Status of Organic and Inorganic Nutrients in Waters and Sediments at the Habitat of the Mangrove Sesarmid Crabs from the Ryukyu Islands, Japan

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Abstract

To estimate the relative importance of mangrove swamps for sesarmids habitat, total organic carbon (TOC) and inorganic nutrients in water, and the sediment C/N ratios were determined from three different sites of the Ryukyu Islands: the Shira River mangrove swamp at Iriomote Island, the Nuha River mangrove swamp at Okinawa Main Island, and the Nagura River mangrove swamp at Ishigaki Island, during December 2000, August 2001, and September 2002, respectively. The concentrations of total organic carbon in mangrove waters were 1.28, 1.52 and 0.60 ppm in the Shira, Nuha and Nagura rivers, respectively. The concentration of inorganic nutrients were determined from those mangrove waters are sodium (Na^+), potassium (K^+), ammonium (NH_4^-), chlorine (Cl^-), fluorine (F^-), bromine (Br^-), nitrate (NO_3^-), phosphate (PO_4^{-2}) and sulfate (SO_4^{-2}). No satisfactory explanation was found for the high concentrations of sodium and chlorine. The mangrove sediments C/N ratios were 17.9, 12.8 and 25.2 in the Shira, Nuha and Nagura rivers, respectively. The C/N ratio of Nuha river sediment was lower than that of the Shira and Nagura river, indicating higher nutritional value because of many organic matters decomposed here. Sediments from three mangroves had a mean C/N ratio of 18.6, indicating lower C/N ratios could be a richer source of nitrogen, which is regular ingestion by sesarmid crabs. Significant differences ($P<0.0001$) were found among the TOC concentrations in mangrove waters and C/N ratios in mangrove sediments from these three sites.

Key words : Mangrove swamps, sesarmid crabs, habitat, water, sediment, total organic carbon, inorganic nutrient, carbon/nitrogen ratios.

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Introduction

Crabs of the family Sesarmidae are typically found in sheltered creeks and estuaries in association with mangroves or salt marshes in both tropical and subtropical climates. They form probably the largest, and certainly the most conspicuous, consumer group within these environments (Davie, 1994). They have an intimate relationship with the surface water and soft sediments, which they burrow in and ingest, thus significantly modifying them in many ways, physically and chemically. Like all intertidal animals, sesarmid crabs are very tolerant of widely fluctuating environmental conditions, such as temperature, salinity, pH and water level.

The aquatic organisms use water as a medium for their shelter, feeding, reproduction and larval rearing (Reid and Wood, 1976). As the environmental medium, water enters into and maintains the integrity of the entire ecosystems (Reid and Wood, 1976). Most of the mangroves in Okinawa Island are riverine forests, floodplains along river drainages, which are inundated by most high tides. Concentrations of dissolved inorganic nitrogen are low in tropical mangrove waters, and are dominated by ammonium, which is the first product of the biodegradation of organic matter. Amounts of nitrate and nitrite in mangrove swamps are usually lower (Alongi *et al.*, 1992). They decrease with increasing oxygen availability, primary productivity and the mixing with ocean water.

Little information is available on the distribution and dynamics of dissolved nutrients in tropical mangrove waters (Watanabe, 1993). Detailed studies on nutrient dynamics in tropical coastal waters are limited to coral reef areas or pelagic shelf waters (Boto and Wellington, 1984; Alongi *et al.*, 1992; Robertson, 1988). In the riverine forest type mangrove, the swamp is inundated by river runoff in the wet season and traps land-derived material, which later out-welled by the tidal mixing and transportation during inundation (Tanaka and Choo, 2000). Thong *et al.* (1993) demonstrated that inorganic nitrogen increased after heavy rains or when tides inundated the mangrove forest floor. Therefore, the nutrient mixing diagrams may give different results between spring and neap tides, and between the wet and dry seasons, which will effect the distribution of macrobenthos in the mangrove swamps.

