UNIVERSITI PUTRA MALAYSIA

MODELING ABOVE GROUND BIOMASS, SOIL CARBON DETERMINATION AND ECONOMIC VALUE OF CARBON STOCK OF SELECTED MANGROVE SPECIES IN MARUDU BAY, SABAH, MALAYSIA

NORHAJAR ESWANI BINTI MOHAMAD EHSAN

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By

NORHAJAR ESWANI BINTI MOHAMAD EHSAN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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June 2016

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The forest absorbs CO_2 during photosynthesis and stores it as organic material in plant biomass and soil. In Malaysia, accurate information on aboveground and soil carbon in the mangrove forests is lacking. Hence, the objectives of this study were to create allometric model for four selected species namely, *Rhizophora apiculata*, *Bruguiera parviflora*, *Avicennia alba* and *Nypa fruticans* and to estimate the total carbon stock for selected species including the soil carbon. In addition, economic value of each species was estimated using current carbon price. This study was conducted at Marudu Bay mangrove forest, Sabah. Forest inventory, destructive sampling and laboratory analysis for carbon content were conducted to develop the allometric models. The allometric models derived from this study for four selected species were

$$TAGB\ Rhizophora\ apiculata=45.87+0.02\times d^2\ h$$

$$\ln(TAGB\ Bruguiera\ parviflora)=\ln(0.812)+(0.44\times\ln(d^2h))$$

$$\ln(TAGB\ Avicennia\ alba)=0.23+1.02\times\ln(dbh)$$

$$TAGB\ Nypa\ fruticans=0.25+(-2.807e^{(-5)}\times D^2\ L)$$

The results show that the average total aboveground biomass, soil carbon, carbon stock and CO_2 is equivalent for Marudu Bay mangrove ecosystem are namely, 138.18 ton/ha, 225.87 tC/ha, 290.44 tC/ha and 1065.92 ton CO_2e/ha. The carbon storage at Marudu bay is estimated at RM29,999.03/ha for the total mangrove ecosystem based on the REDD$^+$ market price ($5). The study also estimates the economic value of carbon stock in Marudu bay mangroves in relation to different species. The allometric equation developed from this study can be used to assess aboveground biomass in the mangrove forest especially

study without destructive sampling. In summary, modeling aboveground biomass, soil carbon determination and economic value of carbon stock assessment is necessary and that it will provides a protocol and valuable baseline data for monitoring biomass, carbon stock, soil carbon and economic value in the Marudu bay mangrove forest.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMODELAN BIOJISIM PERMUKAAN TANAH, PENENTUAN KARBON TANAH DAN NILAI EKONOMI SIMPANAN KARBON UNTUK SPESIES BAKAU TERPILIH DI TELUK MARUDU, SABAH

Oleh

NORHAJAR ESWANI BINTI MOHAMAD EHSAN

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Hutan menyerap CO_2 semasa fotosintesis dan disimpan dalam bentuk bahan organik pada biojisim tumbuhan dan tanah. Di Malaysia, maklumat yang tepat tentang karbon di permukaan tanah dan karbon tanah masih kurang. Oleh itu, objektif kajian ini dijalankan adalah untuk mewujudkan model alometri bagi empat spesies terpilih iaitu *Rhizophora apiculata*, *Bruguiera parviflora*, *Avicennia alba* dan *Nypa fruticans* serta menganggar jumlah stok karbon untuk spesies-spesies terpilih dan karbon tanah. Selain itu , penilaian ekonomi bagi setiap spesies juga dianggarkan berdsarkan harga karbon semasa. Kajian ini telah dijalankan di hutan bakau Teluk Marudu, Sabah, Borneo. Inventori hutan, pensampelan destruktif dan analisis makmal untuk penentuan kandungan karbon telah dilaksanakan bagi membangunkan model alometri. Model-model alometri yang dijana dari kajian ini untuk empat spesies terpilih adalah seperti berikut

