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Emissions and Potential of Global Warming of N_2O Gas of Mangrove Litter Degradation on the West Muna Regency Coast

Emisi dan Potensi Pemanasan Global Gas N_2O Hasil Degradasi Serasah Mangrove di Pesisir Kabupaten Muna Barat

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RESEARCH ARTICLE

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gas chromatography, greenhouse gas, mangrove species, pearson correlation.

ABSTRACT

Comprehensive research was conducted in the mangrove ecosystem of West Muna Regency to investigate the absorption of greenhouse gas (GHG) and degradation of its litter-produced GHG emissions, including N_2O and carbon. The ecosystem consisted of four stations, namely Mangrove Maginti (station I), Mangrove Tiworo Tengah (station II), Mangrove Tiworo Islands (station III), and Mangrove Sawerigadi (Station IV). The research aimed to determine emissions and global warming potential (GWP) of N_2O gas resulting from the degradation of mangrove litter. The team used a syringe mounted on the hood to collect gas samples and gas chromatography for concentration analysis. The correlation of emissions to environmental variables was analyzed using the Pearson correlation method. The results showed that all species' most significant and smallest average emissions were at stations III and II, with values of 0.0019 mg/m^2/hour and 0.0015 mg/m^2/hour, respectively. Water temperature showed a weak relationship with N_2O emissions, namely r = 0.3511 ($p < 0.05$), while water salinity did not strongly correlate with N_2O emissions (r=-0.4471; $p < 0.05$). The average GWP value ranged from 0.3665–0.6314 CO_2e mg/m^2/hour. Species *R. apiculata* and *B. cylindrica* at stations III and II had the largest and smallest GWP values of 0.8392 and 0.1912 CO_2e mg/m^2/hour, respectively.

KATA KUNCI
Kromatografi gas, gas rumah kaca, spesies mangrove, korelasi pearson.

INTISARI

Mangrove memiliki kemampuan menyerap gas rumah kaca (GRK) tetapi juga menghasilkan emisi N_2O yang terbentuk melalui degradasi serasah mangrove. Penelitian dilakukan di ekosistem mangrove Kabupaten Muna Barat yang dibagi menjadi empat stasiun yaitu Mangrove Maginti (stasiun I), Mangrove Tiworo Tengah (stasiun II), Mangrove Tiworo Kepulauan (stasiun III) dan Mangrove Sawerigadi (Stasiun IV). Penelitian bertujuan untuk mengetahui emisi dan potensi pemanasan global (GWP) gas N_2O hasil degradasi serasah mangrove. Gas diambil melalui syiringe yang dipasang pada sungkup. Analisis konsentrasi gas menggunakan metode kromatografi gas. Korelasi emisi terhadap variabel lingkungan dianalisis dengan metode korelasi Pearson. Hasil penelitian menunjukkan bahwa rerata emisi terbesar seluruh spesies terdapat pada stasiun III sebesar 0,0019 mg/m^2/jam, sedangkan yang terkecil terdapat pada stasiun II sebesar 0,0015 mg/m^2/jam. Suhu perairan menunjukkan hubungan yang lemah dengan emisi gas N_2O yaitu r = 0,3511 ($p < 0{,}05$). Selain itu, salinitas perairan tidak memiliki nilai korelasi yang kuat terhadap emisi gas N_2O (r = -0,4471; $p < 0{,}05$). Rerata nilai GWP berkisar antara 0,3665 – 0,6314 CO_2e mg/m^2/jam. Spesies R. apiculata yang ditemukan pada stasiun III mempunyai nilai GWP terbesar yakni 0,8392 CO_2e mg/m^2/jam. Spesies B. cylindrica yang ditemukan pada stasiun II mempunyai nilai GWP terkecil yaitu 0,1912 CO_2e mg/m^2/jam.

Introduction

The phenomenon of climate change caused by increasing greenhouse gas (GHG) emissions is a hot topic of discussion in international circles. Various research has attempted to determine its impacts. Badjeck et al. (2010) and Shawket et al. (2019) reported that aspects of agriculture, health, and fisheries are affected by climate change. Cheung et al. (2009), Drinkwater et al. (2009), and Jones et al. (2013) reported that climate change has a direct impact on rising water temperatures and sea levels, waves, rainfall, pH, oxygen, and wind speed. Furthermore, these changes decrease ecological benefits and services from the coast, marine, and freshwater ecosystems (Brander 2010; Wang et al. 2016). Coulthard (2008), Ohwayo et al. (2016), and Asch et al. (2017) reported that climate change could trigger damage to the coast and marine ecology and decrease fishery production and loss of community livelihoods.

