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Research Article

Quantification, Monetary Valuation, and Recognition of Mangrove Blue Carbon Assets: An Environmental Accounting Study and Natural Capital Potential in Surumana Village, Donggala Regency

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Abstract: This research aims to internalize the ecological value of Blue Carbon in the mangroves of Surumana Village, Donggala Regency, into an accounting framework based on the principles of Environmental Accounting and Carbon Economic Value (NEK). A descriptive quantitative research method was employed, utilizing Systematic Stratified Sampling (10 x 10 m plots) for field inventory. Above Ground Biomass (AGB) data were calculated using Multivariate Allometric Equations and converted into Carbon Dioxide Equivalent (CO2e) stocks using IPCC standard factors. The subsequent key stage involved Monetary Valuation of the total CO2e using a proxy price from IDX Carbon (IDR 144,000/tCO2e). Physical quantification results indicate that the total CO2e stock stored in the Surumana Mangroves (4.34 Ha) is 28,764.48 Ton CO2e, dominated by the Nypa fruticans species (71.95%). The Monetary Valuation (Fair Value) resulted in a total asset value of IDR 4,141,376,012.67. This valuation figure meets the Level 1 Input criteria in the Fair Value measurement hierarchy (PSAK 113) as it utilizes active market transaction prices.From an accounting perspective, this Blue Carbon stock fulfills the criteria for Biological Assets and is recognized as regional Natural Capital. The recognition of this IDR 4.14 billion asset is essential for supporting the preparation of the regional Natural Resource Balance Sheet (NSA) and enhancing local government accountability. Consequently, mangrove degradation can now be recorded as a measurable impairment of asset value, fostering conservation protection based on measurable economic value.

Keywords: Accounting Framework; Biological Assets; Blue Carbon; Mangrove Degradation; Monetary Valuation

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1. Introduction

The issue of global warming has become a pivotal topic of discussion, drawing significant attention from various parties worldwide. The rise in earth's surface temperature, caused by carbon emissions entering the atmosphere at a higher rate than carbon sequestration by plants, has increased atmospheric carbon concentrations and triggered the greenhouse effect. Global warming is an ongoing natural phenomenon resulting from the greenhouse effect, primarily driven by the increasing concentration of Carbon Dioxide (CO2) in the atmosphere. As a form of climate change, global warming is projected to cause rising sea levels and an increase in extreme weather events.

Given its extensive impact across many spheres of life, environmental issues have evolved into a primary global concern, especially in recent years (SDGs, 2025). Beyond global climate change marked by rising average temperatures, environmental impacts also encompass air pollution, ecosystem degradation, and a lower quality of human life. Therefore, one proposed solution to reduce atmospheric CO2 levels is the rehabilitation of forest vegetation.

Thus far, mangroves are known as abrasion barriers against tsunamis and as vital ecosystems supporting the breeding of fish and crabs; however, they are also recognized for their critical function as carbon dioxide absorbers, which are more effective than rainforests or peatlands (Wihel et al., 2014). Mangrove forests can sequester carbon efficiently through photosynthesis (Kakarika & Yanti, 2025). According to Kauffman et al. (2018), mangrove forests serve as a mitigation effort against global warming due to their function as carbon (C) sinks. Syukri et al. (2018) state that mangrove forests store carbon in biomass, located both above the substrate (leaves, stems, and branches) and below the substrate (roots and sediment), with carbon storage capacity three x greater than almost all other forests on earth.

The mangrove ecosystem is spread across 105 countries and is one of the most productive and beneficial ecosystems for coastal protection (Eddy et al., 2016). Furthermore, mangrove ecosystems provide economic, social, and cultural benefits for coastal communities. Indonesia, Brazil, Malaysia, and Papua New Guinea together account for 50% of the global mangrove ecosystem area (Jakovac et al., 2020). However, globally, between 137–636 km2 of mangrove ecosystems are lost annually, representing 0.16–0.39% of ecosystem loss per year (Easteria et al., 2022).

