenerative capacity, as reflected by population size, seed production, soil seed bank, and germination rate. This study aimed to analyze individual abundance, soil seed bank potential, and germination rates of L. grandiflora across two land-use types, namely intensively cultivated paddy fields and abandoned paddy fields that have been left uncultivated for five years, in Sidey District, Manokwari Regency, West Papua, Indonesia. Abundance was assessed using the quadrat method, while seed production and germination rates were evaluated through seed counts per capsule and the seedling emergence method at two soil depths. The results showed that the abundance of L. grandiflora in intensively cultivated fields ranged from 80 to 160 individuals m^{-2}*, whereas in abandoned paddy fields it ranged from 50 to 90 individuals* m^{-2}*. Welch's t-test revealed that the abundance of L. grandiflora differed significantly between the two land types studied* ($p < 0.05$)*. Likewise, the number of seeds per capsule was significantly higher in intensively cultivated paddy fields* ($p < 0.05$)*. In contrast, abandoned paddy fields exhibited a higher soil seed bank and higher germination rates* ($p < 0.05$) *than intensively cultivated fields. Soil samples from greater depths showed lower germination rates of L. grandiflora, as well as longer germination times, compared with surface soils. The abundance, seed production, soil seed bank, and germination rate can serve as early indicators of the invasive potential of L. grandiflora. These findings indicate that agricultural activities, particularly fertilization, play an important role in enhancing the invasive potential of L. grandiflora in lowland paddy field ecosystems*

Keywords*: fertilization residues, weeds, abundance, seeds bank potential, germination*

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INTRODUCTION

Invasive plants pose a serious threat to tropical ecosystems by rapidly growing, outcompeting native species, and altering ecosystem structure and function. Their presence has been reported to reduce biodiversity [1], act as difficult-to-control weeds [2], [3], and alter water and nutrient cycles [4]. These disturbances increase the risks of hydrometeorological disasters, eutrophication, and soil erosion [5]. Previous studies have shown that invasive plants can thrive in nutrient-poor environments, with their distribution strongly influenced by water availability, light intensity, and soil moisture [4], [6], [7].

Abandoned paddy fields are characterized by low oxygen availability, high soil moisture, and high exposure to sunlight. Vegetation in these areas is typically dominated by grasses, herbaceous plants, lianas, and shrubs less than two meters in height [8]. Intensive land use results in relatively rapid nutrient cycling (N, P, K) within these ecosystems [9]. However, such fields are often abandoned for several years due to declining yields, pest outbreaks that are difficult to control, and poor drainage conditions [10]. Once abandoned, residual fertilizers can accelerate weed growth [11].

One of the dominant weeds in abandoned paddy fields in Sidey District, Manokwari, is *Ludwigia grandiflora* (Michx.) Greuter & Burdet is an invasive species with high environmental adaptability. This plant grows rapidly, produces a large number of seeds per capsule, exhibits high germination rates (>70%), and possesses adventitious roots that enable survival under low-oxygen soil conditions [12], [13], [14]. In addition, *L. grandiflora* produces allelopathic compounds [15], [16], has high biomass production, and is capable of accumulating heavy metals such as cadmium [17] as well as phosphate derived from fertilizer residues [18]. These characteristics further strengthen L. grandiflora's invasion potential in abandoned paddy fields.

The spread of *L. grandiflora* in Manokwari, West Papua, has been rapid because its seeds are easily dispersed by water. In active paddy fields, *L. grandiflora* commonly grows along irrigation channels. In contrast, in open abandoned paddy fields, it can persist for more than three years and potentially produce a substantial soil seed bank. Preliminary surveys indicate high abundance in abandoned paddy fields; however, data on its invasion potential in Indonesia, particularly in the lowlands of Manokwari, West Papua, remain limited. Assessing plant invasion is crucial because invasive species threaten biodiversity. One rapid approach to determining invasion potential is to measure individual abundance, seed production, and soil seed bank potential [19].

Research on the invasive plant *Ludwigia grandiflora* in tropical regions remains limited, with most studies conducted in non-tropical areas [12-16]. More specifically, studies on the ecology of invasive plants in Papua are scarce. The invasive potential of *L. grandiflora* on

Papua Island, Indonesia, has not yet been investigated, despite its high abundance in wetlands associated with abandoned agricultural lands and surrounding canals. Therefore, this study aimed to analyze the abundance, seed production, soil seed bank potential, and germination rates of *L. grandiflora* in the intensively cultivated and abandoned rice fields in the Sidey District, Manokwari, West Papua.