Apart from carbon dioxide (CO_2) and methane (CH_4), nitrous oxide (N_2O) becomes the main contributor to GHG emissions. N_2O has a global warming potential (GWP) of up to 298 times compared to CO_2 gas (IPCC 2001). N_2O gas is formed from the activity of microorganisms in the soil through chemical reactions in the form of nitrification and denitrification that occur aerobically and anaerobically (Hogarth 2007). Pathak (1999) states that the formation of N_2O gas has increased with the increasing concentration of organic matter entering the waters.

The formation of gas occurs in wetland ecosystems, especially mangrove ecosystems. Meanwhile, mangrove litter accumulating in sediments through decomposition produces N_2O gas emissions and triggers climate change. Previous research reported that emissions in mangrove sediments range from 0.03 to 1.58 mg/m^2/hour (Chen et al. 2010; Allen et al. 2011; Chen et al. 2012; Konnerup et al. 2014; Castillo et al. 2017). Hernandez and Junca-Gomez (2020) found that N_2O gas emissions ranged from 0.04 – 3.25 3.25 µg/m^2/min, while Ma et al. (2023) reported 7.19 - 15.63 µg/m^2/hour. These emissions correlate negatively and positively with water salinity and sediment temperature (Hernandez & Junca-Gomez 2022).

N_2O gas emissions are the total emissions value obtained by placing the lid on the mangrove substrate without distinguishing the type of species. Rahman et al. (2020b) reported that on the coast of West Muna Regency gas emissions in each mangrove litter are relatively different and slightly affected by seasonal variations, especially the duration of rain. Even though the report of Rahman et al. (2020b) has shown variations, information regarding daily emissions and the GWP from the degradation of mangrove litter has yet to be described. It is imperative to acquire knowledge about this subject to facilitate the effective absorption of GHG and the prevention of climate change through low-emissions practices and optimal management of mangrove ecosystems. Therefore, this research determines emissions of N_2O gas resulting from the degradation of mangrove litter in the coast area of West Muna Regency.

Materials and Methods

Time and Research Sites

This research took place in January - December 2019 in the area of the mangrove ecosystem of West Muna Regency. The location consisted of four observation stations, namely District of Maginti (Station I), District of Tiworo Tengah (Station II), District of Tiworo Kepulauan (Station III), and District of Sawerigadi (Station IV), as shown in Figure 1. Meanwhile, the similarity of vegetation characters dominated by Rhizophora and Sonneratia species became the criteria for selecting the research sites. The division into four stations was assumed to represent the mangrove ecosystem condition in West Muna Regency.

The water condition in the mangrove ecosystem area was influenced by river water inputs, affecting fluctuations in water salinity. Mangrove ecosystems in river areas had brackish to salty salinity ranging from 15–33 ppt. Furthermore, the mixing of sea and freshwater resulted in the salinity of the ecosystem. The main mangrove species in the West Muna Regent coast mangrove ecosystem were *Bruguiera cylindrica,*

