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Performance of Integrated Mangrove-Aquaculture (IMA) in District of Sidoarjo, East Java Indonesia

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Abstract. Indonesia holds 23% of the world's mangroves but has witnessed significant declines, especially on Java Island, in the past 30 years. Ministry of Environment and Forestry (MOEF) data from 2021 reports 3.36 million hectares of mangroves, down by about 1 million hectares. The main reason is conversion to shrimp ponds, totaling around 322,000 hectares according to the Indonesian Shrimp Forum (FUI, 2021). Despite covering 93%, traditional ponds contribute only 29% to national shrimp production, a key export accounting for 40% of fisheries revenue.To mitigate further mangrove loss, the Ministry of Marine Affairs and Fisheries (MAF) targets an annual shrimp production of 2 million tons by 2024 through Integrated Mangrove-Aquaculture (IMA). Introduced in 1978, IMA's productivity remains limited despite evaluations in Sidoarjo District, East Java. Polyculture ponds cultivate shrimp (tiger and vannamei), milkfish, and seaweed, with productivity ranging from 17.9 to 363.8 kg/ha/year for shrimp and additional 1,920 to 14,120 kg/ha/year for seaweed. Mangrove integration primarily occurs on embankments (>95%), covering 5% of the pond area, with few (<5%) on the platform (8%-10% coverage), affecting productivity inversely with farm size due to limited farmer management capability. This article explores IMA implementation in Sidoarjo District and suggests improvements for enhanced production.

1 Introduction

Mangrove is a unique ecosystem in coastal areas, with high productivity and serves as a provider of various goods and services for human life. Mangroves act as areas that can attenuate the impact of waves and storms, serving as nursery grounds for various species [1]. Globally, despite covering only 0.05% of the Earth's land, mangroves make a substantial

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contribution by capturing 14% of the carbon present in coastal ecosystems [2]. The substantial carbon storage capacity of mangroves is closely tied to their capability to sequester both autochthonous and allochthonous organic carbon in the soil over long periods, a phenomenon often termed "blue carbon" [3]. This process involves organic carbon being buried, which helps store carbon in mangrove ecosystems for a long time.

Mangroves cover 16.39 million hectares globally, with 33.8% of this area found in Southeast Asia [4]. Meanwhile, Indonesia boasts approximately 3.4 million hectares of mangroves [5], constituting 20.7% of the global mangrove area and representing the largest mangrove extent in the world. Unfortunately, Indonesian mangroves have significantly decreased over the past 30 years, with Java experiencing a 70% decline in mangrove areas alone. Regions like the east coast of Sumatra were also heavily affected by logging, although precise records are often unavailable, and some areas have recovered. This destruction is primarily due to conversion into shrimp ponds [6]. Described that through deforestation, shrimp farms severely impact the mangrove soil microbial community and its functioning. The consequences are mainly biodiversity and ecosystem services losses, including microbial regulation of biogeochemical cycles and carbon sequestration. Furthermore their study shows the importance of natural mangrove forest recovery, enhancing such ecosystem services by the soil microbial communities.

Shrimp is vital for Indonesia as it commands a large share of the export market, contributing 40% to the total revenue from the fisheries sector. Consequently, the Ministry of Marine Affairs and Fisheries (MAF) has set a target to produce 2 million tons of shrimp in 2024. Meanwhile, according to FUI [7], as of 2021, there were approximately 322 thousand hectares of active shrimp ponds. The majority still consist of traditional ponds (93 %) with production < 400 kg/ha/year, with only about 7 % being semi-intensive or intensive ponds with productivity > 7 – 30 tons/ha/year. Increasing the productivity of traditional ponds is one of the government's strategies and implementing IMT would be a wiser step to boost traditional pond products while simultaneously preventing further damage to mangrove forests. This practice contributes to reducing blue carbon emissions by promoting mangrove restoration, ultimately leading to increased blue carbon sequestration.

The objective of this article is to assess the effectiveness of Integrated Mangrove-Aquaculture (IMA) practiced in the district of Sidoarjo, East Java Province, and to explore methods for enhancing IMA technology.

