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N_2o Flux From South Andaman Mangroves And Surrounding Creek Waters

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Abstract

Nitrous oxide (N_2O) flux from mangroves and their surrounding creek waters were estimated in the south Andaman mangroves of Wright Myo (Andaman Sea) and Red Skin Island (Bay of Bengal). These regions may play an important role in greenhouse gas cycling and so water (dissolved N_2O) and air samples were analyzed. Importantly, previous studies excluded emissions estimates for creek waters surrounding mangroves. This study includes direct emission estimates for both mangrove forest sediment and surrounding mangrove creek waters made using static and free-floating chambers respectively. Additionally, indirect estimates for creek waters based on dissolved gas concentrations and a relationship between gas transfer velocity and wind speed were made.

In the present study, the N_2O emission rates from Andaman mangroves varied between 0.161 and 3.02 µmol N_2O m^{-2} h^{-1}. The average direct emission rate from the mangrove sediments were 0.416 µmol N_2O m^{-2} h^{-1} and 0.873 µmol N_2O m^{-2} h^{-1} from the mangrove creek waters. This was extrapolated for the entire mangrove cover of Andaman to give 230.96 g yr^{-1} of N_2O. High N_2O emissions from mangrove creek waters than from the mangrove forest sediments may be attributed to nitrification in the water column but it is unclear what relative proportions of the creek fluxes derive from terrestrial and marine carbon and nitrogen sources.

Keywords: N_2O flux, Andaman mangroves, Direct emission, Mangrove sediments, Mangrove creek waters, N_2O emission rate, Mangrove N_2O emission, Indirect emission estimates.

Introduction

Nitrogen cycle perturbations have compromised air quality and human health, acidified ecosystems, degraded and eutrophied water bodies and coastal estuaries [1,2]. Nitrous Oxide (N_2O), a part of the N cycle, along with other trace gases like methane (CH_4) and carbon dioxide (CO_2) have the greatest impact on our climate because of their high radiative forcing [3]. Gases like CH_4 and N_2O though found in trace quantities in comparison with the over abundant CO_2 have a greater warming potential. When N_2O is emitted into the atmosphere it disperses, but it is not rapidly deposited back to the ground like NO_x or NH_3, the reason is its relatively long residence time in the atmosphere (~150 yrs) [3]. When we compare N_2O and CO_2 on a molecule for molecule basis, the global warming potential of N_2O is over 296 times greater than that of CO_2 [4]. Recent studies in temperate regions have confirmed that estuarine ecosystems are significant sources of global [5]. N_2O is estimated to contribute about 6% to total climatic forcing and that the concentration in the air has increased by about 8% since the Industrial Revolution and it is currently increasing by about 0.2-0.3% per year [4].

Estuaries and coastal seas are important sources of climatically active trace gases to the atmosphere, impacting regional or even global tropospheric budgets [6]. The coastal zones, as natural sources of N_2O and CH_4, play a major role in the global budget of atmospheric N_2O, but only a minor role in the global budget of atmospheric CH_4 [4]. However, measurements of estuarine N_2O and CH_4 are still sparse and the derived emission estimates are associated with large uncertainties [7]. Hence, this present study aids in better understanding of the contribution of N_2O flux from the Andaman mangroves and the surrounding coastal waters. The objective is to study emission rates and the specific tasks were: water samples analysed for dissolved gases and nutrients, static and floating chamber deployed in the mangrove sediment and creek waters respectively to measure direct emission rates.

Study Area

Mangrove forests are an important part in many tropical estuaries and deltas and their high productivity may have a major influence on adjacent coastal zones [8] that grow in the intertidal zone. According to Forest Survey of India [9], out of 4,866 km^2 of mangrove wetlands in India, nearly 56.7 % (2,583 km^2) are present along the east coast and 23.5 % (1189 km^2) along the west coast. The remaining 19.8 % (929 km^2) is found in the Andaman and Nicobar islands.