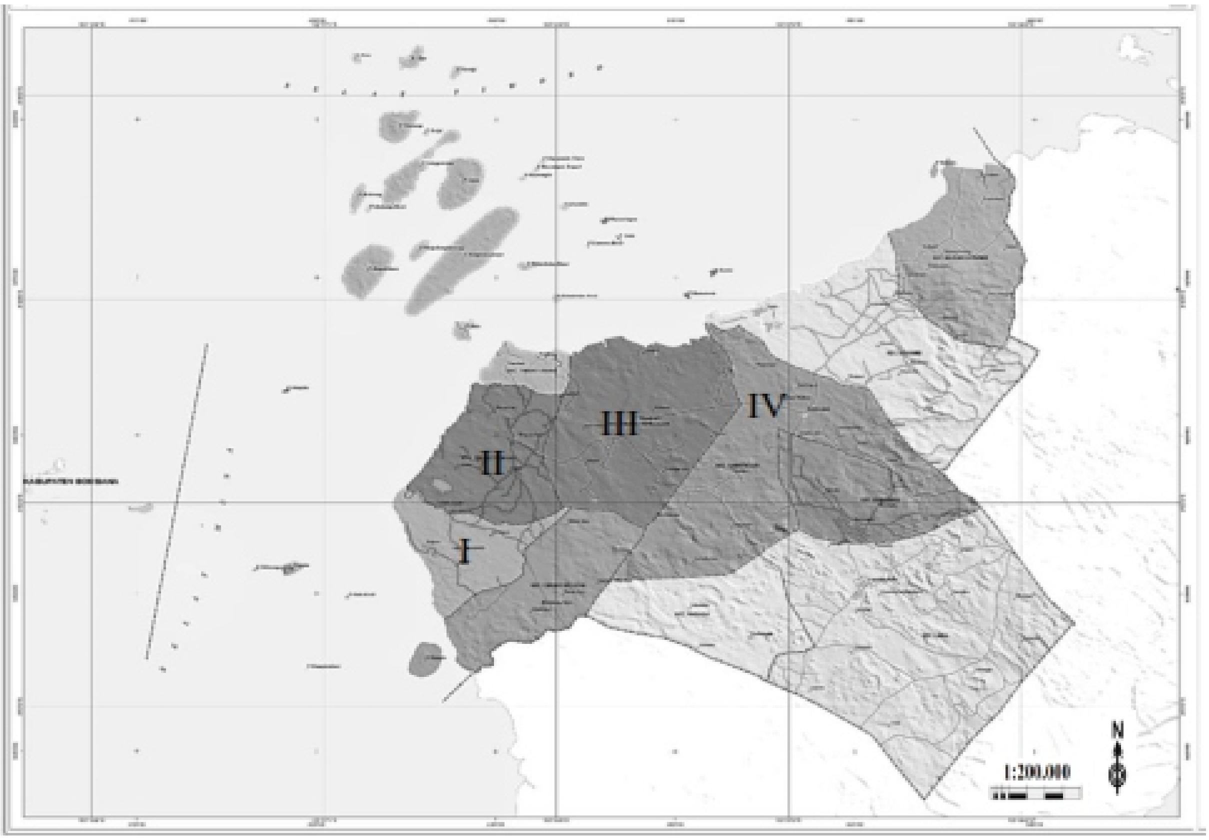

Figure 1. The map of the study site

Table 1. The materials and instruments used for the research

No.	Materials	Function
1.	Chamber	to trap gas in mangrove litter
2.	Syringe	to take gas from the chamber
3.	Injection (50 ml)	to take gas through the syringe
4.	Vials (10 ml)	to store gas samples
5.	Clamp	close the air circulation from the syringe to the chamber or vice versa
6.	Equipment box	to store all equipment tools
7.	Solation and glue	to close the chamber
8.	Gas Chromatography	to analyze the concentration of N2O gas

B. gymnorrhiza, Rhizophora apiculata, *R. mucronata, R. stylosa*, and *Sonneratia alba*. (Rahman et al. 2020a). These species live on various substrates (silt, sandy silt, and silty sand) (Noor et al. 2006; Hogarth 2007; Rahman et al. 2014).

Research Materials

This research used materials and instruments for data collection and analysis, as summarized in Table 1.

Gas Sampling

Gas sampling involved placing a hood under the canopy of each mangrove species, namely *B. cylindrica, B. gymnorrhiza, R. apiculata, R. mucronata, R. stylosa,* and *S. alba*. The litter collection from each mangrove species used a 2 x 4 m litter trap. Subsequently, 600 grams of wet litter were gathered from each species and placed on a square plate measuring 1 x 1 x 1 m, and the litter was left to decompose for 30 days. A 0.5 x 0.5 x 1 m chamber was placed inside the square plate to collect gas resulting from litter decomposition. We used a syringe to extract the gas, which was transferred into a 10 ml bottle (Rahman et al. 2020b). Furthermore, gas sampling was carried out for 8 hours with intervals of two hours (08.00, 10.00, 12.00, 14.00, 16.00) at each station with an observation period of three months (Station I = January - March, Station II = February – June, Station III = July – September, Station IV = October – December).

Measurement of Water Parameters

Water parameters (temperature and salinity) were measured in situ at two-hour intervals each during the gas sampling period. Water parameters were also measured to determine the effect on the value of carbon emissions from the degradation of mangrove litter.

Data Analysis

N_2O Gas Emission

Before conducting emission/flux analysis of N_2O gas, we measured the gas concentration using the gas chromatography method. Two ml of gas through a thermal conductivity detector were analyzed by flow for five minutes with three repetitions of N_2O gas concentration. The analysis of N_2O gas concentration took place at the Laboratory of the Agricultural Environmental Research Institute (BALINGTAN), Regency of Pati, Java of Central. The analysis of the N_2O emission value used the equation modified from Nazareth and Gonzalves and the N_2O gas concentration value (2022).

$$F=\left|\frac{S*V*t*mW}{(RT*A)}\right| \quad (1)$$

Notes:

F: N_2O gas emission (mg/m^2/hour), S: slope of regression of the gas concentration measured every two hours, V: volume of the chamber (L), A = area covered by the chamber (m^2), R: ideal gas constant = 0.082 L. atm/K/mol, T = temperature in the chamber (K), t: time transformation constant = (1 hour/gas sampling time interval), and mW = relative atomic mass of N_2O (44 mg/mole).