2 Methods

Data collection involved a multifaceted approach, which included: 1) reviewing research articles and reports from pertinent agencies, 2) conducting on-site visits to coastal aquaculture areas in the Sidoarjo District where the IMA (silvofisheries) concept was implemented, assessing aspects such as pond design/construction, layout, mangrove coverage, irrigation systems, and commodities, and 3) conducting interviews with traditional fish farmers, community leaders, and relevant agencies to gather insights on cultivated commodities, productivity, aquaculture management, and marketing strategies. The entire data collection process was carried out between July and August 2023. The study focuses are mangrove-ponds landscape in coastal area as shown in Figure 1.

The gathered data are analysed descriptively and compared to standard values referenced from literature and field experience.

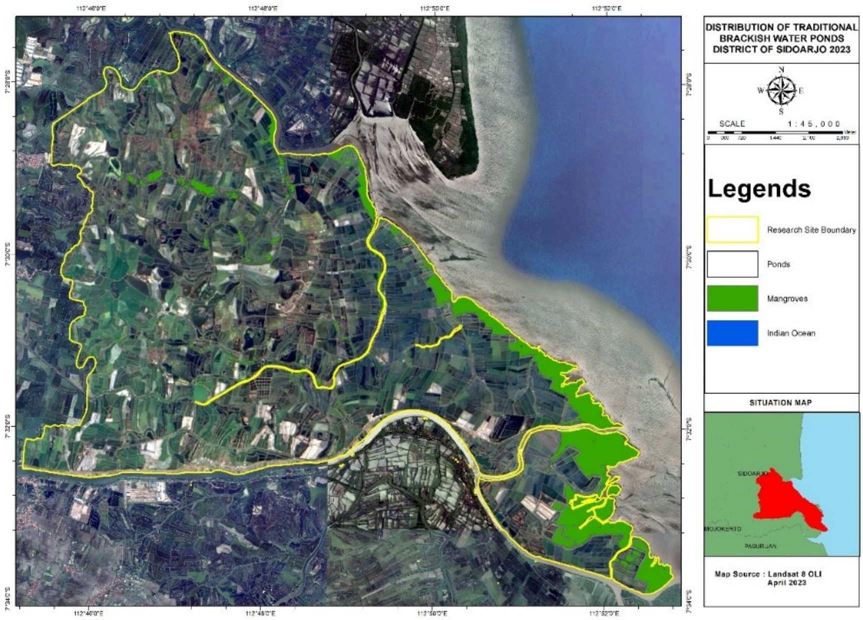

Fig. 1. Study area, mangrove landscape in District of Sidoarjo.

3 Results and Discussion

3.1 Result

3.1.1 Pond Design/Construction

The District of Sidoarjo, covering 21,000 hectares of coastal areas with approximately 21 kilometres of coastline. In the coastal areas of Sidoarjo, there are approximately 15,500 hectares of brackish water ponds. Direct field observations indicate that the existing ponds are constructed in traditional way, characterized by irregular shapes and large sizes: ponds larger than 4.0 hectares (2%), ponds between 3.0 and 4.0 hectares (9%), ponds between 1.0 and 3.0 hectares (68%), and ponds between 0.5 and 1.0 hectares (79 %). In general, the ponds are over 20 years old. The pond construction is illustrated in Figure 2.

The pond construction follows the typical traditional pond design, where the pond body is divided into two based on water depth. The first area is a shallow water region ("plataran" or platform) with a water depth of 15-30 cm, while the second area surrounding the "plataran" is called the "caren," which is 4-6 meters wide with a water depth of around 100-120 cm.

In terms of mangrove planting, two types of IMA/silvofishery ponds are found: a) Ponds with mangroves planted on the embankment with a distance of 1-2 meters from one to each other's. The type of pond is called "open silvofishery" pond, b) Ponds where mangroves are allowed to grow/planted in the middle part of the "plataran" (platform), known as "Empang Parit" silvofishery ponds [8]. Both types of ponds are illustrated in Figure 3. The majority (>95 %) of ponds in Sidoarjo are of the "open silvofishery" type, with only a small portion (<5 %) being of the "Empang Parit" type.