METHODS

Study Site

This study was conducted in the Sidey District, Manokwari Regency, West Papua Province, Indonesia (0°45′0″S, 133°33′32.5″E). This study employed two types of land use: intensively cultivated (IC) and abandoned paddy fields (AP). Data were collected from four experimental units: two intensively cultivated paddy fields and two abandoned paddy fields left uncultivated for approximately 5 years (Figure 1). Intensively cultivated fields were defined as fields used for rice cultivation at least once per year, whereas abandoned fields had not been planted with rice for approximately five years. The total area of the intensively cultivated fields was approximately 1.5 ha, while the abandoned fields covered approximately 0.75 ha.

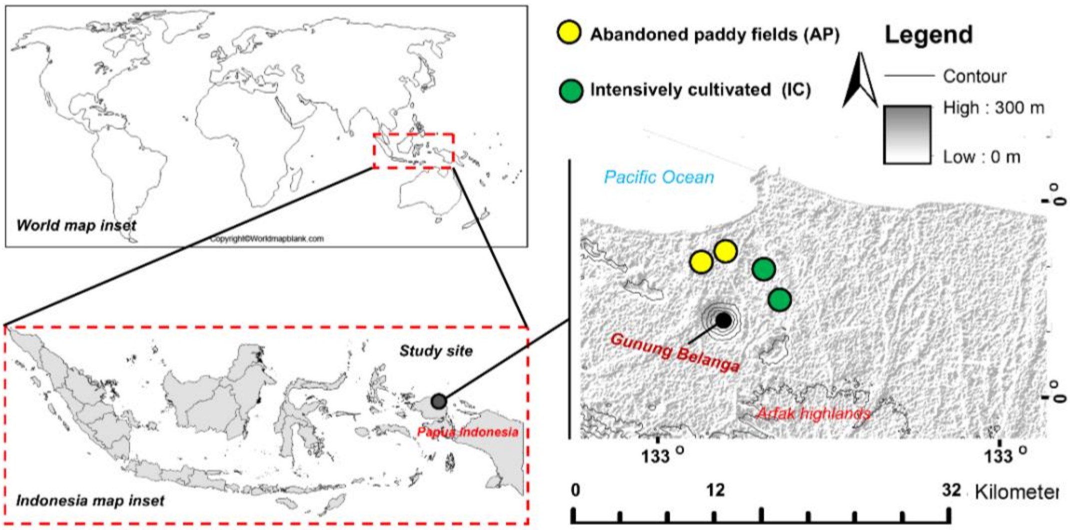

Figure 1. Research location map

Measurement of *L. grandiflora* Abundance

Abundance measurements in this study were exploratory in nature. The abundance of *L. grandiflora* was assessed across four experimental units, comprising two units in intensively cultivated paddy fields and two units in abandoned paddy fields. Within each experimental unit, abundance was measured three times using the quadrat method, resulting in a total of six quadrats for each land-use type.

Quadrats were constructed from PVC pipes with an area of 0.5 m^2 [20]. Quadrats were placed purposively because the study area is relatively homogeneous and dominated by *L. grandiflora*. All individuals of *L. grandiflora* within each quadrat were uprooted and counted. The study assumed a single-factor completely randomized design, with the invaded areas considered relatively homogeneous. A similar quadrat method was also adapted from the previous study by Flory and Clay [21] and Stohlgren [22] on invasive plant species.

Measurement of Seed Production and Soil Seed Bank Potential

Aboveground seed production was estimated by counting seeds from seven randomly selected mature capsules per plot (0.5 m^2). Soil seed bank potential was assessed using the seedling emergence method by excavating soil (30 cm × 30 cm) beneath *L. grandiflora* cover at depths of 0–10 cm and 10–20 cm. Soil samples were incubated at room temperature for 7–28 days under a 12-hour light|12-hour dark cycle. The number of emerging seedlings was recorded throughout the incubation period. This study followed the methodology described by Delange et al. [13].

Data Analysis

First, we validated the data obtained from the field and laboratory. Data preprocessing involved transforming all datasets into Z-scores, which were then used for further analysis. Meanwhile, data visualization was performed using the original, untransformed data.

