**Original Research Article**

**Study of Greenhouse Gases: Nitrous Oxide (N₂O) Emissions in the Seagrass Beds of Tanjung Tiram and Halong Beach, Inner Ambon Bay**

**Abstract**

N2O gas is the third largest contributor to global warming at 7.9% after CO2 76.7% and CH4 14.3%. Although the concentration of N2O is smaller than CO2 and CH4 in the atmosphere, which are the largest contributors to global warming, it has a relatively long lifetime of 150 years. Coastal ecosystems such as seagrass ecosystems, in addition to having the ability to absorb greenhouse gases, can also release N2O gas due to organic matter originating from land and litter from seagrass itself. Research on the concentration and emissions of greenhouse gases in seagrass beds is still minimal. Therefore, research on N2O gas emissions needs to be conducted to provide additional scientific information on greenhouse gas emissions in the Tanjung Tiram and Halong Beach seagrass areas, Ambon Dalam Bay. This research was conducted in June - September 2023. Gas sampling was carried out by placing a cover on the sediment in the seagrass beds according to the dominant species living there. The gas that has been taken is then put into a 10 ml vial bottle to be analyzed for greenhouse gas concentration in the greenhouse gas laboratory of the Agricultural Instrument Standardization Agency (BSIP) of Pati Regency, Central Java. After the greenhouse gas concentration value is obtained, the carbon emission value analysis is carried out. Statistical analysis for N2O gas concentration using single factor ANOVA. The highest N2O concentration at the Tanjung Tiram location was found in the *Thalassia hemprichii* species 0.372 ppm and the lowest in the *Enhalus acoroides* species 0.355 ppm while the highest N2O concentration at the Halong Beach location was found in the *Halodule pinifolia* species 0.376 ppm and the lowest in the *Cymodocea rotundata* species 0.346 ppm. The highest N2O emissions at the Tanjung Tiram location were in the *H. pinifolia* species 0.01289 mg/m2/hour and the lowest in the *T. hemprichii* species 0.00484 mg/m2/hour, while the highest N2O emissions at the Halong Beach location were in the *T. hemprichii* species 0.00923 mg/m2/hour and the lowest in the *H. pinifolia* species 0.0183 mg/m2/hour.

Keywords: N₂O concentration, N₂O emissions, greenhouse gases, seagrass beds

**INTRODUCTION**

The increase in greenhouse gases in the atmosphere has led to global warming and climate change. The primary greenhouse gases contributing to global warming are N₂O, CH₄, and CO₂. Human activities such as the use of fossil fuels like petroleum and coal, population growth leading to increased waste production, and environmental degradation through deforestation along coastal areas and inland for the development of settlements, plantations, mining, and aquaculture have contributed to the rise of greenhouse gases in the atmosphere (Rahmadania, 2022).

N₂O is the third-largest contributor to global warming, accounting for 7.9% after CO₂ at 76.7% and CH₄ at 14.3% (IPCC, 2007). Although the concentration of N₂O in the atmosphere is lower than that of CO₂, which is the primary contributor to global warming, N₂O has a relatively long lifetime of 150 years (Lilitnuhu, 2024). This means that N₂O persists in the atmosphere longer than CO₂ and CH₄. Furthermore, N₂O has a Global Warming Potential (GWP) of 310, indicating that its capacity to trap heat from infrared radiation is 310 times more effective than CO₂ (Wahyudi, 2016).

Greenhouse gases such as nitrous oxide, carbon dioxide, and methane can originate from human activities and some do occur naturally (Kweku et al 2018). According to Samiaji (2012), naturally, N₂O is produced through the denitrification process by anaerobic bacteria in sediments or soil, while anthropogenically, N₂O can come from agricultural fertilizers, waste, and fuel combustion. Coastal ecosystems, such as seagrass ecosystems, not only have the ability to absorb greenhouse gases but can also release N₂O due to organic matter originating from land and seagrass litter itself.