There are several factors in sediments other than organic contents that could affect crab distribution. Some of these are salinity, water content, and burrowing preferences of different crab species (Iriondo, 1999). Hence, before concludes that sediment nature influences crab distribution by affecting feeding, a correlation between the crab distribution and organic content of the sediments they occupy must be demonstrated. While total organic carbon indicates the quantity of food available in estuarine sediments, does not show the origins of food. The ratio of organic carbon to nitrogen can often provide an indication of the origin of the organic material and the nutritional quality, which is an important consideration in the feeding ecology of marine macrobenthos.

The sesarmid crabs preferred sediments more than leaves of the resident mangrove, suggesting that sediments may be of higher dietary importance to the crabs (Skov and Hartnoll, 2002). Although several studies have noted that crabs may feed on mud or sediment (Camilleri, 1992), none has examined the nutritional basis for this behaviour. The sediments had C/N ratios three times lower than mangrove leaves, indicating that sediments could have higher nutritional value than leaves (Skov and Hartnoll, 2002). Bacteria may certainly reach high densities in mangrove mud and are highly digestible by sesarmid crabs (Alongi, 1988).

The major objective of this study is to investigate the effect of mangrove water and sediment quality on the habitat of sesarmid crabs. The approaches used are those of field parameters, and mangrove waters and sediments analysis.

Materials and Methods

Study sites

Three different sites within the Ryukyu Islands were surveyed in order to establish the association with the habitat of the sesarmid crabs. These sites were the Shira River mangrove swamps on Iriomote Island, the Nuha River mangrove swamp on Okinawa Main Island and the Nagura River mangrove swamp on Ishigaki Island, in the Okinawa prefecture. Three transects were run in each site. Along each transect, up to five stations were selected, according to the variations in topography and vegetation. Distance from landward to seaward of each station of the study sites are presented in Table 1.

Table 1. Stations on each transect with distance from landward to seaward of three mangrove swamps in the Okinawa Island.

Sites and Stations	Distance from landward to seaward (m)		
	Transect-1	Transect-2	Transect-3
Shira River mangrove swamp			
Station-1	20	10	10
Station-2	40	50	20
Station-3	60	90	30
Station-4	80	120	60
Station-5	100	160	100
Nuha River mangrove swamp			
Station-1	13	11	03
Station-2	17	18	08
Station-3	25	33	16
Station-4	31	46	21
Station-5	35	58	36
Nagura River mangrove swamp			
Station-1	00	00	00
Station-2	44	16	15
Station-3	80	36	31
Station-4	120	62	42
Station-5	165	91	55

The Shira River is located on the eastern part of the Iriomote Island, where it drains eastward into the Pacific Ocean (Fig. 1). There are extensive mangrove swamps on both banks, dominated by *Bruguiera gymnorrhiza*, where *Rhizophora stylosa, Sonneratia alba, Pandanus pandanus* and *Avicennia marina* are very common. Three transects were run from upstream to river mouth approximately 400m (Fig. 2). Transect-1 (100m) was run from the landward edge of the mangroves bordering the road to the Iriomote Wildlife Centre, characterised by a predominance of tall (5-6m) *Bruguiera* and dense *Pandanus* stands. Soils were characteristically grey and black soft mud. Transect-2 (160m) started at the land edge on the bank of a small channel, and lead out into the river mouth. Muddy soils were common at the starting, but the transect proceeded into huge open sandy flats. At the landward edge, *R. stylosa* (2-4m) was dominant, mixed with *A. marina* (1-2m) and *S. alba* (3m). Transect-3 (100m) started from the swamp edge bordering some terrestrial vegetation. Clay-mud soils were once again predominant. *Pandanus* and *Bruguiera* stands were dominant, and there were some trees of *Hibiscus* sp. towards the terrestrial end. Transect ended in small channel whose depth was 70cm at low tide.