Correlation of Water Parameters to N_2O Emissions

The Pearson Correlation method analyzed the correlation of water temperature and salinity parameters on N_2O gas emissions. Pearson correlation analyzes the relationship between two variables and is denoted by r (Kent State University Library 2023). The coefficient of correlation (r) ranges from -1 to +1; the closer to -1 or +1, the temperature or salinity parameter shows a strong correlation to the value of gas emissions (Nazareth & Gonzalves 2022). Meanwhile, if the value of r is getting closer to 0, it shows the weak effect of temperature or salinity on the importance of N_2O emissions. Analysis of variance (ANOVA) determines the significance of the environmental variables' effects on N_2O emissions in each type of mangrove litter.

Global Warming Potential (GWP) of N_2O Gas

The Global Warming Potential (GWP) of greenhouse gases is the equivalent value of the radiation emission of N_2O gas in the atmosphere. The calculated GWP is the GHG radiation equivalent for 100 years (IPCC 2001). Analysis of the GWP value of N_2O gas referred to the IPCC equation (2001) as follows.

$$F_e = Fm \times GWP \quad (2)$$

Where Fe is the CO_2e flux or emissions value (mg/m^2/hour) as an approximation of GWP value, Fm is N_2O gas flux (mg/m^2/hour), GWP is GWP value N_2O gas, namely the conversion value of emissions per mole of N_2O gas equivalent to 298 times CO_2e emissions over 100 years.

Result and Discussions

N_2O Gas Emission

At the I, II, III, and IV stations, the largest and smallest N_2O emissions were in *R. mucronata* and *B. cylindrica, B. gymnorrhiza* and *B. cylindrica*, *R. apiculata* and *B. cylindrica*, and *R. apiculata* and *S. alba* with emissions value of 0.0024 and 0.0008 mg/m^2/hour, 0.0021 and 0.0006 mg/m^2/hour, 0.0028 and 0.0012 mg/m^2/hour, and 0.0021 and 0.0012 mg/m^2/hour, respectively (Figure 2). All species' largest and smallest average emissions were at stations III and II, with emissions values of 0.0019 and 0.0015 mg/m^2/hour. The isolation of litter for each mangrove species in this study by capturing it in a hermetically sealed manner to prevent the ingress of organic matter from the outside allowed the identification of the differences. The organic matter mixed and became part of the litter decomposition process. As a result, the gas stream produced was purely from 600 grams of decomposition product, corresponding to the leaf litter wet weight of all mangrove species. In addition, each mangrove species' low greenhouse gas flux was because the mangrove ecosystem on the West Muna Coast was still pristine and unpolluted by industrial waste, except for a small amount of domestic waste. The tides could quickly dilute household waste entering the waters of mangrove ecosystems. No waste stayed in the ecosystems for extended periods.

Chen et al. (2010) reported that N_2O production positively and negatively correlated with NO_3- and NH_4^+ because nitrification (oxidation of ammonium by nitrifying bacteria under aerobic conditions) and denitrification (reduction of nitrites and nitrates by denitrifying bacteria under anaerobic conditions) supported by the availability of oxygen (Purvaja & Ramesh 2001; Kreuswiezer et al. 2003; Rusmana 2006; Chen et al. 2010) and inorganic nitrogen content (Corredor et al. 1999) dominated the production of N_2O gas. According to Huang et al. (2014), N_2O gas production positively correlated with the combination of ammonium (NH_4^+), nitrate (NO_3^-), and oxygen availability, with a value of r = 0.764.

Pearson's correlation analyzed the relationship between temperature parameters and N_2O emissions and showed a weak relationship with a value of r = 0.3511 (p <0.05). The temperature variable showed no significant effect on N_2O emissions in all mangrove species. The temperature had no significant effect on N_2O emissions in R. *mucronata* (r = -0.0696 ; p < 0.05) and in S. *alba* (r = 0.1816 ; p < 0.05). Meanwhile, for the species R. *stylosa*, the temperature had a moderate effect on N_2O emissions with a correlation value of r = 0.6516 (p <0.01) (Table 2). Variations in water temperature showed a nonlinear relationship to N_2O emissions. N_2O emission fluctuations did not follow the trend of water temperature fluctuations. The lowest gas emission was 0.0005 mg/m²/hour, and the largest was 0.0030 mg/m²/hour, respectively, at 26.2 °C