Two locations in Inner Ambon Bay with seagrass beds are Tanjung Tiram and Halong Beach. These two sites have the potential to absorb and release greenhouse gases. Research on the concentration and emission of greenhouse gases in seagrass beds remains very limited. In Maluku, two studies have been conducted on CO₂ emissions in seagrass beds (Siahaya et al., 2023; Krisye et al., 2023a). Therefore, research on N₂O emissions is necessary to provide additional scientific information regarding greenhouse gas emissions in seagrass bed areas.

**Method**

**Time and Location of the Study**

This study was conducted from June to September 2023 in the seagrass bed areas of Tanjung Tiram and Halong, Inner Ambon Bay (Figure 1). These two locations have relatively extensive seagrass beds with more than one species present. According to Rugebregt et al. (2020), four species were found in Tanjung Tiram, while five species were identified at Halong Beach. The species selected for this study were those that dominantly inhabit both locations.

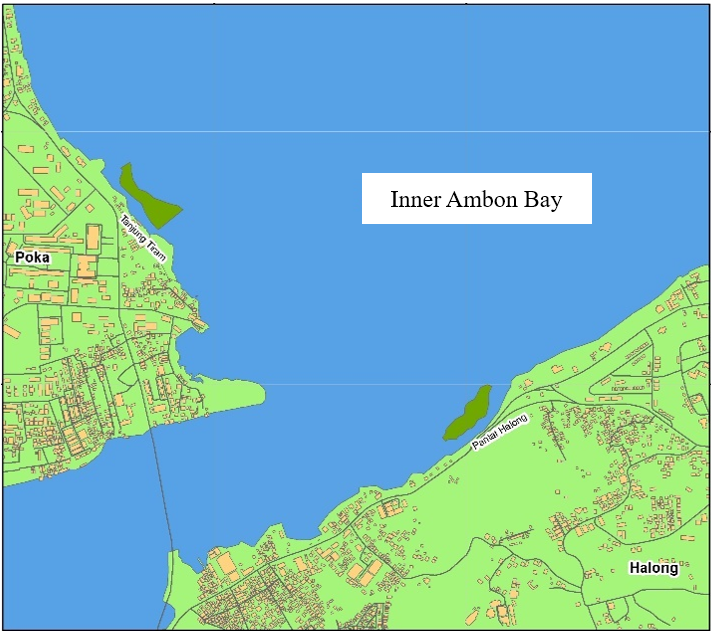


Figure 1. Research Location

**Data Collection**

**Water Characteristics Data**

Data collection for the water characteristics of the ecosystem included temperature, salinity, and pH, which were measured in situ using a thermometer, hand refractometer, and pH meter. Meanwhile, nitrate levels in the water were measured ex situ, where water samples were collected and brought to the laboratory for analysis.

**Gas Sampling Method**

Gas sampling was conducted by placing a chamber over the sediment in the seagrass beds, targeting the dominant species present. Each location consisted of five chamber placement points, with a distance of 20 meters between points. The time interval for gas collection between points was 10 minutes. The chamber was placed at each point for 120 seconds, with gas samples collected five times at 30-second intervals, specifically at t = 0s, 30s, 60s, 90s, and 120s (Lin et al., 2020; Nazareth & Gonsalves, 2022). The collected gas was then transferred into 10 mL vial bottles (Rahman et al., 2018; Rahman et al., 2020) for greenhouse gas concentration analysis at the Greenhouse Gas Laboratory of the Agricultural Instrument Standardization Agency (BSIP) in Pati Regency, Central Java.

The use of this chamber has the potential for error if the chamber is not perfectly stuck to the sediment, therefore to ensure that there are no mistakes, the hood is inserted and pressed from above so that gas leakage does not occur.

**Data Analysis**

**Greenhouse Gas Concentration Analysis**

The analysis of greenhouse gas concentration, specifically CH₄, was conducted using the gas chromatography-mass spectrometry (GC-MS) method. The analysis involved extracting 2–3 mL of gas from the vial bottle and passing it through a thermal conductivity detector using a syringe.