$$\text{TAGB Rhizophora apiculata}=45.87+0.02\times d^2 h$$

$$\ln(\text{TAGB Bruguiera parviflora})=\ln(0.812)+(0.44\times\ln(d^2h))$$

$$\ln(\text{TAGB Avicennia alba})=0.23+1.02\times\ln(dbh)$$

$$\text{TAGB Nypa fruticans}=0.25+(-2.807e^{(-5)}\times D^2 L)$$

Keputusan kajian membuktikan bahawa purata keseluruhan biojisim di permukaan tanah, karbon tanah, stok karbon dan CO_2 untuk ekosistem bakau di Teluk Marudu ialah 138.18 tan/ha, 225.87 tC/ha, 290.44 tC/ha dan 1065.92 tan CO_2e/ha. Penyimpanan karbon di Teluk Marudu dianggarkan pada RM29,999.03/ha untuk keseluruhan ekosistem bakau berdasarkan harga pasaran REDD ($5). Kajian juga menganggarkan nilai ekonomi karbon di hutan bakau Teluk Marudu untuk pelbagai jenis spesies. Persamaan alometrik yang dijana dari kajian ini boleh digunakan untuk menilai biojisim di permukaan tanah untuk hutan bakau terutamanya kajian yang tidak melibatkan pensampelan

destruktif. Secara ringkasnya, pemodelan biojisim permukaan tanah, penentuan karbon tanah dan nilai ekonomi simpanan karbon adalah perlu dan ia dapat memberikan satu protokol dan garis panduan berharga untuk memantau biojisim, stok karbon, karbon tanah dan nilai ekonomi di hutan bakau Teluk Marudu.

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I certify that a Thesis Examination Committee has met on 23 June 2016 to conduct the final examination of Norhajar Eswani binti Mohamad Ehsan on her thesis entitled "Modeling Aboveground Biomass, Soil Carbon Determination and Economic Value of Carbon Stock of Four Selected Mangrove Species in Marudu Bay, Sabah" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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This is to confirm that:
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LIST OF ABBREVIATIONS

AGB	Aboveground biomass
BGB	Belowground biomass
C	Carbon
CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
CH_4	Methane
CHNS	Carbon, Hydrogen, Nitrogen, Sulfur
CO_2	Carbon dioxide
CV	Coefficient of Variance (statistical measure)
DBH	Diameter at breast height
EU ETS	Europen Union's Emission Trading System
FAO	Food and Agriculture Organization
GHGs	Greenhouse gases
ha	hectare
IPCC	Intergovernmental Panel on Climate Change
LN	Natural Log
$Mg\ C\ ha^{-1}$	Megagram carbon per hectare
Mg	Megagram; 1 Mg= 1 ton
NFI	National Forest Inventory
NPV	Net Present Value
PES	Payment for Ecosystem Services
R^2	Coefficient of Determination (statistical measure)
REDD	Reducing Emission from Forest Degradation and Deforestation

SD	Standard deviation (statistical measure)
SOM	Soil Organic Matter
TAGB	Total aboveground biomass
TC	Total carbon
t ha^{-1}	Ton per hectare
UNFCC	United Nation Framework Convention on Climate Change
SAS	Statistical Analysis System
SPSS	Statistical Package for Social Science

CHAPTER 1

INTRODUCTION

1.1 General Background

The Intergovernmental Panel on Climate Change (IPCC) in its Fourth assessment report, summarized that global climate change or commonly known as global warming has occurred at an alarming rate (IPCC, 2007). The increase of greenhouse gases (GHGs) was the major cause of this change. Human activities such as fossil fuel burning, clearing of forest and industrial revolution were responsible for the increment of greenhouse gases in the atmosphere. The emission of GHG especially carbon dioxide (CO_2) results in uncertain weather and also increase in global temperature.

