CO₂ Efflux from Shrimp Ponds in Indonesia

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Abstract

The conversion of mangrove forests to aquaculture ponds has been increasing in recent decades. One of major concerns of this habitat loss is the release of stored ‘blue’ carbon from mangrove soils to the atmosphere. In this study, we assessed carbon dioxide (CO₂) efflux from soil in intensive shrimp ponds in Bali, Indonesia. We measured CO₂ efflux from the floors and walls of shrimp ponds. Rates of CO₂ efflux within shrimp ponds were 4.37 kg CO₂ m⁻² y⁻¹ from the walls and 1.60 kg CO₂ m⁻² y⁻¹ from the floors. Combining our findings with published data of aquaculture land use in Indonesia, we estimated that shrimp ponds in this region result in CO₂ emissions to the atmosphere between 5.76 and 13.95 Tg y⁻¹. The results indicate that conversion of mangrove forests to aquaculture ponds contributes to greenhouse gas emissions that are comparable to peat forest conversion to other land uses in Indonesia. Higher magnitudes of CO₂ emission may be released to atmosphere where ponds are constructed in newly cleared mangrove forests. This study indicates the need for incentives that can meet the target of aquaculture industry without expanding the converted mangrove areas, which will lead to increased CO₂ released to atmosphere.

Results

Measures of CO₂ efflux within shrimp ponds showed that rates of CO₂ efflux from the walls were 3.15 μmol m⁻² s⁻¹ which exceeded emissions from the floors of the pond which were 1.15 μmol m⁻² s⁻¹ (Figure 1, F₁,28 = 25.66, P<0.0001). Extrapolation of the point of CO₂ efflux from shrimp ponds to other shrimp ponds in Indonesia indicates that shrimp ponds contribute significantly to the CO₂ emissions in Indonesia.

Introduction

Soil is one of major sources of CO₂ emissions to the atmosphere [1,2,3]. Soil respiration, determined by measuring the CO₂ efflux from soil surface, is primarily from the respiration of soil organisms and roots [1,3]. On a global scale, rates of soil respiration in vegetated biomes have a positive relationship with plant productivity, which contributes to soil metabolic activity [1]. In the absence of vegetation, e.g. when land is converted to aquaculture ponds, the microbial community plays a major role in soil respiration and can release large amounts of CO₂ to the atmosphere [1,4]. During pond construction and operation sediments are exposed to air, microbial activity accelerates which may result in increases in CO₂ efflux from the soil [5,6].

Mangroves are known to be habitats that sequester and store significant amounts of carbon, referred as ‘blue’ carbon [7–10]. The carbon stored in mangroves is mostly found below ground, comprised of highly organic soils and roots [7,11]. The removal of the mangrove forest (aboveground biomass) leads to reduction of carbon sequestration and the release of soil carbon stocks in the form of CO₂ to the atmosphere [5,6,12]. Recent studies have provided global estimates of the CO₂ efflux contribution to global greenhouse gas (GHG) emissions due to mangrove loss in order to assess the potential implications of continuing mangrove wetland conversion and the potential for GHG mitigation schemes [5,6,12,13], yet there are few empirical studies of GHG emissions from aquaculture ponds that occur in converted mangrove areas.

The conversion of mangroves to aquaculture ponds has been a critical issue in Indonesia. With a cover of 3,112,989 ha of mangrove forests, which is the largest portion of remaining global mangrove cover [13,14], Indonesia’s coasts also comprise extensive areas of aquaculture ponds [15,16,17]. Increasing shrimp production in the 1990s led to the expansion of mangrove forest conversion to aquaculture ponds at a rate of 3.67% per year [15]. Rapid conversion of mangrove forests to aquaculture ponds mainly occurred in regions in Sumatra and Kalimantan, however many of those areas have been abandoned in the past decades [15]. Recently, the government has begun to manage the abandoned areas and has expressed interest in increasing shrimp production through revitalisation of existing shrimp ponds [17]. There has also been a substantial effort to restore ponds to mangrove forests by both government and non-government organizations [15,18]. But there is little information of the carbon emissions that are avoided through restoration, which could provide further incentives for restoration of non-productive ponds.