**Greenhouse Gas Emission Analysis**

After obtaining the greenhouse gas concentration values, carbon emission analysis was conducted using the equation from Rahman et al. (2020):

F = ⎸

Note:

**F**: Carbon gas flux (µg/m²/hour); **S**: Regression slope of carbon gas concentration measured every 30 seconds (ppm/s); **V**: Chamber volume (L); **A**: Surface area covered by the chamber (m²); **R**: Ideal gas constant (0.082 L·atm/K·mol); **T**: Temperature inside the chamber or air temperature (K); **t**: Time transformation constant = (1 hour / gas sampling interval = 3600 seconds / 30 seconds = 120); **mW**: Relative atomic mass of C (CH₄: 16 g/mol)

**Statistical Analysis**

Statistical analysis for N2O gas concentration using single factor ANOVA. This statistical test can compare the difference in N2O gas concentration in seagrass in Tanjung Tiram with seagrass in Halong Beach.

**RESULTS AND DISCUSSION**

**Seagrass Species**

The dominant seagrass species found at the study sites consisted of four species. In Tanjung Tiram, three species were identified: *Halodule pinifolia*, *Enhalus acoroides*, and *Thalassia hemprichii*, while in Halong Beach, four species were found: *Cymodocea rotundata*, *Halodule pinifolia*, *Enhalus acoroides*, and *Thalassia hemprichii*. This is by research from Rugebregt et. al (2020) regarding seagrass species found in Tanjung Tiram and Halong Beach. Both Tanjung Tiram and Halong Beach host 28.57% of the total 14 seagrass species found in Indonesian waters (Krisye et al., 2023b). In Maluku waters, ten seagrass species have been recorded (Irawan, 2017). Differences in seabed substrate types influence the variation in seagrass species present, as each seagrass species has its own substrate preference for growth and survival (Yunita, 2014).

**Water Parameters**

The average temperature in the seagrass beds of Tanjung Tiram was 25°C, while at Halong Beach, it was 31°C. The temperature difference between the two study sites was influenced by weather conditions during observations — Tanjung Tiram experienced rainfall, whereas Halong Beach had clear weather. Water temperatures in Indonesian waters range between 24.6°C and 32.3°C (Patty, 2018), making these temperatures still favorable for seagrass growth.

The average salinity in the seagrass beds of Tanjung Tiram was 28.3‰, while at Halong Beach, it was 28.8‰. These salinity levels are still within the normal range for seagrass growth. According to Abdullah et al. (2023), seagrass has a salinity tolerance ranging from 10‰ to 40‰. Based on water quality standards outlined in Government Regulation of the Republic of Indonesia Number 22 of 2021, salinity values should range between 33‰ and 34‰, with changes not exceeding ±5‰.

The average pH in the seagrass beds of Tanjung Tiram was 7.5, whereas at Halong Beach, it was 7.6. These pH values fall within the normal range for seagrass growth. According to Government Regulation of the Republic of Indonesia Number 22 of 2021, the standard water quality for pH ranges between 7 and 8.5. Based on the measured environmental parameters, the seagrass bed conditions at Tanjung Tiram and Halong Beach are considered good.

The average nitrate concentration in the seagrass beds at both Tanjung Tiram and Halong Beach was 0.01 mg/L. According to Government Regulation of the Republic of Indonesia Number 22 of 2021, the standard water quality limit for nitrate is 10 mg/L, indicating that the nitrate levels in the seagrass beds at Tanjung Tiram and Halong Beach are still within normal or good limits.

**N₂O Concentration**

The N₂O gas concentration for each seagrass species across locations showed relatively similar values. At the Tanjung Tiram site, the highest N₂O concentration was found in *T. hemprichii* at 0.372 ppm, while the lowest was in *E. acoroides* at 0.355 ppm. At the Halong Beach site, the highest N₂O concentration was observed in *H. pinifolia* at 0.376 ppm, while the lowest was in *C. rotundata* at 0.346 ppm (Figure 2).

