An ecological study on nutrients behavior of a pristine river

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Abstract River water and seawater NH4+ and NO3− concentrations were measured during summer and autumn, 2007, to examine temporal and spatial changes in a pristine river and coastal bay located in the northern part of Okinawa Island, Japan. The river water inorganic nitrogen concentrations ranged from 0.43 to 0.70 μmol NH4+ L−1 and 15.06 to 35.38 μmol NO3− L−1 during the summer and from 0.07 to 0.31 μmol NH4+ L−1 and 18.48 to 28.13 μmol NO3− L−1 during the autumn. The seawater inorganic nitrogen concentrations ranged from 0.00 to 1.04 μmol NH4+ L−1 and 0.00 to 23.35 μmol NO3− L−1 during the summer and from 0.00 to 0.29 μmol NH4+ L−1 and 0.00 to 1.15 μmol NO3− L−1 during the autumn. At the same time, the seawater suspended solid (SS) concentrations were up to 10 mg L−1 during the summer and 3.5 mg L−1 during the autumn. The highest NH4+ and NO3− concentrations in the bay were found near the river mouth, which indicates that these materials are probably discharged from the river. The river water NH4+ and NO3− concentrations were higher than the seawater concentrations during both seasons, but the seawater NH4+ and NO3− concentrations were not relatively higher than in other coastal areas of Okinawa Island. NH4+ and NO3− can negatively influence coral growth in this bay, and the corals were absent at the high NH4+ and NO3− concentration sites in the bay. Inorganic nitrogen from seawater may have flown into the bay during rainfall events.

Keywords Ammonium, Nitrate, Suspended solids, River, Coral reef

Introduction

Materials originating in terrestrial regions are affected by biological, chemical, and physical processes as they travel in rivers and arrive at the sea (Mulholland and Olsen 1992; Schlacher and Wooldridge 1996). In recent years, studies have suggested that excessive nutrient and organic matter inflow from anthropogenic activities damages not only river ecosystems (Jarvie et al. 2006), but also marine ecosystems (Turner and Rabalais 1994). Therefore, to protect coastal ecosystems, one must consider ecological connectivity.

The landscape of Okinawa Island clearly differs between the southern and northern parts. The northern part of Okinawa Island has large forests, whereas the southern part of Okinawa Island is an urbanized area with no forest. The amounts of nitrogen in rivers of urban and farm areas are shown to be higher than in forested areas (Lenat and Crawford 1994; Tong and Chen 2002). Such different land–use types on Okinawa Island must affect the river and coastal ecosystems differently.

For understanding the influence of river water on the
coral reef and other coastal ecosystems, one must obtain basic information on the material flow from a river head to the sea. The purpose of this study was to examine temporal and spatial changes in inorganic nitrogen in a forested river on Okinawa Island.

**Material and methods**

This study was conducted on Teniya River and bay located in the northern part of Okinawa Island, Japan (Fig. 1). Teniya River is approximately 3 km in length, and its middle to upper streams are mainly covered by a large forest. A few residences exist around the lower stream area, and agricultural fields are present around the middle stream area. Water samples were collected at seven points on the river during June and October 2007: U1 (upper stream riverpool), U2 (upper stream riffle), M1 (middle stream riverpool), M2 (middle stream riffle), L1 (lower stream riverpool), L2 (lower stream riffle), and RM (river mouth) and at 30 coral reef points inside of Teniya Bay: nos. 1 to 30. Each water sample was collected on the clear day after a rain event.

The water samples were directly collected from the surface of the river and the sea using plastic bottles. Prior to collecting the samples, the bottles were rinsed with a 0.01 M HCl solution to prevent bacterial buildup and subsequent alteration of the sample. Immediately after the collections, the water samples were placed on ice and brought to the laboratory in a cool box. The samples were kept in a −40°C until the NH$_4^+$ and NO$_3^−$ measurements were made. The NH$_4^+$ and NO$_3^−$ concentrations were measured using an automatic water analyzer (QuAAtro, Bran+Luebbe, Norderstedt, Germany).

Data analyses were conducted using Stat View 5 software (SAS Institute Inc., Cary, NC, USA). A one-way analysis of variance was used to evaluate differences in the river water NH$_4^+$ and NO$_3^−$ concentrations among all river points. Fisher’s PLSD test was used to detect differences between river sampling points. To examine correlation coefficients among materials in the bay, the coefficients were tested using Fisher’s r to z test. Results were considered significant if $p<0.05$ for Fisher’s PLSD and if $p<0.001$ for Fisher’s r to z test.