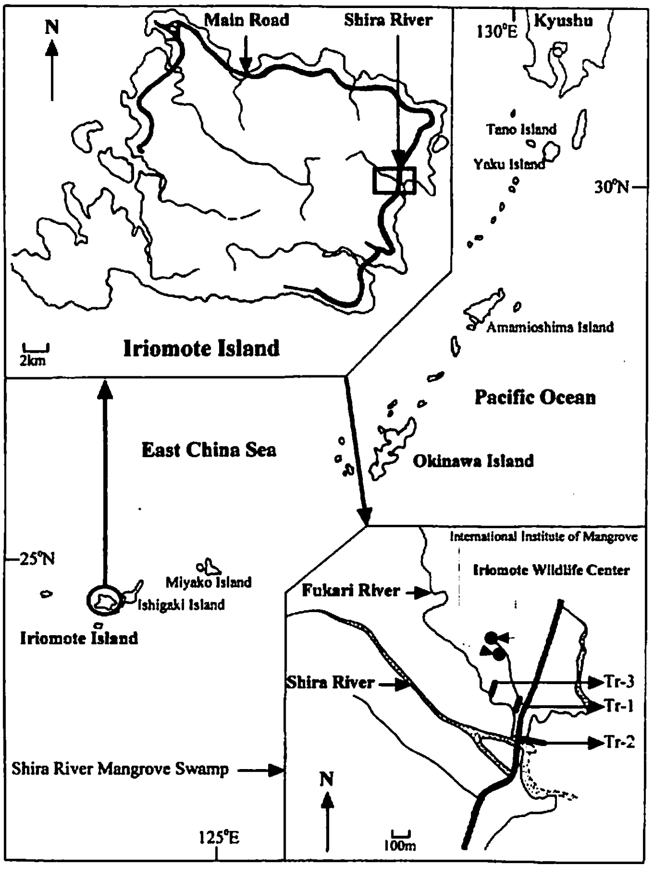

Fig. 1. Map showing the study sites in the Shira River mangrove swamp at Iriomote Island (Transects 1-3).