Decision maker has been discovered in the utilization of forests for mitigation (Ptaff et al., 2000). This is because forests are a major sink of carbon and plays an important role in the global carbon cycle (Schroeder, 1992). The forestry aspects are included in the articles of Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC). Those countries that ratified Kyoto Protocol should be committed to update their reports on national inventories and provide information on anthropogenic emissions and carbon dynamics at the periodical conference of the parties (UNFCCC, 1998). The inventory information from the forestry sector must include the carbon stock changes which resulted in the emission of or reduction in GHG emission (Brown, 2002). According to Santili et al. (2005) the reduction of GHG emission for industrialized countries was emphasized in the Kyoto Protocol. However, deforestation in developing countries was considered one of the major contributors to GHG emissions.

In developing countries, Kyoto Protocol failed to encompass the reduction in deforestation, sustainable management of forests and forest degradation through carbon credit mechanism even though it has been considered as a keystone in abating the climate change. The importance of deforestation and forest degradation has been recognized after a series of discussions especially at the Bali conference (2007) namely Conference of Parties (COP) of the UNFCCC. Reducing Emission from Deforestation and Forest Degradation (REDD) was agreed by parties of UNFCCC as a new strategy to be included in carbon accounting to reduce emission of GHGs. More comprehensive mechanism has been introduced, namely REDD+ which focused on reducing emission from deforestation and forest degradation (Thompson et al., 2011) and now it has evolved into REDD++ (Copenhagen, 2010 and Cancun, 2012) to mitigate GHG emission. In order to participate in REDD++ forest should have a potential to sequester carbon.

In tropical forest of developing countries, deforestation has become a very common phenomenon. Southeast Asia's tropical forests comprised the highest rate of deforestation worldwide (Langner and Siegert, 2009). It is estimated about 5.5 Gt CO_2 emission occurred due to the deforestation in tropical regions (Gullison et al., 2007). Latest figures showed that the tropical forest loses about 13 million annually. For the period 2000-2005, the accounting of the net loss is 7.3 million ha/year which is less than the 8.9 million ha/year compared to the previous decades (FAO, 2005). It is estimated about 1.7 Gt carbon per year was released from land use (IPCC, 2000). Thus, avoiding deforestation is one of the methods of mitigation and countries should be compensated when reducing their national compensation (Boyd, 2010). Deforestation will affect the global climate change because a large quantity of carbon will be released to the atmosphere when the forests are cleared and converted (Murdiyarso and Adiningsih, 2007). According to Stern (2007), the contribution of greenhouse gas emission from deforestation combined with forest degradation about 17-20% which is more than emission by the whole transportation system (IPCC, 2007). In order to reduce CO_2 emission, forest management might be implemented by maintaining the existing carbon pool (Dixon et al., 1994), increasing forest lands (Binkley et al., 2002), , lenghtening logging cycle and substituting forest bio-fuels for fossil fuels (Backeus et al., 2005). Therefore quantifying and understanding forest biomass is essential. Accurate estimation of forest biomass is important for GHG inventories and terrestrial carbon accounting (Krankina et al., 2004).

About 60% of the world's terrestrial carbon is shared by forest vegetation and soil (Winjum et al., 1992). According to Trumper et al. (2009), terrestrial ecosystem store carbon almost three times as much as in the atmosphere. Various types of forests comprise a variation of carbon stock and must be assessed to quantify total carbon sequestrated in forest ecosystems. To project carbon stock over time, carbon pool estimation under existing land uses can provide a baseline data.

In order to balance global carbon cycle, forest shows dual characters. In one aspect, the process of photosynthesis enables carbon dioxide to be sequestrated from the atmosphere, while in others it releases carbon through land use change. When the tree capacity and area expands, the sink capacity of forests also increases. According to Prentice et al. (2001), forests store more CO_2 than the atmosphere. Commonly, 50% dry weight of biomass is carbon (MacDicken, 1997). Forests play a significant role in the emission of carbon in the atmosphere. Carbon stored in aboveground, belowground and soils are released back to the atmosphere when trees are cut down. Reforestation, afforestation, conservation and sustainable management of forests are the very simple and least cost effective solution to mitigate global climate change (Stern, 2007). Sustainable forest management will be the milestone steps in trading off the carbon concentration in order to mitigate global climate change since forests function as emission as well as viable sinks of atmospheric carbon (Banskota et al., 2007).