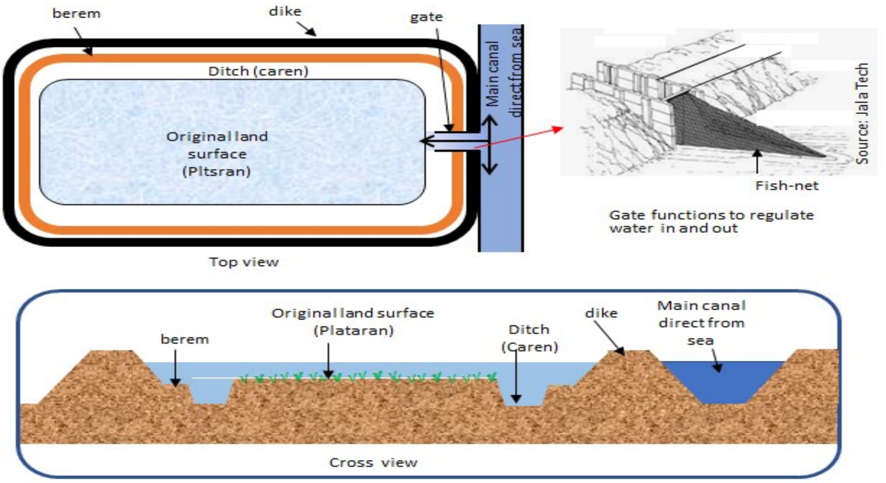

Fig. 2. Schematic of traditional brackish water ponds developed in Sidoarjo.

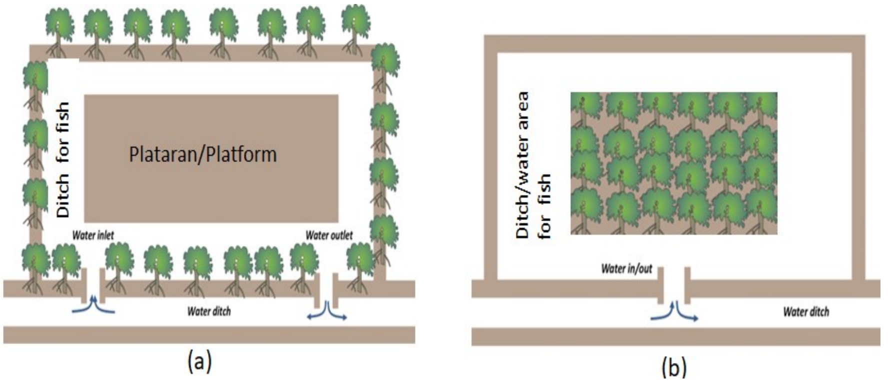

Fig. 3. IMA with "opensystem-silvofisheries" (a) and "empang parit-silvofisheries" (b).

Mangrove trees planted on the embankment cover approximately 5-8 % of the area. Meanwhile, mangroves planted or allowed to grow in the middle of the platform have a coverage area of around 8-10 % (Figure 3). To facilitate the inflow or outflow of water in the ponds, gates made of wood or concrete with dimensions of 1 meter wide and 2 meters high are installed. The number of gates ranges from 1 to 2 units depending on the pond's size, and they are equipped with nylon mesh screens with a mesh size of 100-500 µm (Figure 2).

3.1.1 Irrigation system

A typical unit farm usually consists of a main setlement pond (approximately 600 m2) and several cultivation plots arranged in a series with irregular patterns. Water flows in and out of one plot through another, as illustrated in Figure 4 below.

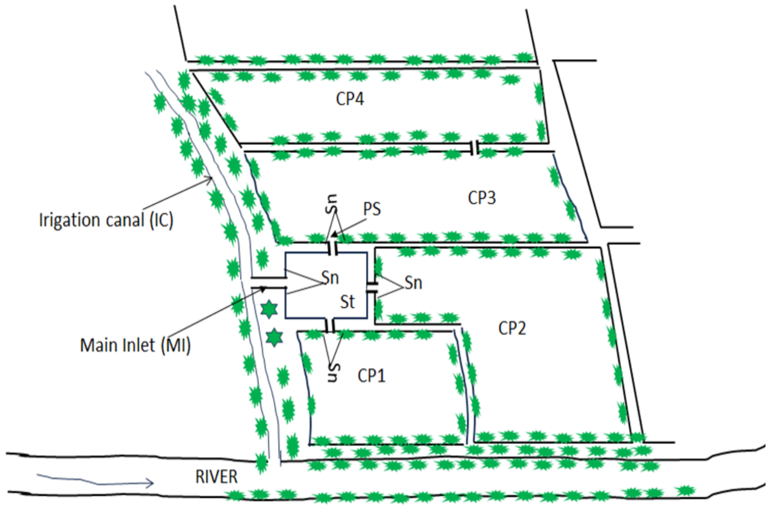

Fig. 4. Layout of traditional IMA ponds. St = setting ponds; PS = secondary gate; Sn = screen net; CP 1-4 = culture pond 1-4.