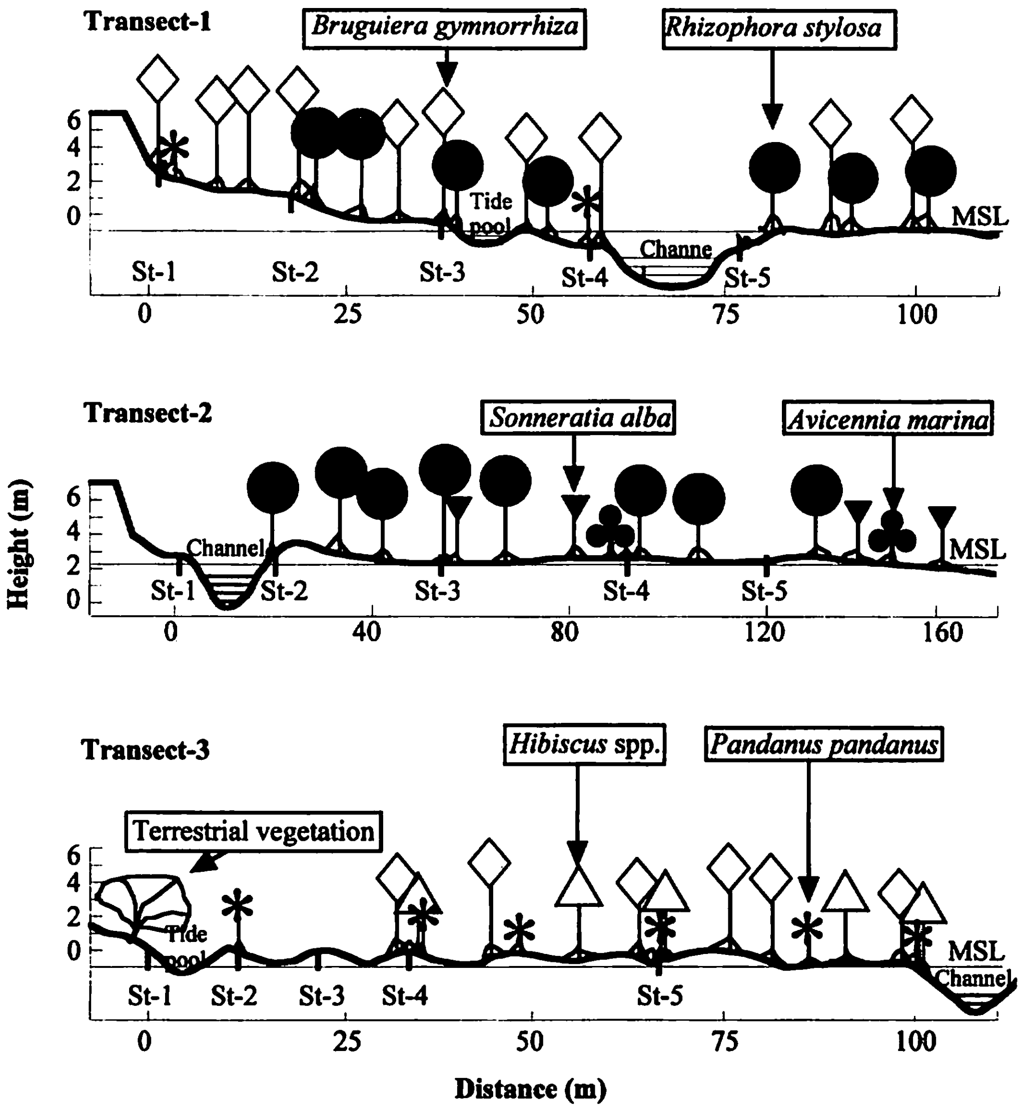

Fig. 2. Schematic profiles of the sesarmid habitat study sites at each transect of the Shira River mangrove swamp at Iriomote Island. MSL indicates mean sea level.

The Nuha River is located in the southern part of the Okinawa Island, and runs northward to the Manko estuary and then to the East China Sea (Fig. 3). On both banks in lower courses, there is a mangrove forest consisting of *Kandelia candel* and *R. stylosa*, while *K. candel* is the dominant species, found in marginal areas, bordering the low tide water line and the forest boundaries. Three transects of the river were made at 200m intervals from the upstream to approximately 1km into the river mouth (Fig. 4). Transect-1 (50m) was made at the uppermost region. It crosses a short and thick stand of *K. candel* about 3m high with herbaceous and sandy flats on both sides of the watercourse. The main watercourse depth at low tide was 75cm. Transect-2 (60m) was dominant with a medium height of *K. candel* (4-5m). The main watercourse depth at low tide was 80cm. Transect-3 (60m) was made at the river mouth, and crosses a short and thick stand of *K. candel* about 2m height, and sandy flats on both sides of the watercourse. The main watercourse depth at low tide was 80cm. Black soft, clay or sandy mud, were found throughout this study site.

The Nagura River is located on the western part of the Ishigaki Island, where it drains westward into the Pacific Ocean (Fig. 5). There are mangrove swamps on both banks, dominated by *B. gymnorrhiza, R. stylosa* and *S. alba*. Three transects were run, from the upstream to approximately 400m in the river mouth (Fig. 6). Transect-1 (200m) was run from the landward edge of the mangroves boundary to the river mouth, characterised by a predominance of tall *B. gymnorrhiza* and *R. stylosa*. Soils were