Knowledge and awareness of the importance of mangroves in sequestering carbon remain relatively limited. Although mangroves cover only 0.4% of the world's forest area, they play a massive role as carbon sinks and storage, ranging from over 4 gigatons C/year to 112 gigatons C/year. Indonesia, which holds 75% of Southeast Asia's total mangrove forests, has yet to optimize their function. Conversely, mangrove forests are experiencing systematic degradation due to human interests. Many mangrove forests have been converted into aquaculture ponds (Prakoso et al., 2023), ecotourism sites, and fishing vessel routes, where the carbon footprints left behind are absorbed by the trees.

The destruction of mangrove ecosystems in Indonesia is categorized as high, threatening carbon stocks over the last six decades (Ilman et al., 2016). The primary causes of mangrove deforestation include urban development, aquaculture, mining, and the overexploitation of timber, fish, crustaceans, and mollusks (Alongi, 2014).

The challenges of global climate change are driving a paradigm shift in entity performance reporting moving from a narrow focus on profit toward a broader accountability for "Planet and People." In this con, the accounting discipline is required to evolve, encompassing the measurement and disclosure of nonfinancial values, particularly environmental ones. Mangrove forests, as storages of Blue Carbon, are a prime example of crucial natural capital. Indonesia possesses 3.3 million hectares of mangroves (KLHK, 2021), yet deforestation rates continue to threaten this climate mitigation potential. When mangroves are converted, the stored carbon assets turn into environmental liabilities in the form of CO2 emissions a loss that often goes unrecorded (Bebbington et al., 2024).

With 3.3 million hectares of mangrove forests (KLHK, 2021), Indonesia is the owner of the largest mangrove area in the world, accounting for approximately 23% of the total global area. This position entails great responsibility as well as significant potential in global efforts to prevent the greenhouse effect. Ecologically, mangrove forests are proven to store up to five x more organic carbon per hectare than inland tropical forests, with the majority of carbon stocks (50–90%) stored in soil sediments that remain stable for thousands of years (Donato et al., 2011).

This potential is officially integrated into Indonesia's commitment through Presidential Regulation No. 98 of 2021 concerning the Carbon Economic Value (NEK), which aims to utilize natural ecosystems, including mangroves, as a means of climate mitigation through domestic carbon trading schemes. The success of Indonesia's mangrove conservation is key to achieving the emission reduction targets (NDC/Nationally Determined Contribution) agreed upon internationally (Murdiyarso et al., 2015).

Despite Indonesia's vast ecological role, the rate of mangrove deforestation and land conversion remains high, largely driven by the failure of conventional economic and accounting systems to recognize the monetary value of stored carbon stocks. This is where Environmental Accounting becomes essential: to internalize ecological values, such as CO2e emission prevention, into measurable economic values.

Sulawesi Island, as one of the islands with the highest coastal biodiversity in Indonesia, holds vast and important mangrove ecosystems. Massive coastal development and mining issues often threaten these ecosystems. Consequently, Sustainability Accounting at the provincial and regency levels in Sulawesi needs to provide reliable quantitative data regarding their natural capital. This data is essential for preparing the Natural Resource Balance Sheet (NSA) in accordance with the SEEA framework, ensuring that regional environmental assets are held accountable.

This research focuses on the mangrove ecosystem in Donggala Regency, specifically in South Banawa District. Geographically, this area is part of the Central Sulawesi coastal hotspot, which is vulnerable to land conversion threats and natural disasters. Therefore, the function of mangrove forests in this region is not only as a carbon sink but also as a physical protective barrier. Specifically, Surumana Village has a mangrove area that serves as the primary pillar of the local coastal ecosystem and is a biological resource utilized by the local community. The quality of the mangrove stands in Surumana, characterized by species diversity and a relatively good stand structure, indicates a significant potential for Blue Carbon storage.

In general, this research aims to internalize the ecological value of Blue Carbon into an accounting framework by applying Environmental Accounting principles in Surumana Village, Donggala Regency. These specific objectives include three main aspects: quantitatively estimating the Above Ground Biomass (AGB) stocks and Carbon Dioxide Equivalent (CO2e) sequestration stored in mangrove stands; performing a monetary valuation of the total CO2e stocks using the IDX Carbon voluntary market price to determine potential asset value; and analyzing the implications of these valuation results in the con of the Recognition, Measurement, and Reporting of Environmental Assets to support the preparation of the Natural Resource Balance Sheet (NSA) and Sustainability Accounting at the local government level.