In the second step, we analyzed the Z-score–transformed data to compare the invasive potential between the two land-use types. Differences in invasion potential (abundance and seed production) between two land-use types were analyzed using a Welch t-test at a significance level of $p < 0.05$. All statistical analyses were performed using R software [23] with the *rstatix* and *ggplot2* packages

RESULTS AND DISCUSSION

Overview of *L. grandiflora* Invasion

This study successfully documented the invasion of *L. grandiflora* in lowland paddy fields in Sidey District, Manokwari Regency, West Papua Province, Indonesia. Intensively cultivated (IC) paddy fields exhibited greener vegetation and more vigorous growth of *L. grandiflora* compared to abandoned paddy (AP) fields that had been left uncultivated for five years. Across all four study sites, approximately 90% of the area was dominated by *L. grandiflora*, as shown in Figure 2, indicating that this species has invaded.

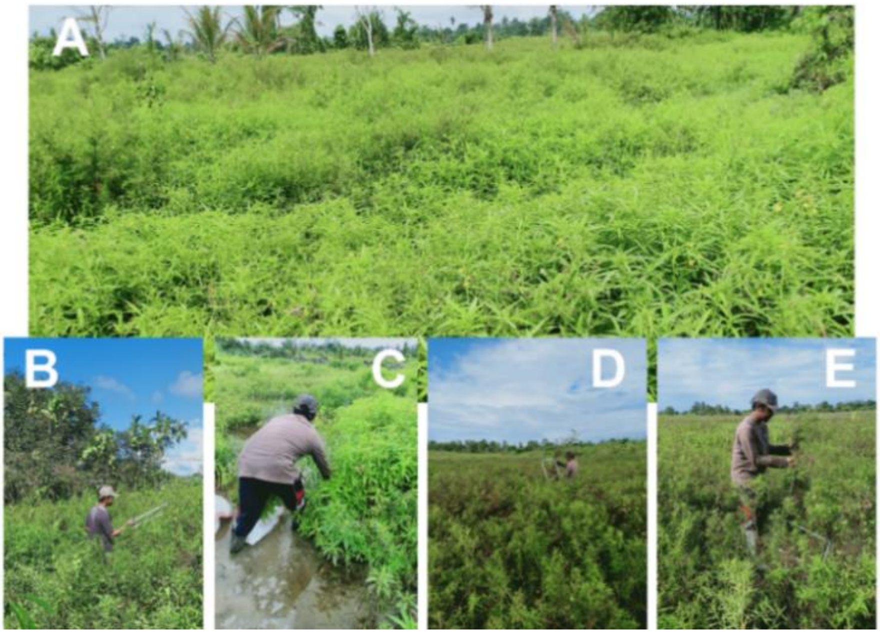

Figure 2. Site conditions of paddy fields dominated by *L. grandiflora*. Notes: (A) *L. grandiflora* stands in abandoned paddy fields; (B, C) intensively cultivated paddy fields (IC); (D, E) paddy fields abandoned for five years (AP)

Abundance of *L. grandiflora*

Although this study was limited to intensively cultivated and abandoned paddy fields, with a relatively narrow sampling intensity, the results showed that intensively cultivated paddy fields (IC) exhibited a higher abundance of *L. grandiflora* than abandoned paddy fields (AP) (Figure 3). An independent samples t-test revealed a significant difference between intensively cultivated and abandoned paddy fields (Welch's t-test: $t = 3.66$, $df = 7.07$, $p = 0.0079$). Abundance among sampling plots in intensively cultivated fields was more variable than in abandoned fields, as reflected by higher standard deviation values. These variations were likely attributable to differences in soil nutrient availability.

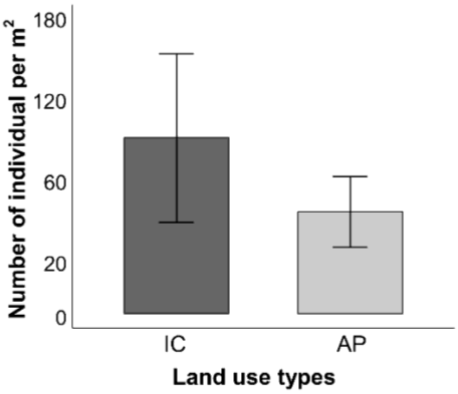

Figure 3. Abundance of *L. grandiflora* under two different paddy field land-use types. Error bars indicate the standard deviation.