The position of the ponds relative to the coastline (straight line) varies between 1 and 10 kilometres, but due to the winding channels constructed, longer water channels are created. The length of the channels, measured from the river mouth to the main pond gate, varies from 1 to 12 kilometres. The ponds receive water through irrigation channels relying on tidal energy. The water depth at the main gate during high tide ranges from 85 cm to 170 cm, depending on the distance of the pond from the estuary. This depth condition lasts for 14 to 20 hours, allowing for water exchange during both high and low tides.

3.1.2 Water quality

Throughout the field studies, water quality parameters were sampled randomly from the ponds under investigation. The measured water quality parameters were compared to the standard parameters set by the Department of Marine Affairs and Fisheries (2016), as detailed in Table 1.

Table 1. Water quality of silvofisheries ponds in District of Sidoarjo.

No	Parameter	Unit	Farm 1	Farm2	Farm3	Farm 4	Standard*
1	Salinity	‰	34.3	32.7	26.4	25.3	5 - 40
2	Temperature	°C	34.0	32.3	31.5	32.4	28 - 32
3	pH		6.61	5.4	7.38	7.12	7.5 - 8.5
4	Disolved Oxygen	mg/L	6.2	6.57	5.2	5.5	> 3.0
5	Alkalinitas	mg/L	112.00	97.60	117.60	134.40	100 - 250
6	Orto Fosfat (PO_4-P) +	mg/L	0.079	0.021	0.066	0.136	≥0.1
7	TAN (NH_3-N) +	mg/L	0.051	0.052	0.104	0.154	<0.01
8	Nitrat (NO_3-N)	mg/L	0.223	0.224	0.069	0.080	0.5
9	Nitrit (NO_2-N) +	mg/L	<0,005	<0,005	0.008	0.005	0.01
10	TSS +	mg/L	65	12	<8	61	<50

*Stadard set by Dept of Marine affair and Fisheries Decree No. 75/PERMEN-KP/2016

The importance parameter of water quality such as pH, Dissolved oxygen (DO) and toxic gasses (TAN, Nitrite) are in the range of ideal value for shrimp and fish live. There was not any issue related to water quality.

3.1.3 Comodities and Culture Methods

In Sidoarjo, fish farmers predominantly engage in traditional polyculture aquaculture practices. Many of these farmers receive technical guidance from PT. Alter Trade Indonesia (ATINA), on adopting environmentally friendly cultivation methods. These methods involve avoiding harmful chemicals and refraining from using artificial feed to produce organic fish. PT. ATINA provides a detailed standard operation manual for traditional shrimp culture, covering pond preparation, selection of shrimp/fish seeds, disease control, growth monitoring, and proper harvesting methods to obtain organic products [9].

Most fish farmers (>95 %) cultivate milkfish (*Chanos chanos*) with a stocking density of 0.5 – 1.0 fingerlings/m2, combined with either tiger shrimp (*P. monodon*) at a density of 2.0 – 10 Post Larvae/m2 or white leg shrimp (*L. vannamei*) at a density of 10 – 25 Post Larvae/m2. Only amount of farmers (<5%) cultivate seaweed (*Gracilaria* sp) along with shrimp and fish. Sseaweed requires specific soil conditions, which were not included in the scope of this study. There is no specific land and water preparation, as ponds cannot be completely drained. Milkfish are stocked once a year, while shrimp are stocked twice. Meanwhile, farmers who also cultivate seaweed stock it only once for 1-2 years.

Throughout the cultivation process, the growth fish/shrimp relies solely on natural feed, with no artificial feed used. Water circulation is contingent upon tidal currents, which occur irregularly, typically 1-2 times per week. The fish/shrimp products are asserted to be organic and certified by relevant institutions.