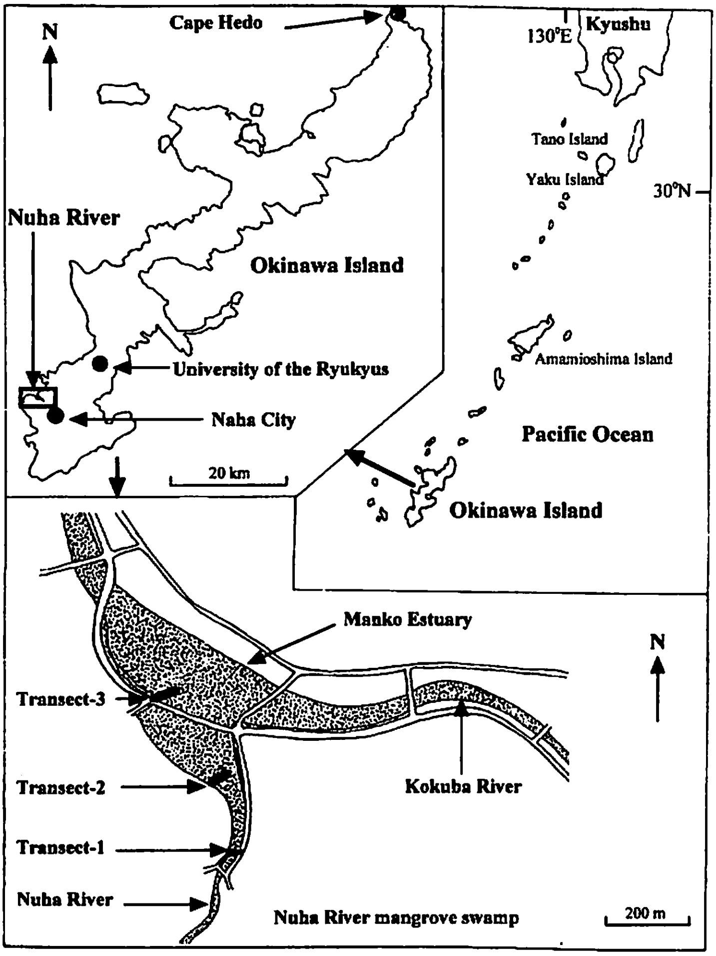

Fig. 3. Map showing the study sites in the Nuha River mangrove swamp at Okinawa Island (Transects 1-3).