Intensively cultivated fields are continuously managed and receive greater inputs of chemical fertilizer residues, particularly nitrogen, phosphorus, and potassium. When such fields are temporarily unmanaged, these residual nutrients may promote the vigorous growth of *L. grandiflora*. In contrast, abandoned paddy fields have generally been left unmanaged for longer periods, during which residual fertilizers may have been leached by water or absorbed by vegetation, resulting in lower soil fertility and reduced plant abundance. Similar patterns have been reported for aquatic invasive plants such as *Phragmites karka* and *P. australis*, whose abundance is strongly dependent ($p<0.05$) on soil nutrient content, particularly nitrogen and phosphorus derived from fertilization residues [7]. Plant invasions are often associated with higher plant–soil nutrient concentrations in otherwise nutrient-poor environments [24]. For example, *Centaurea diffusa* is highly dependent on soil phosphate availability [25], whereas population outbreaks of *Bidens pilosa*, *Microstegium vimineum*, and *Mikania micrantha* are influenced by increased soil nitrate concentrations [26], [27].

The significant differences observed in the abundance of *L. grandiflora* between intensively cultivated paddy fields and abandoned paddy fields may indicate that intensively cultivated fields, once abandoned, are likely to become dominated by *L. grandiflora*. Such dominance may inhibit the growth of other weed species. Both *L. grandiflora* and *L. decurrens* have been reported to produce allelopathic compounds such as loliolide and dehydrololiolide [28], as well as quercitrin, prunin, and myricitrin [15]. These compounds are thought to inhibit the growth of other weeds and suppress seedling establishment, including that of *L. grandiflora* itself, thereby contributing to relatively stable population densities. Further studies are required to elucidate the mechanisms of intra- and interspecific competition within areas dominated by *L. grandiflora*.

Seed Production of *L. grandiflora*

Welch's t-test revealed a highly significant difference between intensively cultivated (IC) and abandoned (AP) paddy fields ($t = 5.29$, $df = 80.12$, $p < 0.001$) (Figure 4). Intensively cultivated paddy fields tended to produce more seeds per capsule than abandoned fields.

These intensively managed fields generally contain higher levels of inorganic fertilizer residues, such as nitrogen (N), phosphorus (P), and potassium (K), which are presumed to influence fruit and seed quality in *L. grandiflora*. In contrast, abandoned paddy fields likely receive lower nutrient inputs from fertilization, resulting in reduced fruit and seed quality.

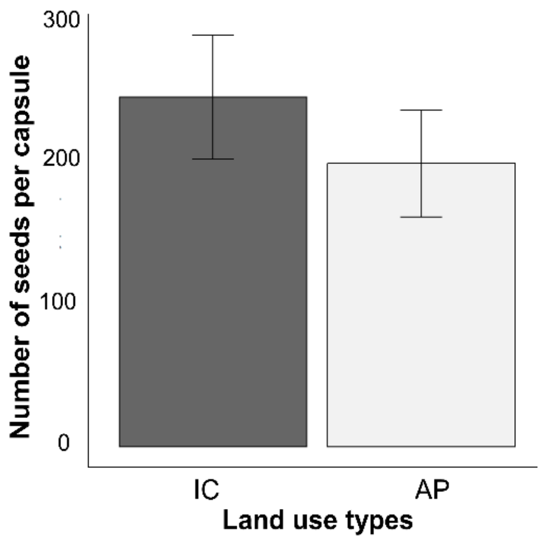

Figure 4. Number of seeds per capsule of *L. grandiflora* under two different paddy field land-use types. Error bars indicate standard deviation.

This study provides improved insight into how plant invasion potential is influenced by seed bank capacity. In the invasive grass *Melinis minutiflora*, seed production and germination rate increase in response to high soil nitrogen and phosphate concentrations [29]. Similarly, elevated soil N, P, and K levels have been reported to dramatically increase seed production in the invasive species *Rumex crispus* and *R. obtusifolius* compared with control treatments [30], [31].

Soil Seed Bank Potential

The seedling emergence method demonstrated that the number of germinated seeds differed significantly between the two study sites ($p < 0.05$). Abandoned paddy fields (AP) exhibited a higher soil seed bank potential of *L. grandiflora* at both soil depths of 0–10 cm and 10–20 cm compared to intensively cultivated (IC) paddy fields (Figure 5). Overall, *L. grandiflora* seeds were more abundantly accumulated in the upper soil layer (0–10 cm) than in the deeper layer (10–20 cm).