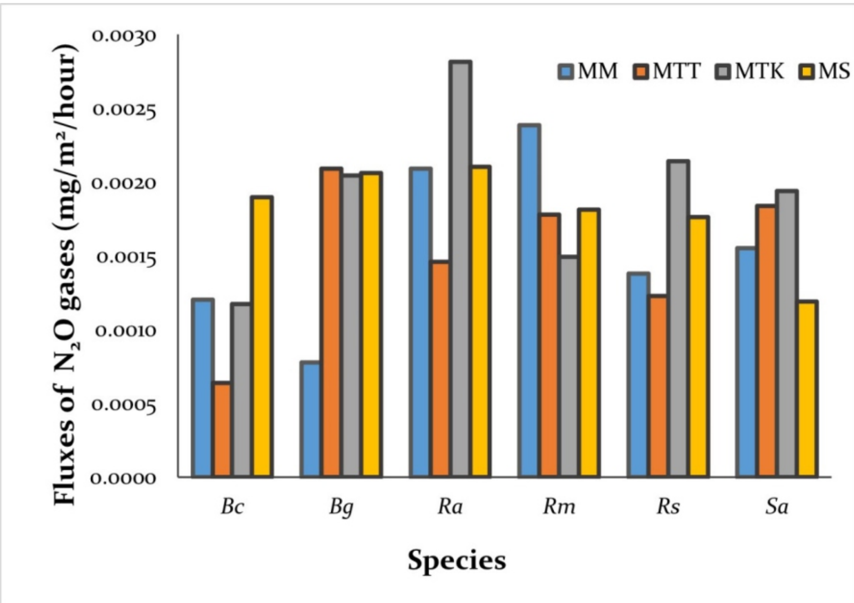

Figure 2. N_2O gas emissions on each mangrove species on the West Muna Regency Coast; MM is mangrove in Maginti, MTT is mangrove in Tiworo Tengah, MTK is mangrove in Tiworo Kepulauan, and MS is mangrove in Sawerigadi: *Bc = Bruguiera cylindrica, Bg = Bruguiera gymnorrhiza, Ra = Rhizophora apiculata, Rm = Rhizophora mucronata, Rs = Rhizophora stylosa, Sa = Sonneratia alba*

Table 2. Correlation coefficient (r) of the influence of environmental variables (temperature and salinity) on N_2O emissions in each mangrove species

Species	Emisi N_2O (mg/m²/hour)	*R*	
		Temperature (°C)	Salinity (ppt)
B. cylindrica	0.0012±0.0007	0.3571*	-0.4456**
B. gymnorrhiza	0.0017±0.0008	0.5276**	-0.4891**
R. apiculata	0.0021±0.0008	0.4482**	-0.4002*
R. mucronata	0.0019±0.0006	0.0696*	0.1615*
R. stylosa	0.0016±0.0005	0.6516**	-0.8292***
S. alba	0.0016±0.0007	0.1816*	-0.3487*
Total	0.0017±0.0003	0.3511*	-0.4471**

Remarks: *r* is correlation coefficient, significant value *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

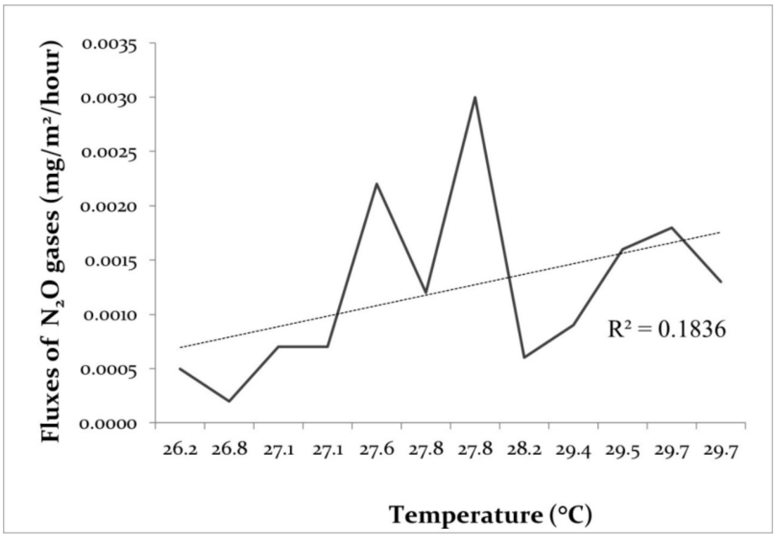

Figure 3. The relationship between water temperature and N_2O gas emissions in the mangrove ecosystem on the coast of West Muna Regency