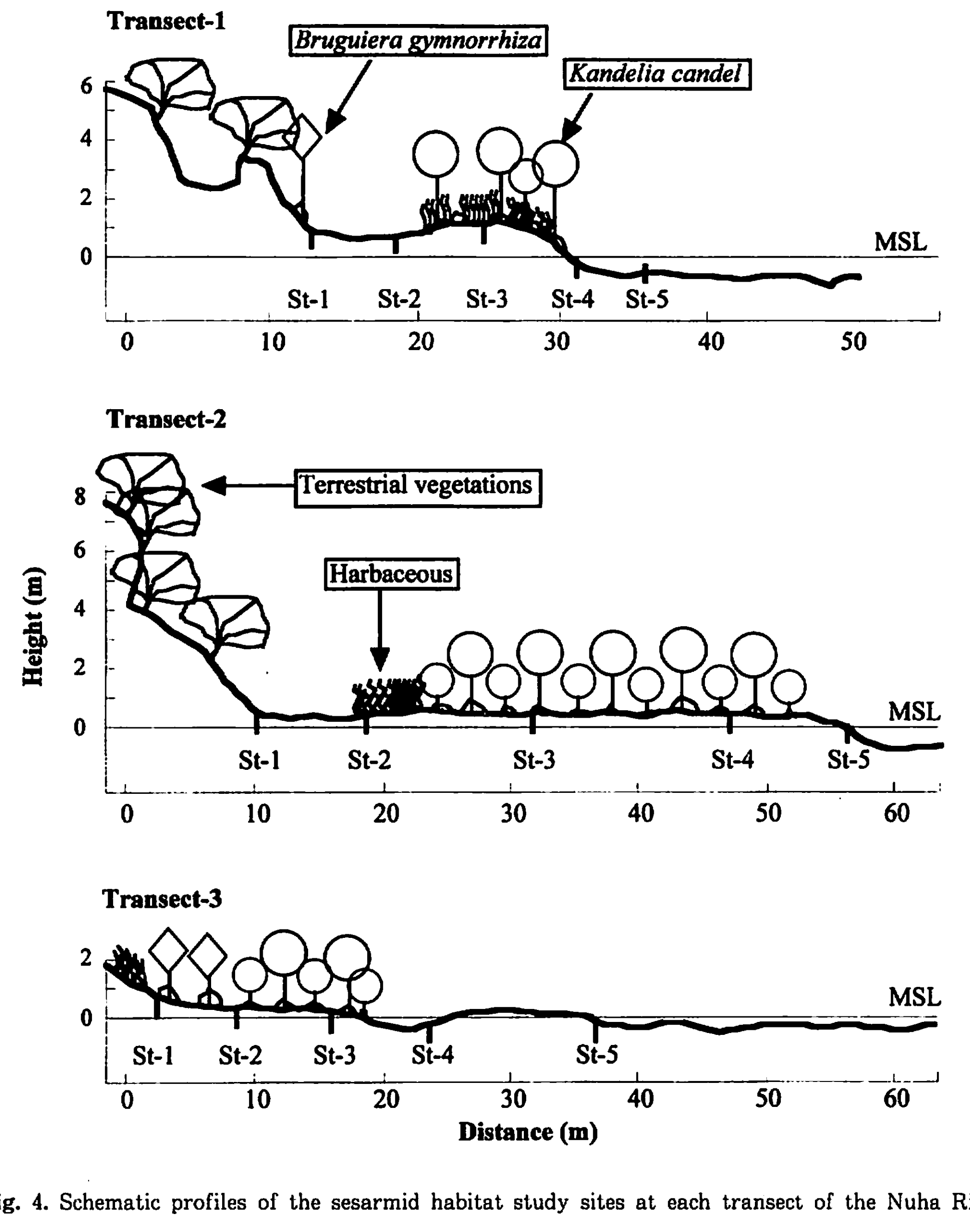

Fig. 4. Schematic profiles of the sesarmid habitat study sites at each transect of the Nuha River mangrove swamp at Okinawa Island. MSL indicates mean sea level.

characteristically grey and black soft mud or rocky. Within the transect sandy flats were very common. The main watercourse at low tide was 35-45cm in depth. Transect-2 (100m) started at the land edge on the bank and led out into the river mouth. Muddy soils were common at the transect start, but the transect proceeded into huge open sandy flats. At the landward edge, *R. stylosa* was dominant, mixed with some *B. gymnorrhiza*. The main watercourse at the transect start was 50cm deep at low tide. Transect-3 (60m) started from

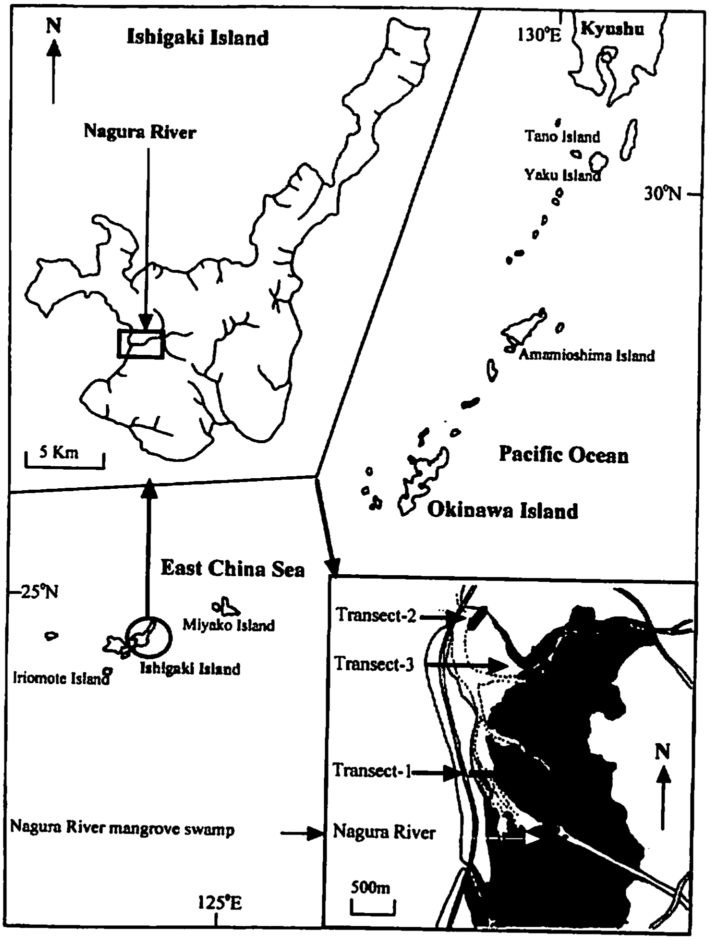

Fig. 5. Map showing the study sites in the Nagura River mangrove swamp at Ishigaki Island (Transects 1-3).