Shrimp and fish are partially harvested (using nets, or other traditional devices) depending on demand and market prices. Shrimp harvesting begins when they reach a weight of 15 grams, which is typically achieved at an age of over 60 days. Meanwhile, milkfish are harvested after reaching a weight of 100 g - 125 g. Interviews revealed that the cultivation yields vary significantly depending on the commodities being cultured, as shown in Table 2**.**

Table 2. Productivity of IMA (silvofishery) based on commodity in District of Sodoarjo.

Items	Values									
	Res*1	Res 2	Res 3	Res 4	Res 5	Res 6	Res 7	Res 8	Res 9	Res 10
Farm size (ha)	4.4	6.6	5.5	12.5	14	5.1	6	7.3	13.7	6.9
Shrimp** (kg/ha/year)	165	174	181.8	100	14.3	40	43	14.7	15	18.8
Milksfish (kg/ha/year)	113	23	182	80	3.6	196	33	28	31	14.6
Total (kg/ha/year)	278	197	363.8	180	17.9	236	76	42.7	46	33.5
Seagrass dry weight (ton/ha/year)	na	na	na	1.92	na	14.12	12	11.06	Na	na

Note: *Res 1-10: responden (farmer) 1-10
** Accumulative tiger and vaname shrimp

For polyculture ponds cultivating milkfish and shrimp, the total productivity varies between 17.9 kg/ha/year and 363.8 kg/ha/year. Meanwhile, for ponds also cultivating seaweed, the productivity ranges from 1,920 kg/ha/year to 12,120 kg/ha/year in additional to fish and shrimp production (Table 3). Generally, the total productivity of fish and shrimp shows a decreasing trend with increasing farm area (Figure 5). The harvest from all commodities is marketed to fish and seaweed processing factories through intermediary traders. They have not encountered any marketing issues so far.

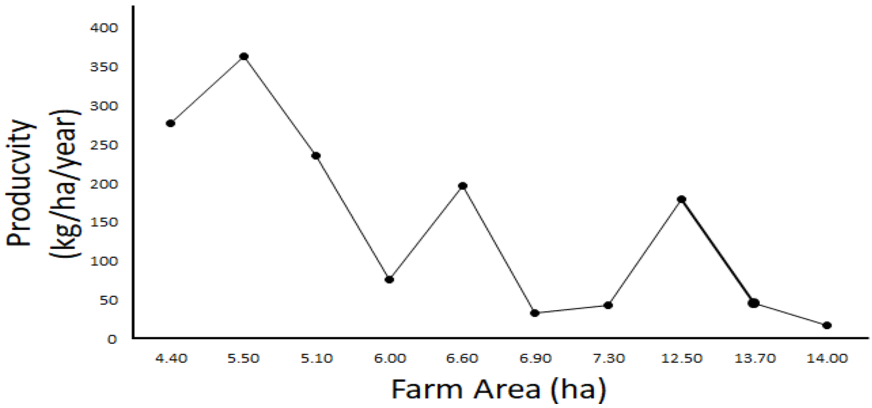

Fig. 5. Productivity of traditional IMA (silvofishery) in Sidoarjo District.

Table 3. Productivities of silvofishery pond in District of Sidoarjao.

Pond size:	1.5 - 16 ha
Harvested commodities:	Mixed: Shrimp, fish, crabs, seagrass
Productivities:	
Shrimp: Shrimp:	72 – 290 kg/ha/year [14] 286 ± 106 kg/ha/year [15]
Mixed:	238 kg/ha/42 day [16]
Mixed:	66.7 – 100.3 kg/ha/4 month [16]
Mixed:	48.7 – 228.7 kg/ha/4 month [16]
This study: Pond size:	 4.4 – 14 ha
Harvested commodities: Mixed Sea grass polyculture	Mixed: Srimp (tiger + vannamei), and Mikfish 17.9 – 363.8 kg/ha/year 1,920 – 14,120 kg/ha/year