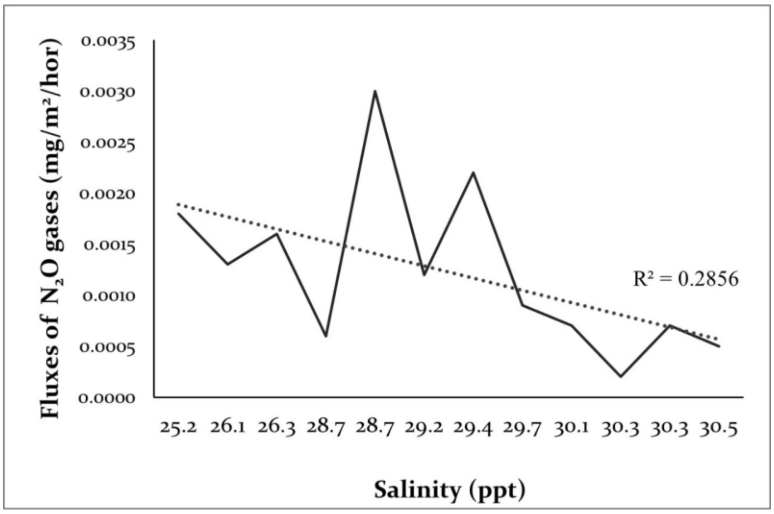

Figure 4. Correlation between water salinity and N_2O gas emissions in mangrove ecosystem on the coast of West Muna Regency

and 27.8 °C. Emissions then decreased at 28.2 °C (0.0006 mg/m²/hour) and increased again at 29.7 °C (0.0013 – 0.0018 mg/m²/hour). These indicated that the temperature of mangrove waters in the range of 26.2 – 29.7 °C was optimal for forming N_2O through nitrification and denitrification processes and showed a nonsignificant difference from the emission values formed at these temperatures (Figure 3).

Water salinity had a weak correlation with N_2O emissions ($r = -0.4471$; $p < 0.05$), indicating that the increase in salinity had a nonlinear relationship to N_2O emissions (Table 2). Water salinity had a weak effect on N_2O emission in each mangrove species. These results aligned with the reports of Hernandes and Junca-Gomez (2020), who found that water salinity had a negative correlation and was nonsignificant in influencing N_2O gas emissions in mangrove sediments. The correlation value was $r = -0.4456$ ($p < 0.01$) for *B. cylindrica* species, $r = -0.4891$ ($p < 0.01$) for *B. gymnorrhiza* species, $r = -0.4002$ ($p < 0.01$) in *R. apiculata*, $r = 0.1615$ ($p < 0.05$) in *R. mucronata* and $r = -0.3487$ ($p < 0.01$) in *S. alba*. Conversely, an increase in salinity correlated strongly with N_2O emissions in *R. stylosa* species ($r = -0.8292$; $p < 0.001$). Figure 4 showed that the largest and lowest N_2O emissions occurred at a salinity of 28.7 ppt with an emissions range of 0.0006 – 0.0030 mg/m²/hour. Therefore, N_2O gas emissions in mangrove litter occurred in the 25.2 – 30.5 ppt salinity range but were not the primary factors considered.

Table 3. GWP contribution value of N_2O gas from mangrove litter degradation on the coast of West Muna Regency.

Locations	CO_2e (mg/m²/jam)					
	Bc	*Bg*	*Ra*	*Rm*	*Rs*	*Sa*
Maginti	0.3590	0.2320	0.6238	0.7108	0.4115	0.4628
Tiworo Tengah	0.1912	0.6237	0.4356	0.5309	0.3657	0.5475
Tiworo Kepulauan	0.3502	0.6094	0.8392	0.4457	0.6382	0.5781
Sawerigadi	0.5657	0.6149	0.6270	0.5403	0.5250	0.3544
Averages	0.3665	0.5200	0.6314	0.5569	0.4851	0.4857

Notes: *Bc = Bruguiera cylindrica, Bg = Bruguiera gymnorrhiza, Ra = Rhizophora apiculata, Rm = Rhizophora mucronata, Rs = Rhizophora stylosa, Sa = Sonneratia alba*

Global Warming Potential (GWP)

N_2O gas was the third contributor after CO_2 and CH_4 to the increase in GHG emissions, which induced climate change (IPCC 2001). Burning of fossil, fuel use, deforestation, and waste organic degradation influenced the increased concentration of N_2O in the atmosphere. It was also increased due to natural processes such as litter degradation in mangrove sediments (Rahman et al. 2018). The GWP of N_2O gas was the radiation potential of N_2O emissions, equivalent to a CO_2 emissions value. The results showed that each species had different GWP values for N_2O gas emissions from mangrove litter degradation. The average GWP value ranged from 0.3665 – 0.6314 CO_2e mg/m²/hour. *R. apiculata* and *B. cylindrica* of Tiworo Kepulauan and Tiworo Tengah mangrove ecosystems had the largest and smallest GWPs, which were 0.8392 and 0.1912 CO_2e mg/m²/hour, respectively (Table 3).