2. Literature Review

Blue Accounting

The discipline of Environmental Accounting has become crucial in the con of global climate change, demanding a shift in entity performance reporting from a narrow focus on profit toward broader accountability for "Planet and People." Environmental Accounting functions to internalize externalities transforming environmental benefits or losses into measurable economic values recognized in financial records. In a macro con, this recognition is governed by the System of EnvironmentalEconomic Accounting (SEEA), which mandates that natural assets, such as mangrove forests, must be recorded in the Natural Resource Balance Sheet (NSA) in both physical units (tCO2e) and monetary terms. The integration of SEEA is vital for measuring natural capital and sustainability performance at the regional governance level.

In line with Environmental Accounting, the concept of Blue Accounting specifically refers to accounting practices focused on marine and coastal ecosystems, such as Blue Carbon. Blue Accounting aims to internalize Blue Carbon stocks (CO2e) stored in mangrove and seagrass ecosystems as Environmental Assets or Biological Assets recognized on the balance sheet. These assets meet accounting criteria because they can be controlled by an entity (Government or conservation communities) and have the potential to generate future economic benefits through carbon trading schemes. The ongoing destruction or conversion of mangrove land can release stored CO2 emissions, turning ecological assets into environmental liabilities. The launch of Presidential Regulation No. 98 of 2021 concerning Carbon Economic Value (NEK) further strengthens the relevance of Blue Accounting in Indonesia. This regulation legitimizes the utilization of carbon values from natural ecosystems, including mangroves, as a means of climate mitigation through domestic carbon trading schemes (Ardiansyah & Firmansyah, 2022).

Blue Carbon is defined as carbon sequestered from the atmosphere and effectively stored by coastal and marine ecosystems, primarily mangrove forests, tidal marshes, and seagrass meadows (Ward et al., 2025). The primary significance of mangroves lies in their storage efficiency, particularly within sediment layers. Serrano et al. (2023) explain that anoxic conditions (oxygendepleted) in mangrove sediments significantly inhibit the decomposition of organic material, allowing carbon to remain stable over geological xcales. This phenomenon results in mangrove organic carbon reserves far exceeding those of terrestrial forests, making them a key to climate change mitigation (Donato et al., 2011).

Indonesia plays a crucial role as the owner of the world's largest mangrove area. This role is institutionalized through Presidential Regulation No. 98 of 2021 concerning Carbon Economic Value (NEK), which mandates the utilization of natural ecosystem carbon values to achieve National Determined Contribution (NDC) emission reduction targets. However, this commitment faces the threat of deforestation. Azhari et al. (2023) note that continuous mangrove land conversion not only eliminates carbon sinks but also releases stored CO2 emissions, transforming ecological assets into significant Environmental Liabilities.

Therefore, the quantification and valuation of these assets are prerequisites for supporting NEKbased governance.

Mangrove Carbon Quantification

Quantification in mangrove forests is conducted through a Systematic Stratified Sampling design to capture biomass heterogeneity across different zones (Sasmito et al., 2022). Field variables, specifically Diameter at Breast Height (DBH) and Total Height (H), are subsequently used in regression models known as Allometric Equations.An Allometric Equation is a predictive model used to calculate AboveGround Biomass (AGB). The selection of the model must account for species and regional characteristics to minimize bias (Siahaan et al., 2021).

The multivariate equation developed by Komiyama et al. (2005), which incorporates the variables (Wood Density), DBH, and H, has become the established standard for mangrove ecosystems in the Southeast Asian region. The explicit use of the factor enhances accuracy, as variations in wood density between species significantly influence total biomass (Fadillah et al., 2023).Once the AGB is calculated, the results are converted into Carbon (C) stocks using a factor of 0.47 (47% of dry biomass), which is the standard factor recommended by the IPCC (2006). Subsequently, the Carbon is converted into CO2e using a molecular ratio of 3.67. This physical quantification (tCO2e) is the required unit for participation in both international and domestic carbon markets (Simard, 2019).