**Results**

The river water NH$_4^+$ concentrations during the summer ranged from 0.43 to 0.70 μmol L$^{-1}$ (Fig. 2a) and during the autumn ranged from 0.07 to 0.31 μmol L$^{-1}$ (Fig. 2b). The river water NH$_4^+$ concentrations during the summer were twice to that during the autumn. The river water NO$_3^−$ concentrations during the summer increased with water flow: approximately 15 μmol L$^{-1}$ at U1 and U2, approximately 23 μmol L$^{-1}$ at M1 and M2, and around 34 μmol L$^{-1}$ at the L1, L2, and RM (Fig. 2c). The river water NO$_3^−$ concentrations during the autumn varied from 18 μmol L$^{-1}$ at the U1 and U2 to 28 μmol L$^{-1}$ at the M1 and M2 to 25 μmol L$^{-1}$ at the L1, L2, and RM (Fig. 2d). No clear difference in the river water NO$_3^−$ concentrations...
was observed between summer and autumn. The river water \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations were higher during the summer than during the autumn. Although the river water \( \text{NH}_4^+ \) concentrations decreased from the L1 and L2 to the RM during both seasons, the river water \( \text{NO}_3^- \) concentrations at the RM were nearly equal to those at the L1 and L2 during both seasons. There were no correlations between the \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations during either season. The river water \( \text{NO}_3^- \) concentrations were 20-fold of the river water \( \text{NH}_4^+ \) concentrations during both seasons.

The seawater \( \text{NH}_4^+ \) concentrations during the summer mostly ranged from 0.05 to 0.50 μmol L\(^{-1}\). However, during the summer, the concentrations were \( \leq 0.05 \) μmol L\(^{-1}\) at no. 15 and \( \leq 0.10 \) μmol L\(^{-1}\) at no. 18. The highest concentrations (≥0.50 μmol L\(^{-1}\)) were at nos. 8 and 11. The seawater \( \text{NH}_4^+ \) concentrations during the autumn were generally <0.10 μmol L\(^{-1}\), except at no. 6 where the concentration was 0.29 μmol L\(^{-1}\). The seawater \( \text{NO}_3^- \) concentrations during the summer ranged from <0.01 to 23.35 μmol L\(^{-1}\). The two sites where the concentrations of \( \text{NO}_3^- \) were >23 μmol L\(^{-1}\) during the summer were nos. 8 and 11. However, the summer \( \text{NO}_3^- \) concentrations were <1.0 μmol L\(^{-1}\) at the site no. 24. The seawater \( \text{NO}_3^- \) concentrations during the autumn were ≤0.005 μmol L\(^{-1}\) at all sites, whereas they were ≥0.10 μmol L\(^{-1}\) at nos. 8, 11, and 19. The seawater \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations were higher during the summer than the autumn. The seawater \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations during the summer were highest at nos. 8 and 11 (were located northeast of the RM) than at the other sites in the bay. While the \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations in the bay were lower than those in river water, the \( \text{NH}_4^+ \) concentrations were higher at nos. 8 and 11 during summer and at no. 6 during the autumn than at the RM.

**Discussion**

Both the river water \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations varied from summer to autumn. However, the differences in the concentrations \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) between the river-pools and riffles were not clear during either season. Teniya River is approximately 3 km in length and potentially too short to distinguish pools from riffles. However, the river water \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations increased at L1 and L2 during both seasons. The lower stream and river mouth of Teniya River are not covered with forest, and are directly affected by sun. Water temperature increased by sunlight accelerates microbial actions such as litter decomposition and nitrifying processes. Thus, the high \( \text{NH}_4^+ \) and \( \text{NO}_3^- \) concentrations at L1 and L2 may have been related to an effect of the sun. While the \( \text{NH}_4^+ \) concentrations at L1 and L2 were higher than RM during both seasons, the \( \text{NO}_3^- \) concentrations at L1 and L2 were lower than RM during both seasons. River water \( \text{NH}_4^+ \) concentrations must decrease at the RM due to dilution by seawater. At the same time, river water \( \text{NO}_3^- \) can accumulate around the RM during rain events.