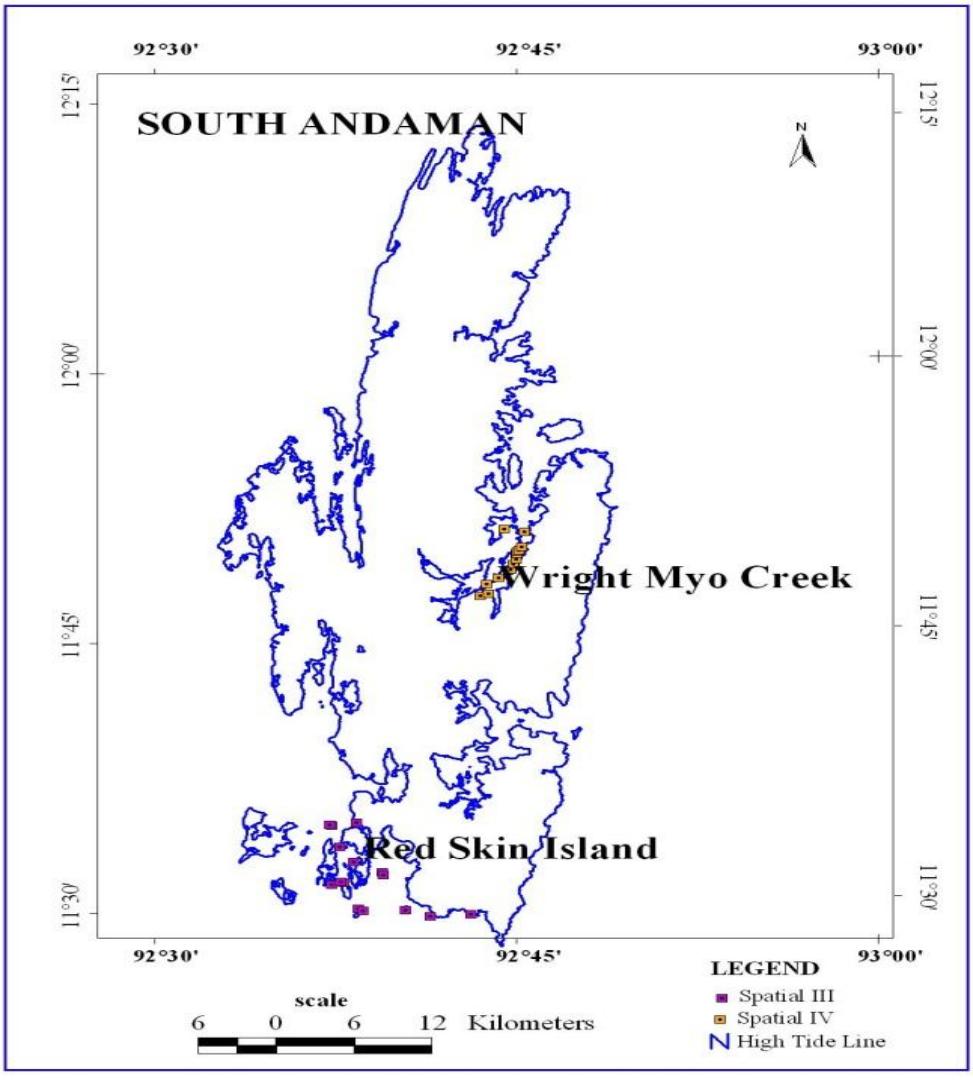
The Andaman mangroves were chosen for study, as they were considered near pristine and formed a major chunk of the Indian mangroves while giving a fair input on emission of trace gases from this coastal community. The Andaman Islands are situated between $10^o30'$ and $13^o42'$ North latitude and $92^o14'$ and $94^o16'$ East longitude in the southeast Bay of Bengal. The Wright Myo mangroves open onto the Andaman sea while the mangroves on Red Skin Islands lie on the Bay of Bengal, this gives an advantage of studying the effects these waters may have on the mangroves. The mangroves at Wright Myo are distributed in a small tidal creek (8 km long 50 meters wide) located on the South Andaman Islands. It is flanked with dense

mangrove vegetation dominated by Rhizophora and Avicennia sp. This mangrove area is subjected to semi-diurnal tides with tidal amplitude of over 2.5 m. While the mangroves on Red Skin Islands are of fringing type and are again dominated by Rhizophora sp., and are subject to a tidal amplitude of over 3m.