Carbon dioxide is simply sunk by trees via the process of photosynthesis. This carbon is now stored as plant biomass. This process is an important strategy to minimize the global climate change. The mechanism of REDD is developed by UNFCCC in Bali, Indonesia. In this mechanism, those countries that help reduce deforestation and forest degradation would be paid in return. Developing countries will be compensated through carbon credit and they have to conserve their forests in their own way. The concept of REDD is not a new idea. In the 1980s and 1990s, environmental scientists proposed the idea to compensate tropical forest conservation. When it was discussed in various events of UNFCCC especially at COP 3 in Kyoto in 1997, it gained popularity at international levels. Kyoto Protocol is a keystone or policy developed to reduce greenhouse gas emission through reforestation and afforestation. However, this policy is unable to reduce carbon through deforestation and forest degradation. A group of tropical countries, Coalition for Rainforest Nation (CfRN) are lobbying to include forest conservation and put forward REDD policy in the next UNFCCC. Finally it gets value in Bali Action Plan, 2007. This has now been REDD++ which includes sustainability management and forest enhancement in excess to reduce emission.

Assessing carbon storage is very important in the forest ecosystem as stated in Kyoto Protocol to account national GHG (IPCC, 2000). Saugier and Roy (2001) recorded about 60 Pg C every year as exchange between atmosphere and terrestrial ecosystem. Tropical forests also provide several ecosystem services such as biodiversity and climate regulation. Almost 50% of describe species and even larger amount of unidentified species are reportedly being supported by the biodiversity and ecosystem of the tropical forest (Dirzo and Raven, 2003).

Tropical Asia forest sequster is about 164 Mg C ha^{-1} (Fearnside, 2000). However, in Southeast Asia, carbon density is typically high which is up to 500 Mg ha^{-1} (Lasco and Pulhin, 2003). A study was conducted by Brown et al. (1993) using geographical information system (GIS) technique to show that Southeast Asia's natural forest alone stores 144 Mg C ha^{-1} in forest vegetation and 148 Mg C ha^{-1} in soil. Similar a study conducted by Iverson et al. (1993) reported that a maximum average C stock on the aboveground biomass in tropical Asia is 185 Mg C ha^{-1}.

Pioneer studies on forest biomass were also conducted by Kira (1976) and Kato (1978), since then numerous studies were conducted to test various methods in estimating biomass of tropical forest (Chave et al., 2005). However, there is still lack of data on carbon concentration of natural tropical forest specifically Southeast Asian countries as the forest conditions are changing rapidly from time to time. Forest carbon stock for particular area possibly overestimated or underestimated. The differences in several forest activities such as the management regimes, environmental factors and human impacts can reflect on the forest heterogeneity which also influenced the information on the standing biomass. Nabuurs et al. (2008) stated that the inventory-based methodology is substantial and reliable in biomass estimation and also in carbon stocking application.

The study of forest potential in sequestering carbon has become a great concern in Malaysia along with other tropical rainforest countries. According to the Department of Statistical Malaysia (2010), Malaysia still occupies 18,242,922 hectares of forest land. Thus indicates that, Malaysia is still maintaining about 55.3% of the land cover as a green area (FDPM, 2009). Abu Bakar (2000) stated that Malaysian forests have a carbon density from 100-160 Mg ha^{-1} for vegetation and 90-780 Mg ha^{-1} for soils. Table 1.1 shows the distribution and extent of major forest types in Malaysia in 2009.