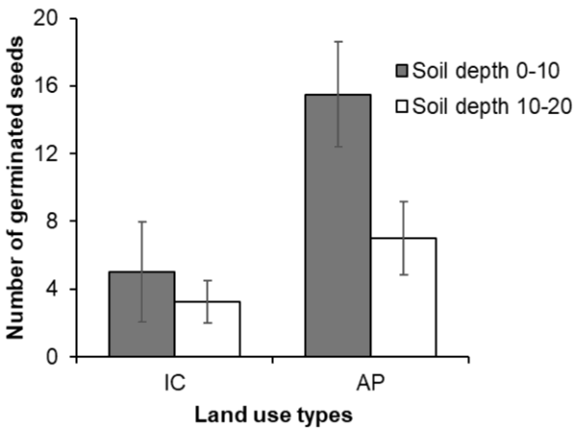

Figure 5. Total number of *L. grandiflora* seeds germinated after a 28-day incubation period under two different paddy field land-use types. Error bars indicate standard deviation.

These results indicate that longer periods of land abandonment lead to greater accumulation of *L. grandiflora* seeds in the soil. Intensively cultivated fields are presumed to have shorter plant life cycles due to mowing, herbicide application, or other weed control practices, resulting in fewer seeds being deposited and stored in the soil. In contrast, abandoned paddy fields tend to undergo natural succession, allowing longer life cycles of *L. grandiflora* and ultimately producing larger quantities of seeds that fall to the soil and accumulate there. In a 15-year successional ecosystem, the invasive plant *Chromolaena odorata* was reported to produce a soil seed bank of up to 300,000 seeds per square meter, increasing exponentially over 10 years [19]. A similar trend has been observed for the invasive species *Acacia dealbata*, which accumulates a persistent soil seed bank over time following forest fires [32].

Seed germination patterns of *L. grandiflora* also differed between the two land-use types. Results from the 28-day incubation revealed that samples from different soil depths exhibited distinct germination rates. Soils from both intensively cultivated (IC) and abandoned paddy fields (AP) at a depth of 0–10 cm exhibited higher germination rates through day 14. In contrast, soils from both land-use types at a depth of 10–20 cm exhibited higher germination rates up to day 21 (Figure 6).

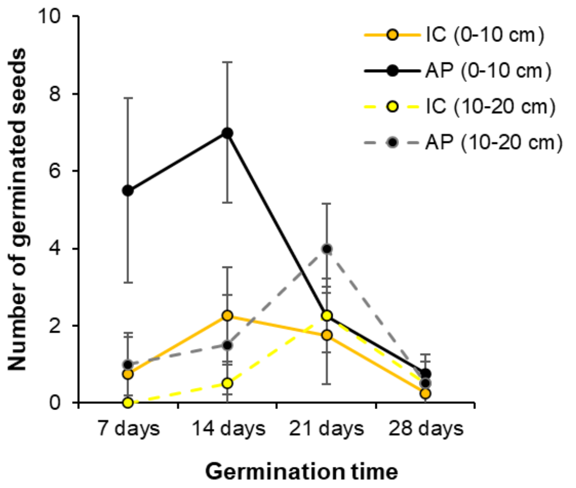

Figure 6. Germination rates of *L. grandiflora* seeds from different soil depths under two different land-use types. Error bars indicate standard deviation.

Soil depth can influence seed dormancy [33]. This study confirms that seeds located near the soil surface tend to germinate more rapidly than those buried deeper. Similar findings have been reported by Benvenuti [34] and Mašková and Poschlod [35], who showed that increasing burial depth reduces germination rates and increases dormancy. These effects may be associated with hypoxic conditions, lower temperatures, and reduced nutrient availability—particularly phosphorus—in deeper soil layers [36]. Furthermore, abandoned paddy fields tended to exhibit higher numbers of germinated seeds than intensively cultivated fields, likely due to greater seed accumulation, which increases the probability of seedling emergence from the soil.

CONCLUSION

Land-use type significantly influences the abundance, seed production, and soil seed bank potential of *L. grandiflora* in Sidey District, Manokwari, West Papua. Intensively cultivated paddy fields exhibited higher plant abundance and greater numbers of seeds per capsule, whereas abandoned fields showed higher soil seed bank and germination rates. These findings indicate that agricultural activities, particularly fertilization, play an important role in shaping the invasion dynamics of *L. grandiflora* in lowland paddy ecosystems. Therefore, we predicted that intensively cultivated paddy fields are more prone to rapid invasion by *L. grandiflora*.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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