The \( \text{NH}_4^+ \) concentrations during both seasons were twofold higher in the river water than in the seawater, and
the NO$_3^-$ concentrations during both seasons were 100-fold higher in the river water than in the seawater, except at some points. This indicates that high concentrations of NH$_4^+$ and NO$_3^-$ are supplied from Teniya River to the oligotrophic bay. Tada et al. (2003) reported that the seawater NH$_4^+$ concentrations on the coral reef area located at the northern part of Okinawa Island are approximately 0.3 μmol L$^{-1}$ and this concentration is nearly equal to that in Teniya Bay. However, Takagi et al. (2008) found that the inorganic NH$_4^+$ and NO$_3^-$ concentrations on seaweed and a mixed coral area located in the northern part of Okinawa Island are around 10 μmol L$^{-1}$ and 2.0 μmol L$^{-1}$ respectively. The NH$_4^+$ concentrations in Teniya Bay were nearly equal Tada et al.’s (2003) value, whereas the NH$_4^+$ and NO$_3^-$ concentrations in Teniya Bay greatly differed from Takagi et al.’s (2008) value. Furthermore, range of inorganic nitrogen concentration suitable for coral growth is 0.1 to 3 μmol L$^{-1}$ for NH$_4^+$ and 0.1 to 1.4 μmol L$^{-1}$ for NO$_3^-$ (Shimoda et al. 1998). In Teniya bay, the NH$_4^+$ concentrations at all sampling points and NO$_3^-$ concentrations at most of the sampling points during both seasons are shown in Shimoda et al. (1998). It is reported that there is relationships between river mouth nutrient concentrations and coral coverage in Okinawa’s northern area (Shilla et al. unpublished data). Therefore, it is possible that the inorganic nitrogen discharged from Teniya River does not cause strong damage to coral growth. Rather, there is a possibility that nutrient from Teniya River contribute to a part of primary production in oligotrophic coral reef ecosystem. To clarify river’s nutrient influence to coral growth, comprehensive information like total nutrient discharge is necessary.

SS concentration data were obtained from a Teniya Bay survey conducted by Okinawa Prefecture. The SS concentrations were measured in seawater samples taken from the same sites and at approximately the same time. The SS concentrations were <10 mg L$^{-1}$ during the summer and <3.5 mg L$^{-1}$ during the autumn. Corals were absent at the high NH$_4^+$ and NO$_3^-$ concentration sites. A positive correlation was found among the NH$_4^+$, NO$_3^-$, and SS concentrations during the summer, but no correlation was seen among them during the autumn. Therefore, NH$_4^+$ and NO$_3^-$ may have flowed with SS into the bay during the summer. However, no difference in the SS concentrations was detected between the seasons.

Figure 3 shows monthly changes in precipitation on the northern part of Okinawa Island in 2007, as well as daily changes in June and October. Because the precipitation was greater in June than October, the moisture in forest soils around the river must also be higher in June than in October. High soil moisture results in increased biomass and activity of microorganisms (Stark et al. 1995; Schimel et al. 1999). Inorganic nitrogen levels in forest soil can be higher during summer than autumn due to litter decomposition during summer. However, high sedimentation levels limit light availability (James et al. 2005). The SS concentrations at the RM in the northwest of Okinawa Island are 0.7–60 mg L$^{-1}$ on clear days and 19.3–912 mg L$^{-1}$ on rainy days (Higa et al. 2001). Compared to Higa et al.’s (2001) results, the SS concentrations in Teniya Bay...
were low. Therefore, soil damage to coral growth may be lower in Teniya Bay than in other coastal areas on the northern part of Okinawa Island.

The river water NO$_3^-$ concentrations were obviously higher than the river water NH$_4^+$ concentrations during both seasons. Inorganic nitrogen in the forested Teniya River is expected to originate mainly in litter. Inorganic nitrogen is supplied through litter decomposition processes and released into the ocean. Generally, NH$_4^+$ concentrations are lower than NO$_3^-$ concentrations in forested rivers (Binkley et al. 2004), and NO$_3^-$ is the dominant nitrogen form in such a forested river. While an obvious difference existed between the seawater and river water NH$_4^+$ and NO$_3^-$ concentrations during the autumn, no obvious difference between them was observed during the summer. The distribution of seawater NH$_4^+$ concentrations clearly differed between the summer and autumn. The seawater NH$_4^+$ extended into the whole bay however, higher concentrations were obtained at the far points of RM points than at the near points. NH$_4^+$ inflow may occur from outside of the bay. Conversely, the distributions of the seawater NO$_3^-$ and SS concentrations were similar between the seasons. All of the high NH$_4^+$, NO$_3^-$, and SS concentrations were commonly found at nos. 8 and 11 during the summer. These materials probably easily accumulated through influences from currents.

References