Figure 2. N2O Gas Concentration

Based on the results of the single factor ANOVA statistical test, the concentration values ​​of N2O gas in seagrass in Tanjung Tiram and seagrass in Halong Beach were not significantly different with P-values ​​of 0.493 for *T. hemprichii*, 0.050 for *E. Acoroides*, and 0.079 for *H. pinifolia* respectively (Table 1). This is also confirmed by the results of the analysis of the same nitrate concentration in both locations, namely 0.01 mg/L.

Table 1. Single factor anova test results for N2O gas concentration in each seagrass species

|  |  |  |  |
| --- | --- | --- | --- |
| Spesies | N2O Concentration (ppm) | | P-value |
| Tanjung Tiram | Halong Beach |
| *T. hemprichii* | 0,372 | 0,365 | 0,493\* |
| *E. acoroides* | 0,355 | 0,374 | 0,050\* |
| *H. pinifolia* | 0,364 | 0,376 | 0,079\* |

\*not significantly different at the 95% significance level (α = 0,05)

According to Riniatsih (2015), seagrass beds have a role in stabilizing waters so that the waters are calmer. Calmer waters make the distribution of sediment containing N2O concentrations in them not change much. This is what makes the concentration of N2O in the Tanjung Tiram seagrass beds and Halong Beach not much different.

**N₂O Emissions**

At the Tanjung Tiram site, the highest N₂O emissions were observed in *H. pinifolia* at 0.01289 mg/m²/hour, while the lowest emissions were recorded in *T. hemprichii* at 0.00484 mg/m²/hour. In contrast, at the Halong Beach site, the highest N₂O emissions were found in *T. hemprichii* at 0.00923 mg/m²/hour, whereas the lowest emissions were observed in *H. pinifolia* at 0.00183 mg/m²/hour (Figure 3).

These differences may be attributed to substrate type and seagrass leaf morphology (Krisye et al., 2023a). At Tanjung Tiram, *H. pinifolia* grows on sandy substrates with higher porosity compared to muddy substrates, combined with small leaf morphology that does not fully cover the substrate area, facilitating gas release. Conversely, at Halong Beach, *H. pinifolia* is found on sandy substrates containing fine gravel, resulting in larger substrate pores. This increases the likelihood of oxygen (O₂) penetrating more easily, influencing the anaerobic denitrification process (Samiaji, 2012). Research conducted by Lilitnuhu et al (2024) in the mangrove area adjacent to the research location, has a range of N2O emission values ​​of 0.0070 - 0.0212 mg/m2/hour. When compared with this study, the range of N2O emissions in seagrass fields is still relatively low.

Figure 3. N2O Gas Emissions

**Conclusion**

The highest N₂O concentration at the Tanjung Tiram site was found in *T. hemprichii* at 0.372 ppm, while the lowest was in *E. acoroides* at 0.355 ppm. At the Halong Beach site, the highest N₂O concentration was observed in *H. pinifolia* at 0.376 ppm, with the lowest in *C. rotundata* at 0.346 ppm.

The highest N₂O emissions at the Tanjung Tiram site were recorded in *H. pinifolia* at 0.01289 mg/m²/hour, while the lowest emissions were in *T. hemprichii* at 0.00484 mg/m²/hour. In contrast, at the Halong Beach site, the highest N₂O emissions were observed in *T. hemprichii* at 0.00923 mg/m²/hour, while the lowest emissions were recorded in *H. pinifolia* at 0.00183 mg/m²/hour.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References**

Abdullah, S., Tolangara, A., & Ahmad, H. (2023). Study of Types and Distribution Patterns of Seagrass Plants in the Waters of Teluk Buli Village, Maba District. *Bioedukasi Journal*, *6*(1), 197-204.

Government of the Republic of Indonesia. (2021). Government Regulation of the Republic of Indonesia Number 22 of 2021 Concerning the Implementation of Environmental Protection and Management. Government Regulation. Jakarta.

Intergovernmental Panel on Climate Change 2007. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)]. New York: Cambridge University Press.