the swamp edge bordering some terrestrial vegetation. Clay-mud was predominant. *S. alba* were dominant, mixed with some *B. gymnorrhiza* stands. Transect ended in a channel whose depth was 70cm at low tide.

Study materials

To determine the field parameters (salinity, pH, temperature), concentration of total organic carbon (TOC) and inorganic nutrients in water, and concentrations of carbon/nitrogen (C/N) ratios in sediment, samples were collected from above mentioned three different sites of the Ryukyu Islands (Figs. 1, 3, 5). Sampling was carried out during the low tide at daytime in December 2000, August 2001, and September 2002, respectively.

Analysis of field parameters

Level of salinity, pH and temperature of mangrove waters were measured with a

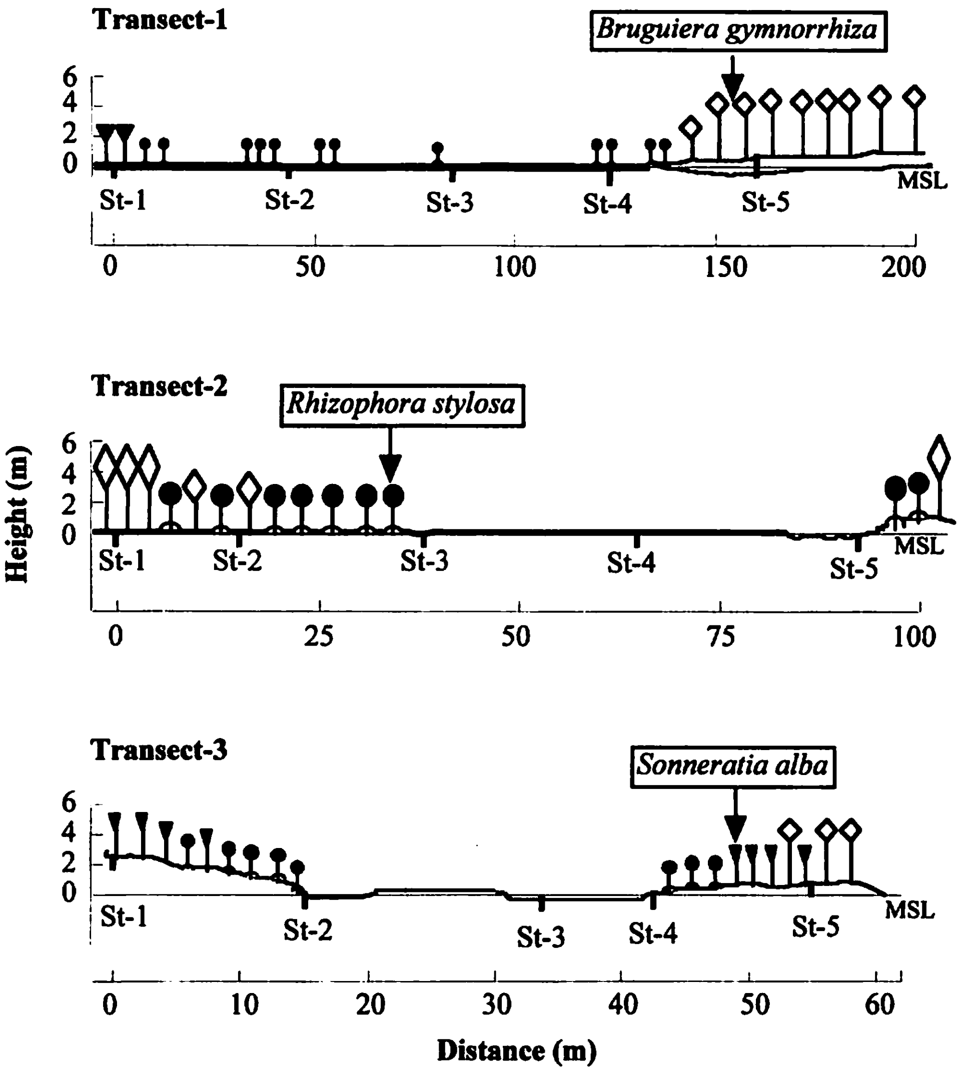

Fig. 6. Schematic profiles of the sesarlnid habitat study sites at each transect of the Nagura River mangrove swamp at Ishigaki Island. MSL indicates mean sea level. Mangrove swamps

hand refractometer (nearest 1‰), pH meter, and a hand thermometer (nearest 0.1℃), from each transect of three sites respectively. These parameters were measured between 11:30 a.m. and 1:30 p.m. in the field directly.

Analysis of mangrove waters

In order to estimate the total organic carbon (TOC) and inorganic nutrients, 300ml of under surface water (5-10cm below the water surface, to avoid most floating particles) were collected from each station of the three different sites, and kept cool in an icebox until reaching the laboratory. Then they were filtered with 0.45μm cellulose acetate filters and diluted with deionised water in proportions of 100^{-1} and 10^{-1} before analysing total organic carbon (TOC) and inorganic nutrients (cations and anions concentrations). The TOC concentrations were measured in a Shimadzu TOC 5000 carbon analyser where followed "total carbon (TC) - inorganic carbon (IC) = total organic carbon (TOC)". The inorganic nutrients sodium (Na^+), potassium (K^+), ammonium (NH_4^+), chlorine (Cl^-), fluorine (F^-), bromine (Br^-), nitrate (NO_3^-), phosphate (PO_4^{-2}) and sulfate (SO_4^{-2}) were analysed using a Dionex DX-120 ion chromatographer. When the analysis could not be done immediately, the samples were kept frozen to avoid changes in the sample's chemical composition.