Blue Carbon Asset Valuation

Environmental Accounting provides a mechanism for internalizing externalities transforming environmental benefits (Blue Carbon stocks) into Environmental Assets recognized in financial records. According to accounting criteria for assets, carbon stocks qualify because they can be controlled by an entity (Government or Conservation Communities) and have the potential to generate future economic benefits through carbon trading schemes.At the macro level, the recognition of Environmental Assets is governed by the System of EnvironmentalEconomic Accounting (SEEA). SEEA mandates that natural assets, such as mangrove forests, must be recorded in the Natural Resource Balance Sheet (NSA) in both physical (tCO2e) and monetary units. Obst et al. (2016) emphasize that integrating SEEA into regional governance is vital for measuring natural capital and sustainability performance.

The launch of IDX Carbon in September 2023, under OJK (Financial Services Authority) regulation, has provided a structured trading platform. The prices formed in this market, regulated by Presidential Regulation No. 98/2021, serve as a proxy for the Fair Value of Carbon Assets, aligning with financial accounting standards such as PSAK 68 / IFRS 13.Griscom (2025) argues that although carbon credit prices are often volatile, recognizing monetary value can be combined with other funding sources (stacking finance) to ensure the sustainability of Blue Carbon conservation projects. Carbon Asset valuation data are essential metrics for Sustainability Accounting and ESG reporting. Isolated tCO2e figures directly demonstrate climate mitigation performance; furthermore, the recognition of the monetary value of these assets supports integrity claims regulated by international initiatives such as VCMI (2025), ensuring that reported climate contributions are backed by valid and measurable data.

3. Research Method

This research employs a descriptive quantitative approach with a case study design focused on the mangrove ecosystem in Surumana Village, Donggala Regency, Central Sulawesi, to internalize Blue Carbon values into an accounting framework. Primary data were collected through a field inventory (November 2025) using a Systematic Stratified Sampling technique within 10 x 10 meter measurement plots. The measured biometric data include Diameter at Breast Height (DBH) and Height (H) for each tree. These data, along with secondary data such as Wood Density () and the IDX Carbon market price, serve as the primary inputs. Data analysis was conducted sequentially: starting with the physical estimation of total Above Ground Biomass (AGB) using the Multivariate Allometric Equation by Komiyama et al. (2005), which was then converted into physical CO2e units using the IPCC factor (3.67). The subsequent key stage is Monetary Valuation, where the total CO2e is multiplied by the domestic carbon market price (IDR 144,000/tCO2e).

Table 1. Operational Variables

Stage	Parameter	Unit	Method	Description
AGB	$0.251 \times D^{2.46} \times \rho \times H^{0.048}$	Ton/Ha	Field Survey	Mangrove Biomass (Komiyama et al., 2008)
C	AGB x 0.47	%	Allometric Formula	Carbon Content (Azzahra et al., 2020)
Carbon Sequestration	C x 3.67	CO2e	Global Wood Density Database (GWDD)	Carbon Sequestration IPCC (2006)
Value	CO2e x Carbon Price	IDR/tCO 2	Global Wood Density Database (GWDD)	Carbon Value (President of the Republic of Indonesia, 2021)

The resulting monetary values are subsequently analyzed from an Environmental Accounting perspective. This analysis aims to provide a justification for the Recognition and Measurement of Environmental/Biological Assets on the local government's balance sheet, in accordance with Fair Value principles. Overall, this methodology transforms ecological data (DBH, H) into financial information (Asset Value) that is relevant for the preparation of the Natural Resource Balance Sheet (NSA) under the SEEA framework, thereby supporting sustainable natural capital based decision making.

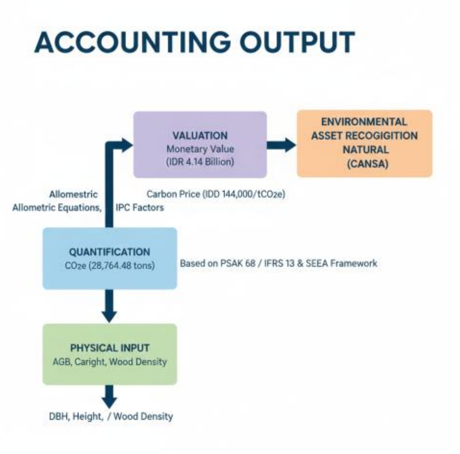

Figure 1. Research Flowchart

4. Results and Discussion

The mangrove ecosystem in Surumana Village is in a relatively pristine ecological condition; however, institutionally, it remains in a weak state. The absence of a management system and environmental asset recording means that mangroves which play a vital role in climate mitigation have never been integrated into the government information system. This gap indicates a structural problem in regional environmental governance, where higheconomicvalue assets are not recognized on the government's balance sheet; consequently, any damage or loss of these assets is never recorded as an environmental loss.