Irawan, A. (2017). Lipi Ambon Seagrass Collection 2008-2015 Lipi Ambon Seagrass Collection Of 2008-2015. Lonawarta, XXIII(2), 1-21

Krisye, K., Fendjalang, S. N., & Rahman, R. (2023a). Concentration and CO2 Emissions in Seagrass Ecosystem Inner Ambon Bay. Agrikan Journal of Agribusiness Fisheries, 16(2), 57-62.

Krisye, K., Rahman, R., Fendjalang, S. N., & Sirajuddin, N. T. (2023b). Types and Coverage of Seagrass in the Waters of Maginti Island, West Muna Regency, Southeast Sulawesi. Grouper: Scientific Journal of Fisheries, 14(1), 24-28.

Kweku, D. W., Bismark, O., Maxwell, A., Desmond, K. A., Danso, K. B., Oti-Mensah, E. A., & Adormaa, B. B. (2018). Greenhouse effect: greenhouse gases and their impact on global warming. *Journal of Scientific research and reports*, *17*(6), 1-9.

Lilitnuhu, M. K., Kesaulya, I., & Rahman, R. (2024). Global warming potential of nitrous oxide (N2O) gas emissions in the mangrove area of ​​Poka Village, Ambon City. Jurnal Laut Pulau: Hasil Penelitian Kelautan, 3(1), 10-18.

Lin C.W, Kao YC, Chou M.C, Wu H.H, Ho C.W, Lin H.J. (2020). Methane emissions from subtropical and tropical mangrove ecosystems in Taiwan. Forests. 11 (470): doi:10.3390/f11040470.

Nazareth, D.R., Gonzalves, M.J. (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/s10661-02109734-3.

Patty, S. I., & Akbar, N. (2018). temperature, salinity, pH and dissolved oxygen conditions in coral reef waters of Ternate, Tidore and surrounding areas. Journal of Archipelago Marine Science, 1(2), 1-10.

Rahmadania, N. (2022). Global Warming Causes of the Greenhouse Effect and Its Mitigation. Journal of Engineering Sciences, 2(3).

Rahman, R., Effendi, H., & Rusmana, I. (2017). Estimation of carbon stock and absorption in mangroves in the Tallo River, Makassar. Journal of Forestry Sciences, 11(1), 19-28.

Rahman, Yulianda F, Rusmana I, Wardiatno Y. (2020). Seasonal fluxes of CO2, CH4 and N2O greenhouse gases in various mangrove species on the coast of West Muna Regency, Southeast Sulawesi, Indonesia. Plant Archives. 20(2): 4301 – 4311.

Riniatsih, I. (2016). Distribution of seagrass species is associated with the distribution of aquatic nutrients in the seagrass beds of Awur Jepara Bay. Journal of Tropical Marine, 19(2), 101-107.

Rugebregt, M. J., Matuanakotta, C., Syafrizal. (2020). Species Diversity, Seagrass Cover, and Water Quality in Ambon Bay. Journal of Environmental Science, 18(3), 589-594.

Samiaji, T. (2012). Characteristics of N2O (Nitrogen Oxide) gas in the Indonesian atmosphere. Berita Dirgantara, 13(4).

Siahaya, M., Tupan, C. I., & Rahman, R. (2023). The Relationship between Seagrass Type Density and CO2 Emissions in Negeri Waai Waters, Salahutu District, Central Maluku Regency. Journal of Tropical Fisheries Management, 7(2), 69-75.

Wahyudi, J. (2019). Greenhouse Gas (GHG) Emissions from Open Burning of Household Waste Using the IPCC Model. Jurnal Litbang: Media Informasi Penelitian, Pengembangan Dan IPTEK, 15(1), 65-76.

Yunitha, A., Wardiatno, Y., & Yulianda, F. (2014). Substrate diameter and seagrass species on the Bahoi coast of North Minahasa: a correlation analysis. Jurnal Ilmu Pertanian Indonesia, 19(3), 130-135.