Materials & Methods

Water samples were collected as two Transects one from Wright Myo boat jetty (11° 47.531' N, 92° 42.316' E) to the end of the creek where it meets the Andaman sea (11° 51.428' N, 92° 43.432' E) another from Wandoor (11° 35.181' N, 92° 36.406' E) to Chidiyatapu (11° 30.159' N, 92° 41.523' E) in order to understand the spatial variation of dissolved nitrous oxide in these locations (Figure 1).

Figure 1. Map of South Andaman showing the spatial survey done on the Andaman Sea and Bay of Bengal



The Survey was done on both locations in the dry season of April 2006 and wet season of August 2006. The August 2011 was done only in Wright Myo mangroves (This season was done to validate the previous data but due to logistical constraints could not be carried in the Red Skin Islands). The static chamber and the free floating chamber were deployed in the mangrove sediments of Wright Myo and Red Skin Island mangroves and the surrounding creek waters of South Andaman.

The direct measurements of the intertidal mangrove forest (sediment-water-air) N_2O emissions were determined using static acrylic chamber (Figure 2) of 50 x 40 x 70 cm in volume is inserted ~10 cm into the sediment to enclose ~ 40 dm^3 bottom water and ~ 100 dm^3 air. Chamber air was continuously circulated with a small D.C. pump and sampled every 30 minutes via a sterile needle into gas-tight vials (vacutainer, ISOCHEM tubes of 10 mL capacity) for later analysis.

The direct measurements in mangrove creek waters (water-air exchange of N_2O) were made using a free-floating chamber (Figure 2). The chamber has an inner diameter of 30 cm and a total height of 46.5 cm. The height of the chamber containing air is 25 cm. The chamber headspace occupies a volume of 17.7 L. The water level inside the chamber is up to a height of 21.5 cm and it covers a water surface area of 707 cm^2. The chamber has an opening on the top, which is fitted with a cork and a needle from which samples were collected in vacutainers. Air samples were collected over a period of three hours and at 30 minutes intervals. Air, water and soil temperatures, and flux chamber water levels were all continuously monitored.

Figure 2. The Static (left) and free floating (right) chambers used in the direct flux measurements of N_2O

Gas analysis was done by automated, high precision gas chromatography (Shimadzu 14B). Indirect emission flux estimates were also made for creek waters based on applying a gas transfer velocity-wind speed relationship [10] to dissolved gas concentrations in surface waters and *in-situ* wind speeds measured with a hand held anemometer (accuracy ± 0.1 m s^{-1}). Transfer velocities of N_2O and CH_4 were converted from corresponding values for CO_2 [11].

Results & Discussion

Dissolved nutrient and N_2O in the transect studies.

In Wandoor to Chidiyatappu Transect the dissolved N_2O concentration ranged from 7.76 to 12.65 µmol/l with a mean value of 11.10 µmol/l in the dry season (April 2006) while in the wet season (August 2006) ranged from 4.39 to 7.19 µmol/l with a mean value of 5.93 µmol/l. The dissolved NH_4 ranged from 16.2 to 46.42 µmol with a mean value of 31.23 µmol in the dry season (April 2006) while in the wet season (August 2006) ranged from 7.8 to 20.7 µmol with a mean value of 16.3 µmol. The dissolved NO_3 ranged from 5.05 to 14.2 µmol with a mean value of 10.28 µmol in the dry season (April 2006) while in the wet season (August 2006) ranged from 12.4 to 21.0 µmol with a mean value of 15.0 µmol. The DO ranged from 7.42 to 9.6 mg/l with a mean value of 8.77 mg/l in the dry season (April 2006) while in the wet season (August 2006) ranged from 8.6 to 10.8 mg/l with a mean value of 10.0 mg/l. The salinity variation ranged from 22.5 to 33.4 with a mean value of 30.36 in the dry season (April 2006) while in the wet season (August 2006) ranged from 26.2 to 29.2 with 28.8 as mean value. The temperature variation ranged from 31.2 to 32.5ºC with a mean value of 31.94ºC in the dry season (April 2006) while in the wet season (August 2006) ranged from 28.9 to 30.6ºC with a mean value of 30ºC (Table 1).