3.2 Discussion

Globally, Integrated Mangrove-Aquaculture (IMA) is recognized as a potential solution to address environmental challenges in shrimp aquaculture, such as biotic depletion, eutrophication, soil and water salinization, and water pollution [10, 11]. This practice contributes to reducing blue carbon emissions by promoting mangrove restoration, ultimately leading to blue carbon sequestration. Integrated mangrove-aquaculture (IMA) or silvofishery has been introduced in Indonesia since 1978 by the Department of Forestry, allowing farmers to cultivate fish and shrimp alongside trees [12]. The purposes of this system in Indonesia are to minimize planting costs (the farmer does the planting), increase farmer's income, and conserve the mangrove forest. However, to date, the development of silvofishery remains very limited among traditional fish farmers, less popular compared to intensive ponds. As one of the objectives of implementing silvofishery is to increase mangrove stands, the production targets for silvofishery ponds are still low. Similar conditions have also been reported by several authors from various countries, such as in Vietnam by [13, 14, 15, 16], as presented in Table 2. Similar results were also reported [17] in Cilacap, Indonesia, that the production of silvofishery ponds conducted in Cilacap was 703 kg/ha/year, or about 230 kg/ha/4 months, consisting of milkfish, tilapia, and shrimp.

There is an interesting finding, where the total production tends to decrease as the farm size increases (Figure 4). Since the water quality conditions do not indicate any constraints, and the technical guidance provided by PT. ATINA is written in a very informative and understandable manner, the decrease in productivity in larger farm sizes appears to be more attributable to management capabilities. The larger scale of farm operations will require better management skills, and it seems that the management capacity is still limited.

In their review [4], summarized that the productivity of shrimp in IMA ponds depends on several factors, including farm size, pond size, availability of natural feed (benthos, periphyton, plankton), water quality (pH, dissolved oxygen), and weather conditions (sunlight, rainfall). Additionally, the number of mangrove plants in IMA ponds in Sidoarjo only covers 5 % of the pond surface. There is a high likelihood that the amount of natural feed associated with mangrove ecology is also very limited.

The presence of mangrove trees significantly influences the presence and variation of microbes. They found that shrimp farming ponds' microbiomes have lower microbial diversity and are dominated by halophilic microorganisms, showing high abundance of multiple antibiotic resistance [3]. On the other hand, control mangrove forests, impacted mangroves (exposed to shrimp farming effluents), and recolonization ponds were more diverse, with a higher abundance of genes related to carbon mobilization. This finding strengthens the notion that increasing mangrove coverage will lead to a higher abundance of beneficial microbes. It is also in line with the organic shrimp farming standards formulated, which suggest that the ideal ratio of water area to mangrove in organic ponds should be 50:50 [18].

The demand for shrimp is currently high and is expected to continue increasing in the future. Extensive farming methods, such as IMA, account for 13.3 % of global production but utilize 46% global pond area [19].

Traditional ponds in Indonesia account for 93% of the total pond area but contribute only approximately 29.1% to national production. Augmenting the number of mangroves stands within traditional IMA ponds, as opposed to maintaining only 5 % coverage, signifies a strategic measure aimed at enhancing national shrimp production. Additionally, identified seven types of bacteria with potential probiotic qualities in mangrove and mud underneath, including *Bacillus* sp., *B. subtilis, B. licheniformis, Pseudomonas* sp., *P. pseudomallei, Vibrio alginolyticus*, and *Microccus* sp. These bacteria serve as a high-quality natural feed for shrimp, thereby enhancing the health performance and natural immunity of shrimp/fish [20].

Currently, guidelines provided by PT. ATINA include the use of precultured probiotics, (commercial probiotics) which may be difficult to authenticate. Natural probiotics from the mangrove niche of IMAs ponds would be the preferred alternative to enhance production rates. By planting more mangroves, the aim is to encourage shrimp to consume more probiotic microbes, thereby bolstering immunity, disease resistance, and ultimately increasing production.

4 Conclusion

Integrated mangrove aquaculture (IMA) or silvofishery has long been known to the Indonesian aquaculture community, yet its development has been relatively slow. Despite the productivity of IMA ponds in Indonesia being comparable to the average IMA ponds in other countries, this research indicates opportunities to enhance productivity through the implementation of IMA with the addition of mangrove trees. The presence of mangrove trees is expected to increase the supply of natural feed and probiotic bacteria, thus boosting shrimp immunity, which in turn will increase production. Further research is required to determine the optimal ratio of mangrove stands to ponds water surface and develop methodologies for their planting.

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