Conclusion

In conclusion, the largest and smallest average emissions from litter degradation for each mangrove species were found at stations III and II, with values of 0.0019 and 0.0015 mg/m²/hour, respectively. The water temperature and water salinity had a weak relationship with N_2O emissions, namely $r = 0.3511$ ($p < 0.05$) and $r = -0.4471$ ($p < 0.05$), respectively. Salinity had a nonlinear relationship to N_2O emissions. The average GWP values ranged from 0.3665 – 0.6314 CO_2e mg/m²/hour. The largest and smallest GWPs were in *R. apiculata* and *B. cylindrica* of Tiworo Kepulauan and Tiworo Tengah mangrove ecosystems, which were 0.8392 and 0.1912 CO_2e mg/m²/hour, respectively.

References

Allen DE, Dalal RC, Rennenberg H, Schmidt S. 2011. Seasonal variation in nitrous oxide and methane emissions from the subtropical estuary and coastal mangrove sediments, Australia. Plant Biol. 13: 126 – 33. https://doi.org/10.1111/j.1438-8677.2010.00331.x

Asch RG, Cheung WWL, Reygondeau G. 2017. Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change. Mar Pol; http://dx.doi.org/10.1016/j.marpol.2017.08.015.

Badjeck MC, Allison EH, Halls AS, Dulvy NK. 2010. Impacts of climate variability and change on fishery-based livelihoods. Mar Pol 2010; 34: 375 – 83. https://doi.org/10.1016/j.marpol.2009.08.007

Brander K. 2010. Impacts of climate change on fisheries. J Mar Sys. 79: 389 – 402. http://dx.doi.org/10.1016/j.jmarsys.2008.12.015

Castillo JAA, Apan AA, Maraseni TN, Salmo III SG. 2017. Soil greenhouse gas fluxes in tropical mangrove forests and in land use on deforested mangrove lands. Catena; 159: 60 – 9. http://dx.doi.org/10.1016/j.catena.2017.08.005

Chen GC, Tam N.F.Y., Ye Y. 2010. Summer fluxes of atmospheric greenhouse gases N_2O, CH_4, and CO_2 from mangrove soil in South China. Sci Tot Environ; 408: 2761 – 7. doi:10.1016/j.scitotenv.2010.03.007

Chen GC, Tam N.F.Y., Ye Y. 2012. Spatial and seasonal variations of atmospheric N_2O and CO_2 fluxes from a subtropical mangrove swamp and their relationships with soil characteristics. Soil Biol Biochem. 48: 175 – 81. doi:10.1016/j.soilbio.2012.01.029

Cheung W.W.L., Lam V.W.Y., Sarmiento JL, Kearney K, Watson R, Pauly D. 2009. Projecting global marine biodiversity impacts under climate change scenario. Fish Fisher. DOI 10.1111/j.1467-2979.2008.00315.x.

Coulthard S. 2008. Adapting to environmental change in artisanal fisheries-insight from a South Indian Lagoon. Glo Environ Cha. 18: 479 – 89. https://doi.org/10.1016/j.gloenvcha.2008.04.003

Corredor JE, Moorel JM, Bauza J. 1999. Atmospheric Nitrous Oxide fluxes from mangrove sediments. Marine Pollution Bulletin. 38 (6): 473-478. https://doi.org/10.1016/S0025-326X(98)00172-6

Donato DC., Kauffman JB., Mackenzie RA., Ainsworth A., Pfleeger AZ. 2012. Whole-island carbon stock in tropical pacific: Implications for mangrove conservation and upland restoration. J. Environ. Manage. 97:89-96. https://doi.org/10.1016/j.jenvman.2011.12.004

Drinkwater KF, Beaugrand G, Kaeriyama M, Kid S, Ottersen G, Perry RI, Pörtner HO, Polovina JJ, Takasuka A. 2009. On the processes linking climate to ecosystem changes. J Mar Sys. 79: 374 – 88. https://doi.org/10.1016/j.jmarsys.2008.12.014

Hernandez EM, Junca-Gomez D. 2020. Carbon stocks and greenhouse gas emissions (CH_4 and N_2O) in mangroves with different vegetation assemblies in the central coastal plain of Veracruz Mexico. Sci of the Tot Environ; 741: https://doi.org/10.1016/j.scitotenv.2020.140276

Hogarth PJ. 2007. The Biology of Mangroves and Seagrasses. America, U.S. Oxford University Press.