Table 2. Mangrove Ecosystem Analysis Result

Species	Area (Ha)	CO2 Biomass (t/land)	CO2 Sequestration	Nominal Value (IDR/tCO2)	Condition
Bakau (*Rhizophora spp*)	0.91	3,415.18	5,890.84	848,280,788.79	Good
Apiapi (*Avicennia spp*)	0.91	1,041.52	1,796.52	258,699,112.81	Good
Tancang (*Bruguiera spp*)	0.11	19.25	33.20	4,780,359.83	Good
Nipah (*Nypa fruti cans*)	1.14	11,997.48	20,694.46	2,980,001,746.63	Good
Teruntum (*Lumnitzera sp*)	0.34	4.65	8.03	1,155,852.31	Good

Butabuta (*Excoecaria agallocha*)	0.20	5.26	9.07	1,305,499.02	Good
Ceriops (*Ceriops tagal*)	0.18	37.01	63.84	9,192,562.43	Good
Teruntum (*Lumnitzera*)	0.26	7.17	12.36	1,779,776.83	Good
Drini (*Lythraceace*)	0.11	1.85	3.20	460,681.93	Good
Gigi Gajah (*Aegiceras*)	0.07	1.67	2.89	415,869.29	Good
Perepat (*Sonneratia*)	0.11	140.51	242.37	34,900,816.59	Good

This research focuses its observations on a total area of 4.34 hectares of the mangrove ecosystem in Surumana Village, South Banawa District, Donggala Regency. This coastal area features a mangrove ecosystem that remains in good condition, as evidenced by field observations. This stability is vital, as a healthy and stable environment is a primary prerequisite for the accumulation of high biomass and carbon stocks. Within the observed area, the study identified eleven mangrove species, with the largest biomass contributions originating from three primary species: *Nipah* (Nypa fruticans), *Bakau* (*Rhizophora spp*), and *Apiapi* (*Avicennia spp*). The growth characteristics of Nypa fruticans across 1.14 Ha and *Rhizophora spp* across 0.91 Ha serve as the main determinants of the total carbon stock in this region. The dense stand structure, particularly for Nypa fruticans which reached a total of 11,997.48 tons of biomass, serves as an indicator of this ecosystem's success in performing its carbon sequestration function optimally.

Based on the calculation of Above Ground Biomass (AGB) converted using carbon fraction factors and standard molecular ratios, the total CO2e stock stored in the Surumana Mangrove ecosystem (4.34 Ha) reaches 28,764.48 tons. Within this composition, the Nipah species (Nypa fruticans) provides the largest contribution at 20,694.46 tons CO2e, representing approximately 71.95% of the total sequestration. The next significant contribution comes from *Bakau* (*Rhizophora spp*) with 5,890.84 tons CO2e. These high CO2e stock figures physically represent the Carbon Units that serve as tradable objects in the market.

Monetary valuation was conducted by applying the Market Price Approach, multiplying the total CO2e by a proxy price of IDR 144,000/tCO2e (based on Carbon Unit transaction prices on the domestic exchange). Consequently, the total Fair Value of Blue Carbon Assets in the Surumana Mangrove is IDR 4,141,376,012.67. This valuation figure is not merely an economic estimate but a valid and reliable measurement within the con of environmental accounting. This value is supported by PSAK 113 concerning Fair Value Measurement. Utilizing prices from the carbon exchange directly fulfills the Level 1 Input criteria, which provides the most reliable evidence of fair value as it reflects quoted prices in an active market. Therefore, this research successfully provides a measurement methodology that is substantially aligned with prevailing financial accounting standards.