This study examined CO₂ efflux from soil in an intensive shrimp farm in Bali, Indonesia. Shrimp aquaculture is one of major aquaculture activities in Bali. In this study we measured the CO₂ efflux from the soil of the floors and walls of the shrimp ponds that were established 20 years ago. Furthermore, we estimated from these measurements a potential annual CO₂ efflux from shrimp ponds using a dataset of aquaculture area in Indonesia. The results of this study have implications for initiatives aimed at preparedness for use of the clean development mechanism (CDM) and other emissions trading in countries with extensive aquaculture.
Conclusion

The conversion of mangrove forests to shrimp ponds resulted in CO₂ losses to the atmosphere for 4.37 kg CO₂ m⁻² y⁻¹ from the walls and 1.60 kg CO₂ m⁻² y⁻¹ from the floors of ponds. Our estimate of annual CO₂ emission from shrimp ponds in Indonesia region was between 5.76 and 13.95 Tg y⁻¹. These values are comparable to CO₂ emissions from other land uses of converted
lowland forests. The CO₂ emission released to atmosphere might be higher than we report here if ponds are constructed in newly cleared mangrove forests. Knowledge of the amounts of CO₂ released from shrimp ponds may contribute to preparedness for use of the clean development mechanism (CDM) and other emissions trading schemes in countries, particularly Indonesia, which have made a commitment to protect mangrove forests concurrently with commitments to meet targets of high production in the aquaculture industry.

Materials and Methods

This study was conducted in Perancak estuary, Bali, Indonesia (3° 23’ 40” S, 114° 37’ 39” E). The area is a coastal plain associated with the Perancak River that is comprised of a mix of paddy fields, mangrove forests and aquaculture ponds. The estuary is characterised by sedimentary limestones and alluvial platforms. The soils are related to the volcanic stratigraphy derived from the Batur volcano [27,28]. Soil organic carbon contents in this area, measured by Sidik et al (unpublished), are 0.019 g C cm⁻² in the mangrove forests. In the 1990s, huge areas of mangrove forests were converted to intensive shrimp ponds, however, there is no literature that provides accurate information of the extent of mangroves cleared for shrimp ponds [26]. We multiplied the mean of CO₂ efflux from ponds by two different estimates of pond areas to generate “high” and “low” estimates of CO₂ emission from ponds. The lower area came from published information from the Ministry of Marine Affairs and Fisheries [17] and the high estimate from literature [16] derived from the Ministry of Agriculture. Our surveys of the area indicated that pond floors occupied approximately 90% of the shrimp pond footprint and walls about 10%. However, walls were three dimensional, typically 1.5 m high and 1 m wide at the top (4 linear meters). We therefore estimated total CO₂ efflux from floors and walls as (0.9 x floor efflux) + (0.1 x wall efflux x 4) to incorporate the three dimensional nature of the walls.

Ethics Statement

The field measurement was undertaken in a private shrimp farm in Perancak, Bali, with the permission from the owner.

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Author Contributions

Conceived and designed the experiments: FS CEL. Performed the experiments: FS CEL. Analyzed the data: FS. Contributed reagents/materials/analysis tools: FS CEL. Wrote the paper: FS. Edited the manuscript: CEL.

Table 1. Comparison of CO₂ emissions from land uses linked to tropical forest loss.

| Type of land conversion | Location                      | Carbon emission         | Source                        |
|------------------------|-------------------------------|-------------------------|-------------------------------|
| Shrimp ponds           | Bali, Indonesia               | 1.60 kg CO₂ m⁻² y⁻¹ (floors) | This study                    |
|                        |                               | 4.37 kg CO₂ m⁻² y⁻¹ (walls) |                               |
| Mangrove clearing      | Belize                        | 2.9 – 10.6 kg CO₂ m⁻² y⁻¹ | Lovelock et al (2011)         |
| Paddy field            | Kalimantan, Indonesia         | 1.4 kg CO₂ – C m⁻² y⁻¹   | Hadi et al (2005)             |
| Abandoned paddy field  | South Kalimantan, Indonesia   | ~1.2 – 1.5 kg CO₂ – C m⁻² y⁻¹ | Inubushi et al (2003)       |
| Oil palm plantation    | South Asia                    | ~0.75 – 1.1 kg CO₂ m⁻² y⁻¹ | Reijnders and Huijbregts (2008) |
| Sago palm plantation   | Sarawak, Malaysia             | 1.5 kg CO₂ – C m⁻² y⁻¹   | Melling et al (2005)          |
| Rice-soybean rotation field | Kalimantan, Indonesia     | 1.1 kg CO₂ – C m⁻² y⁻¹   | Melling et al (2005)          |

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Rice-soybean rotation field Kalimantan, Indonesia 2 kg CO₂ – C m⁻² y⁻¹ Hadi et al (2005)
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