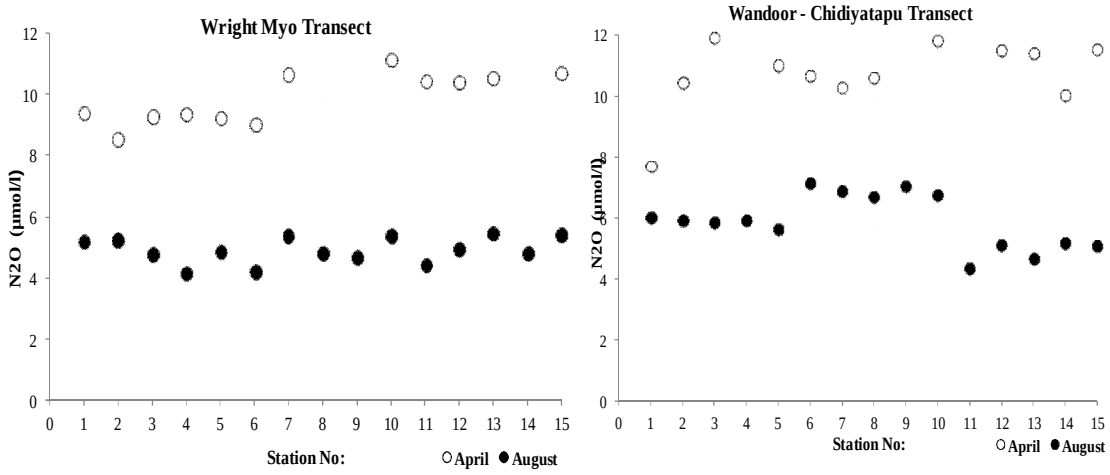
Table 1. Physico-chemical parameters & dissolved N_2O at South Andaman Transects.

Parameters	Wright Myo Mangroves			Red Skin Islands	
	April 2006 (Dry)	Aug 2006 (Wet)	Aug 2011 (Wet)	April 2006 (Dry)	Aug 2006 (Wet)
Salinity	23.3 – 30.8 27.35 ± 0.64	14.2 – 25.4 22.00 ± 0.75	22.9 – 30.1 21.05 ± 0.52	22.5 – 33.4 30.36 ± 0.79	26.2 – 29.2 28.8 ± 0.9
pH	6.503 – 7.473 7.19 ± 0.07	7.0 – 7.5 7.2 ± 0.153	7.4 – 7.6 7.5 ± 0.13	8.09 – 9.22 8.21± 0.07	6.7 – 8.5 7.4 ± 0.473
Water temp (°C)	30 – 32.8 31.11 ± 0.20	28.2 - 29.4 29.1 ± 0.292	28.3 – 29.8 29.0 ± 0.24	29.4 – 31.6 30.34 ± 0.18	28.6 – 29.6 29.0 ± 0.224
Air temp (°C)	30.2 - 37 34.31 ± 0.59	29.8 – 30.4 30.0 ± 0.154	28.0 – 30.6 30.0 ± 0.545	31.2 – 32.5 31.94 ± 0.11	28.9 – 30.6 30.0 ± 0.519
DO (mg/l)	4.43 – 6.01 5.27 ± 0.09	3.3 - 5.6 4.2 ± 0.686	3.7 - 5.8 4.1 ± 0.66	7.42 – 9.6 8.77 ± 0.15	8.6 – 10.8 10.0 ± 0.561
NO_3 (µM)	2.41 – 11.67 6.70 ± 0.70	8.7- 60.5 14.8 ± 2.731	7.9- 59.1 13.8 ± 2.31	5.05 – 14.2 10.28 ± 0.73	12.4 – 21.0 15.00 ± 1.904
NH_4 (µM)	17 - 121 33 ± 1.64	6.0 – 16.0 8.1 ± 2.826	5.8 – 18.3 9.2 ± 0.60	16.2 – 46.42 31.23 ± 1.2	7.8 – 20.7 16.3 ± 0.268
N_2O (nmol/l)	8.54 – 12.81 10.42 ± 0.34	4.2 – 5.5 4.9 ± 0.43	4.38 – 5.4 4.7 ± 0.40	7.76 – 12.65 11.10 ± 0.31	4.39 – 7.19 5.93 ± 0.88

In the Wright Myo Mangrove Transect the dissolved N_2O concentration in Wright Myo Creek to Andaman Sea Transect ranged from 8.54 to 12.81 µmol/l with a mean value of 10.42 µmol/l in the dry season (April 2006) while in the wet season (August