In accordance with the IAI (Institute of Indonesia Chartered Accountants) Financial Reporting Conceptual Framework, the Blue Carbon stock in Surumana meets the criteria for an asset because it holds potential future economic benefits controlled by the Local Government. The legitimacy of this economic value is based on Presidential Regulation Number 98 of 2021 concerning the Implementation of Carbon Economic Value (NEK). From an accounting perspective, this asset can be classified as a Biological Asset and recorded in the regional Natural Resource Balance Sheet (NSA). The recognition of this IDR 4.14 billion asset significantly increases the region's Natural Capital, transforming mangroves from mere maintenance objects (expenses) into productive assets that contribute to the balance sheet.

The results of this study provide clear financial metrics, which are crucial for enhancing local government accountability: (1) With measurable assets, mangrove damage or degradation can be recorded as a financially measurable impairment of asset value. This encourages the government to protect these assets, as conservation failure will be reflected directly as a loss in financial reports. (2) This IDR 4.14 billion value must be integrated into Cost Benefit Analysis (CBA) for any development projects threatening coastal areas. This measurable monetary value provides a strong economic argument for conservation budget allocation and the establishment of incentives for local communities. (3) Valuation based on accounting standards (PSAK 113) and national regulations (Presidential Regulation 98/2021) provide a solid foundation for Donggala Regency to submit proposals

5. Comparison

The results of this study show a carbon stock density of 6,627.76 tCO2e/Ha (derived from 28,764.48 tCO2e per 4.34 Ha). When compared to previous studies, such as Alongi (2014) which estimated average global mangrove carbon stocks, the Surumana ecosystem exhibits a significantly higher sequestration performance, particularly due to the dominance of Nypa fruticans. Furthermore, from an accounting perspective, this research moves beyond traditional ecological studies such as those by Donato et al. (2011) which focused solely on physical quantification. While previous Indonesian studies (e.g., Azhari et al., 2023) higlighted the threat of deforestation, they rarely applied a formal Fair Value measurement based on PSAK 113 or used active market proxies from IDX Carbon.

The integration of Level 1 Inputs (market prices) provides a more robust financial justification than the Replacement Cost or Contingent Valuation methods often used in older environmental economics literature. Thus, this study fills the gap between ecological monitoring and financial reporting, offering a standardized framework for the Natural Resource Balance Sheet (NSA) that is missing in most regional governance models in Central Sulawesi.

6. Conclusions

The results of the physical quantification of Blue Carbon stocks in the Surumana Village Mangrove (4.34 hectares) show a total sequestration of 28,764.48 tons CO2e. This carbon stock is significantly dominated by the Nipah species (Nypa fruticans), which contributes more than 70% of the total stored Carbon Units. The monetary valuation of this asset was conducted by applying a proxy price of IDR 144,000 per CO2e unit from the domestic carbon exchange. The Fair Value calculation resulted in a total asset value of IDR 4,141,376,012.67. This figure clearly represents the economic potential stored as regional Natural Capital.

The measurement of the Blue Carbon asset value at IDR 4.14 billion has been accounting-validated in accordance with the prevailing Financial Accounting Standards (SAK) in Indonesia. The measurement methodology utilizes the Fair Value concept, referring to PSAK 113: Fair Value Measurement. The price of IDR 144,000 used is derived from transactions in an active market (Carbon Exchange), thus fulfilling the Level 1 Input criteria within the measurement hierarchy. Level 1 Inputs are considered the most reliable evidence of fair value and must be used without adjustment, rendering this valuation objective. The validity of this measurement is further strengthened by the official recognition of Carbon Economic Value (NEK) through Presidential Regulation Number 98 of 2021.

The Surumana Mangrove Blue Carbon asset must be recognized in the local government's financial statements as it meets the asset criteria based on the IAI (Institute of Indonesia Chartered Accountants) Conceptual Framework. This asset is classified as a Biological Asset that can be recorded in the regional Natural Resource Balance Sheet (NSA) to increase total regional wealth. Recording this IDR 4.14 billion value drives higher accountability, as any damage to the mangroves will be reflected as a measurable impairment of asset value. Consequently, these valuation results should serve as a basis for development planning, conservation budget allocation, and the mobilization of funding based on measurable economic value.

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Data Availability Statement: The data supporting the reported results, including field biometric measurements (DBH and Height) and carbon calculation spreadsheets, are available on request from the corresponding author. The data are not publicly available due to privacy restrictions regarding the specific coordinates of the community-managed mangrove area.

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