Table 1.1: Distribution and extent of major forest type in Malaysia, 2009 (million ha)

Region	Land Area	Inland Forest	Swamp Forest	Mangrove Forest	Plantation Forest	Forested Land	Total of Forested Land (%)
Peninsular Malaysia	13.18	4.47	0.24	0.10	0.11	5.86	44.6
Sabah	7.36	3.74	0.12	0.34	0.11	4.31	57.5
Sarawak	12.45	7.80	0.09	0.12	0.06	8.07	65.5
Malaysia	32.99	16.01	0.45	0.56	0.28	18.24	55.3

Source: Department of Forestry of Peninsular Malaysia (2009)

According to Donato et al. (2011), within the tropics, mangroves are among the most carbon rich forest which contains about 1,023 Mg carbons per hectare and estimated 49-98% carbon is stored in mangroves. A study conducted by Chmura et al. (2003) stated that carbon burial which is derived from sedimentation estimates combine with typical carbon concentration in mangroves and estimates a value of about 18.4 Tg C yr^{-1} when applied over a global area 160,000 km^2. Carbon storage in sediments varies in mangrove ecosystem from less than 0.5% to <40% with a global median value of 2.2% (Kristensen et al., 2008). Deforestation in mangroves could generate emissions of about 0.02-0.12 Pg carbon per year which is 10% of the total emission from deforestation globally (Giri et al, 2011). Deforestation can also reduce carbon stores in sediments up to 50% over an eight year period as stated by Granek and Ruttenberg (2008). Organic soils in tropical wetland forest such as mangroves are among the largest organic carbon reserves in the terrestrial biosphere (Murdiyarso et al., 2010). Data on carbon storage on the whole ecosystem is surprisingly lacking even though mangroves are well known contain high carbon assimilation and flux rate (Kristensen et al., 2008). Mangrove forest plays a significant role in carbon sequestration for both above ground and below ground (Fujimoto et al., 1996). Spalding et al. (1997)

reported that 2.4% from tropical forest is dominated by mangrove forest. Although the portion of area covered is small, their potential in exchange nutrients with coastal water suggests that these forests make a unique contribution to carbon biogeochemical in coastal oceans (Twilley et al., 1992). The standing biomass per area reaches higher values compared to any other location (Komiyama et al., 2008). The rate of deforestation in Southeast Asia's tropical forest was highest (Gibbs et al., 2010). 25% of the mangroves area were logged and converted to other land uses between 1980 and 2005 (FAO, 2007).

Malaysia and its neighbouring countries are highly dependent on industry and agriculture which contributes to the global warming problem nowadays. Amran et al. (2012) reported that Kuala Lumpur recorded the highest increment of temperature compared to other cities in Malaysia. IPCC and national Academy of Science agreed that this phenomenon is caused by earth warming, unsustainable and human activities (Claussen, 2004). This issue lead to the cost need to be put against the environment which can no longer be treated as a free good, at least to those countries that ratified Kyoto Protocol (Braun, 2009). Payments for ecosystem service are one of the promising instruments to help conserve and manage the sustainable ecosystem through a marketing approach (Alongi, 2011). Borneo has lost over 50% of its native tropical rainforest over the past 20 years due to the impact of human activities throughout the region (Curran et al., 2004). Morel et al. (2012) reported that the Borneo region had the greatest rate of deforestation in the world. The Borneo rainforest is identified as interesting since the above ground biomass (AGB) is on average 60% which is higher than similar ecosystems in the Amazon (Slik et al., 2010). The study conducted by Saatchi et al. (2011) reported that Borneo demonstrates the largest carbon density in terms of carbon storage in Southeast Asia.

Even though there are many studies done on carbon storage and above ground biomass in tropical forests within Southeast Asia especially the neighbouring regions, but there is a lack of standard model for converting tree measurements to carbon stock estimation. Additionally, the precise information about the aboveground and soil carbon storage is lacking in Malaysia particularly in mangrove forests.