2006) ranged from 4.2 to 5.55 µmol/l with a mean value of 4.9 µmol/l (Figure 3). The dissolved NH_4 ranged from 17 to 121 µmol with a mean value of 33 µmol in the dry season (April 2006) while in the wet season (August 2006) ranged from 6.02 to 16 µmol with a mean value of 8.1 µmol. The dissolved NO_3 ranged from 2.41 to 11.67 µmol with a mean value of 6.70 µmol in the dry season (April 2006) while in the wet season (August 2006) ranged from 8.7 to 60.5 µmol with a mean value of 14.8 µmol. The DO ranged from 4.43 to 6.01 mg/l with a mean value of 5.27 mg/l in the dry season (April 2006) while in the wet season (August 2006) ranged from 3.3 to 5.6 mg/l with a mean value of 4.2 mg/l. The salinity variation ranged from 23.3 to 30.8 with a mean value of 27.3 in the dry season (April 2006) while in the wet season (August 2006) ranged from 14.2 to 25.4 with 22.0 as mean value. The temperature variation ranged from 30.2 to 37ºC with a mean value of 34.3ºC in the dry season (April 2006) while in the wet season (August 2006) ranged from 29.4 to 30.4ºC with a mean value of 30ºC. (Table 1)

Figure 3. Spatial and seasonal variation of N_2O concentration in South Andaman mangrove creek transects



N_2O Flux from South Andaman Mangroves

The dissolved N_2O concentrations obtained from water samples are further subject to a calculation given by Clark, which takes into account a variety of physicochemical parameters the primary being wind-speed. This calculation derives an indirect flux rate of N_2O in the creek water, while the Float chamber method gives a direct rate of N_2O flux for the creek water and the static chamber method gives the direct emission estimate for the intertidal mangrove sediments.

Table 2. N_2O emission rates from Wright Myo and Red Skin Island mangroves

Location	Season	Mangrove Forest Sediment	Mangrove Creek Water	
		(µM hr-1 m-2)		
		Static Chamber (Direct)	Chamber Float (Direct)	Clark 1992 (Indirect)
Wright Myo	April 2006 (Dry)	0.49	3.026	0.096
	Aug 2006 (Wet)	0.28	0.161	0.052
	Aug 2011 (Wet)	0.34	0.173	0.093
Red Skin Island	April 2006 (Dry)	0.66	0.436	0.929
	Aug 2006 (Wet)	0.31	0.570	0.560

N_2O fluxes ranged from 0.161 to 3.026 µmol N_2O m^{-2} h^{-1} (this is an average across methods and seasons) and differed significantly between seasons in the mangrove sediments and creek waters (Table 2). Significantly higher N_2O emission was observed during the dry season (3.02 µmol N_2O m^{-2} h^{-1}) when temperature was high and was lowest during wet season (0.161 µmol N_2O m^{-2} h^{-1}). The correlation between N_2O flux and soil temperature was significant by linear regression (r = 0.65). The dry season has been marked with temperature increase caused high level of microbial activity, which increases the decomposition of organic matter and availability of nitrogenous substrate. This condition enhances the process of nitrification and denitrification in mangrove sediments [12]. In addition, diminished tidal inundation during dry season has also been found to increase nitrogen mineralization in sediments and thereby an increase N_2O fluxes. Nitrification is possible in the oxic zones at the soil–water interface and around the root of mangrove vegetation. These oxic zones are of great importance for N_2O emission from mangrove sediments for two reasons. First, these are the sites where N_2O is potentially produced during nitrification. The N_2O thus produced may then rapidly be lost to the atmosphere via pneumatophores of the mangroves. Second, these are sites where ammonium is oxidized through nitrification to nitrate, which then can diffuse into the adjacent anoxic zones to be reduced in the sediment and thus to allow N_2O production.

Nitrification is the prerequisite for N_2O production and denitrification was coupled to nitrification [13, 14]. This is only possible in the oxidized sediment surface, where O_2 is available. However, during wet season lower temperature would result in a combination of decreased microbial activity and slower gaseous diffusion in water. However, the effect of temperature on N_2O production is complicated, since several biochemical processes with different time constants and different dependencies on other variables like oxygen penetration, nitrate and ammonium availability are involved in the overall processes.