Huang J, Chen Y, Sui P, Nie S, Gao W. 2014. Soil Nitrous Oxide Emissions Under Maize-Legume Intercropping System in the North China Plain. J of Integrative Agriculture. 13(6): 1363-1372. https://doi.org/10.1016/S2095-3119(13)60509-2

I.P.C.C. Climate Change. 2001. The Intergovernmental Panel on climate change a scientific basis. Cambridge UK: Cambridge University Press.

Jones PD. 2013. Greenhouse effect and climate data. Reference Mod Earth Syst Environ Sci. 1 – 17. https://doi.org/10.1016/B978-0-12-409548-9.05365-3

Kent State University. 2023. SPSS tutorials: Pearson Correlation. Diakses pada hari Kamis 8 Juni 2023 melalui link https://libguides.library.kent.edu/SPSS/PearsonCorr.

Konnerup D, Portela JMB, Villamil C, Parra JP. 2014. Nitrous oxide and methane emissions from the restored mangrove ecosystem of the Ciénaga Grande de Santa Marta, Colombia. Estuar Coast Shelf Scie; 30: 1 – 9. https://doi.org/10.1016/j.ecss.2014.01.006

Kreuswiezer J, Buchholz J, Rennenberg H. 2003. Emission of methane and nitrous oxide by Australian mangrove ecosystems. Plant Biol; 5: 423 – 31. DOI: 10.1055/s-2003-42712

Ma J, Niu A, Liao Z, Qin J, Xu S, Lin C. 2023. Factors affecting N_2O fluxes from heavy metal-contamined mangrove soils in a subtropical estuary. *Mar Pol Bullet;* 186. https://doi.org/10.1016/j.marpolbul.2022.114425

Nazareth DR, Gonzalves MJ. 2022. Influence of seasonal and environmental variables on the emission of methane from the mangrove sediments of Goa. *Environ Monit Assess.* 194:249. doi: https://doi.org/10.1007/s10661-021-09734-3

Noor YR, Khazali M, Suryadiputra INN. 2006. Pengenalan Ekosistem Mangrove di Indonesia. Bogor, ID: Wetlands International – Indonesia Programme.

Ohwayo RO, Natugonza V, Musinguzi L, Olokotum M, Naigaga S. 2016. Implications of climate variability and change for African lake ecosystems, fisheries productivity, and livelihoods. J Great Lakes Res; 42: 498 – 510. https://doi.org/10.1016/j.jglr.2016.03.004

Pathak H. 1999. Emission of nitrous oxide from soil. Article Reviews. Current Science. 77(3): 359-360. https://www.jstor.org/stable/24102954.

Purvaja R, Ramesh R. 2001. Natural and anthropogenic methane emission from coastal wetlands of South India. Environ Manage. 27: 547 – 57. doi: 10.1111/j.1365-2486.2004.00834.x

Rahman, Yanuarita, D., Nurdin, N. 2014. Struktur komunitas mangrove di Kabupatean Muna. Torani Jurnal Ilmu Kelautan dan Perikanan, 24(2): 29-36.

Rahman, Yulianda F, Rusmana I, Wardiatno Y. 2018. Fluxes of greenhouse gases CO_2, CH_4 and N_2O from mangrove soil in Tallo River, Makassar. J Trop Biol; 18: 149 – 58. DOI: 10.29303/jbt.v18i2.755

Rahman, Wardiatno, Y., Yulianda, F., Rusmana, I., 2020a. Socio-ecological system of carbon-based mangrove ecosystem on the coast of West Muna Regency, Southeast Sulawesi, Indonesia. AACL Bioflux. 13(2): 518-528. http://www.bioflux.com.ro/docs/2020.518-528.pdf

Rahman, Wardiatno, Y., Yulianda, F., Rusmana, I., 2020b. Seasonal fluxes of CO_2, CH_4 and N_2O greenhouse gases in various mangrove species on West Muna Regency, Southeast Sulawesi, Indonesia coast. Plant Archives. 20(2): 4301 – 4311.

Rusmana I. 2006. Gaseous end products of nitrate and nitrite reduction by denitrifying Pseudomonads isolated from estuarine sediment. J Microbiol Indones, 11(2): 279-291.

Shawket N, Elmadhi Y, Kharrim KE, Belghyti D. 2019. Impacts of climate change on fish performance. J Entomol Zoo Stud; 7: 343 – 49.

Wang H, Zhou S, Li X, Liu H, Chi D, Xu K. 2016. The influence of climate change and human activities on ecosystem service value. Ecol Engin. 87: 224 – 39. https://doi.org/10.1016/j.ecoleng.2015.11.027