1.2 Problem Statement

Mangrove forest are a group of trees that grow in the coastal intertidal zone with soft soil. According to Shukor (2004), Sabah comprised the largest proportion of mangrove forest compared to Peninsular and Sarawak about 57% of total area of mangrove forest and Marudu Bay is one of the natural mangrove forest found in Sabah. Four species of mangrove dominated the study area were *Avicennia alba, Rhizophora apiculata, Bruguiera parviflora* and *Nypa fruticans*. The comparison has been made to identify the highest aboveground biomass composition for four selected species which is aboveground biomass can be defined as the total of aboveground organic matter present in trees including twigs, branches, main bole, bark and leaves. Aboveground biomass considered as the major portion of five carbon pools in the terrestrial ecosystem (Vashum and Jayakumar, 2012). Thus, this research were focus on aboveground biomass estimation and models were developed to estimate biomass for future study of any mangrove forest that gave solution and estimation on biomass. This research was conducted to study on economic value of carbon stock of selected species in mangrove forest where mangrove forest among the most carbon rich forest within the tropics (Donato et al., 2011). This research also focus on soil carbon determination at four selected species area by using dry combustion method. Estimating the forest biomass as well as carbon stock is very crucial for monitoring carbon loss during deforestation and gave an idea of the potential of the mangrove forest to sequester and store carbon in the forest ecosystem.

1.3 Objectives

The allometric model assists forest researchers and managers in many ways including the ability to predict future carbon stocks and to explore the effects of proposed forest management practices on both carbon sequestration and biomass production. Models provide an efficient way to prepare resource forecasts, but more importantly their ability to explore management options and conservation alternatives. Foresters are able to predict long-term on the forest carbon stock or a particular management decision. Hence a carbon stock model could assist foresters to examine the likely outcome and can make their decision objectively.

This study concentrates on describing the carbon stock for each specified strata in mangrove forests using regression analysis, estimating the parameters of the carbon stock function based on diameter and combination of diameter and height. Specifically, the research is aimed at

1. Determining the stand density and biomass in the Marudu Bay mangrove forest.
2. Developing local allometric equations to improve the accuracy of the aboveground biomass estimation for *Nypa fruticans*, *Rhizophora apiculata, Bruguiera parviflora* and *Avicennia alba*.
3. Estimating soil carbon stock for *Nypa fruticans*, *Rhizophora apiculata*, *Bruguiera parviflora* and *Avicennia alba* in the Marudu bay mangrove forest.
4. Quantify the total carbon (aboveground and soils) stored in the mangroves of Marudu bay.
5. Estimate the economic value of the stored carbon in the mangroves of Marudu bay.

Therefore, the results of this study are to help forest managers to estimate carbon stocking of a mangrove forest. Thus, allometric models can assist forest managers to minimize time, costs and the risk of field sampling since field inventory are exposed to the risk and uncertainties of environmental and economic constraints.

1.4 Benefit of the Research

The benefits from this study are:

- New knowledge on monitoring belowground carbon stocks in mangrove forest and its economics value.
- The rate of aboveground biomass of mangrove forest can be estimated.
- Documenting the diversity of mangrove species in Marudu bay.
- Provide a complete aboveground biomass information for four mangrove species in Marudu Bay
- Modelling regression equation for aboveground carbon stock will develop and usefull for following study.
- Economic value of aboveground carbon stock in Marudu bay could be determine.
- Development of database software for economic value of coastal and mangrove resources.
- Enhanced ecosystem service of mangrove.
- Method for valuing coastal and mangrove resources improved.

1.5 Organization of the Thesis

This thesis contains a total of five major sections. An overall introduction, problem statement and objectives were presented in Chapter 1. Review of literature was presented in Chapter 2. The literature review covered the mangrove forest, carbon stock and economic valuation of mangrove forests in terms of carbon stocking. Chapter 3 presents the experimental design of the study. In this chapter, the study area was described briefly followed by data collection, sampling method, statistical analysis of the data and economic valuation. Chapter 4 presented the results of carbon content, allometric equation and economic valuation for four main mangrove species in Marudu bay namely, *Rhizophora apiculata*, *Bruguiera parviflora*, *Avicennia alba* and *Nypa fruticans*. Also, this chapter discusses the results of the analysis and compares with other related studies. Finally, Chapter 5 summarized the key findings from this thesis and evaluates their significance. This summary was written from the standpoint of biomass content, allometric equation, soil carbon and economic valuation to address the value of mangrove forest. The thesis will conclude with recommendations for future work to further research about other mangrove species biomass in terms of carbon sequestration and economic valuation including belowground biomass (stilt root) to enhance the accuracy of carbon stock estimation of mangrove forests.

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