N_2O fluxes from mangroves varied in response to the availability of nitrogenous substrate [15]. In the present study, the N_2O flux was correlated positively with dissolved inorganic nutrients (r = 0.85) indicate the significant allochthonous inputs from terrestrial runoff which are rich in ammonium and nitrate and enhance the N_2O flux through microbial metabolism in Andaman mangroves. A similar correlation

between N_2O fluxes and dissolved inorganic nitrogen from the mangroves of Puerto Rico [16, 17]. However, in the present study, it does not allow for a clear discrimination of the differential effects of reduced (ammonium) vs oxidized (nitrate and nitrite) inorganic nitrogenous compounds on nitrous oxide flux, but the former, mole for mole, are more effective in enhancing N_2O flux from mangrove sediments in Andaman. Given the predominance of ammonium over nitrate in surface waters, it is inferred that N_2O flux at Andaman is principally due to microbial nitrification in the water column. Higher N_2O fluxes during the dry season was probably due to enhancement of nitrogen mineralization leading to N_2O fluxes and was reflected in increased level of ammonium and low level of nitrified nitrate-N in the sediment.

The N_2O emission from Andaman mangrove sediments is produced as end products by microbial denitrification, unlike the emission rates from creek waters. N_2O production in coastal sediments increased sharply and showed maxima at complete anoxia. Apart from this, the relationship between pH and N_2O emissions is not so clear, although N_2O emission increases with decreasing pH under conditions, where N_2O was emitted mainly via denitrification. The relationship between pH and N_2O emission is complex and generally difficult to quantify. It is generally accepted that optimal pH for denitrification is between 7 and 8 and higher soil pH leads to greater reduction of N_2O to N_2, [16]. N_2O fluxes in mangroves are generally governed by nitrogen input in the sediment–water column due to decomposition.

Coastal areas especially tropical mangroves have been recognized as major marine contributors to atmospheric N_2O flux [19]. Such contributions may be further enhanced by the anthropogenic releases of nitrogenous products to coastal marine sediments that enhance microbial nitrogen metabolism and, presumably, rates of N_2O fluxes. The estimated fluxes of N_2O from intertidal mangrove sediments of Andaman is within ranges of most published data for mangrove ecosystems worldwide (Table 3).

Table 3. N_2O emission from Andaman mangroves in comparison with some published values from various mangrove sediments

Location	**N_2O (Emission $\mu mol\ m^{-2}\ hr^{-1}$)**	**Reference**
South Andaman Mangroves	0.16 to 3.03	Present study
Pichavaram Mangroves, South India	1.13-1.6	Senthil Kumar (2007)
Muthupet Mangroves, South India	1.5	Barnes et al (2007)
Wright Myo Mangroves, South Andaman Islands	0.12-0.21	Barnes et al (2006)
Sundarbans	0.02	Ramesh et al (2007)
Puerto Rico: SW coast	0.1-7.8	Corredor et al (1999)
Puerto Rico: SW coast	7.7	Bauza (2007)
China	0-4.4	Alongi et al (2005)
SE Queensland Australia	0-3.9	Allen et al (2006)

Previous studies excluded emissions estimates for creek waters surrounding mangroves [20]. In the present study, the N_2O emission rates from Andaman mangroves varied between 0.161 and 3.02 µmol N_2O m^{-2} h^{-1}. The average direct emission rate from the mangrove sediments were 0.416 µmol N_2O m^{-2} h^{-1} and 0.873 µmol N_2O m^{-2} h^{-1} from the mangrove creek waters. This was extrapolated for the entire mangrove cover (929 km^2) of Andaman to give 230.96 g yr^{-1} of N_2O. Emissions from mangrove creek waters exceeded those from the mangrove forest sediments but it is unclear what relative proportions of the creek fluxes derive from terrestrial and marine carbon and nitrogen sources. Such information is important for constraining the net carbon and nitrogen balances of mangrove ecosystems. Hence, creek waters should be included in future work with focus on comparing emissions from similar sites with and without mangroves, emissions before and after mangrove plantation, and emissions from established and eroding mangrove sites. Data from Andaman mangroves imply that emissions of N_2O when converted to CO_2 equivalents may exceed mangrove CO_2 fixation. Hence, mangrove ecosystems may be small net contributors to the greenhouse gas inventory of the troposphere.

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