Analysis of mangrove sediments

To determine the concentration of carbon (C), nitrogen (N), total organic matter (TOM) contents and C/N ratios, sediment samples were collected from the same sites described above for water analysis. Sediment samples for determining C/N ratios were first washed with distilled water in plastic containers to remove salt, taking care not to lose any organic matter. After settling for 24 hours, the water was decanted and samples were oven dried at 60℃ for overnight. Samples were then treated with diluted 2N hydrochloric acid (HCl) overnight to remove carbonates and bicarbonates. To check the complete removal of carbonates and bicarbonates, a drop of 6N HCl was added to each sample. If effervescence was detected, acid treatment was continued until all CO_2 bubbling ceased. Sediments were then oven dried again, and finally ground using a mortar and pestle, and stored in a desiccator prior to analyse in a Shimadzu high-sensitivity C:N Analyzer model NC 80. For each sample, three replicates of 0.1g dry weight were placed in ceramic sample boats and ignited at 830℃ for 1 minute. The connected Chromatopac recorder printed out the C and N amounts as detected by the Sumigraph Detector.

Statistical analysis

Comparative data of TOC of waters and C/N ratios of sediments were recoded and then analyzed using MANOVA on the statistical package Stat View 5. A two-factor ANOVA was used to evaluate differences between stations, transects and sites of the surveying locations. The Post hoc Tukey/Kramer test, Fisher's PLSD test, Wilk's Lamda, Roy's Greatest Root, Hotelling-Lawley Trace and Pillai Trace indicated where there were significant differences in the mean of TOC or C/N ratios.

Results

Analysis of field parameters

The salinity levels of mangrove waters ranged from 5-32, 10-31 and 3-33‰ in the

Shira, Nuha and Nagura Rivers, respectively (Fig. 7). A two-factor ANOVA showed significant differences (df=4, F=5.38, P<0.001) between rivers and transects, while Fisher's PLSD test detected significant differences (P<0.01) only within transects 1 and 3. The pH

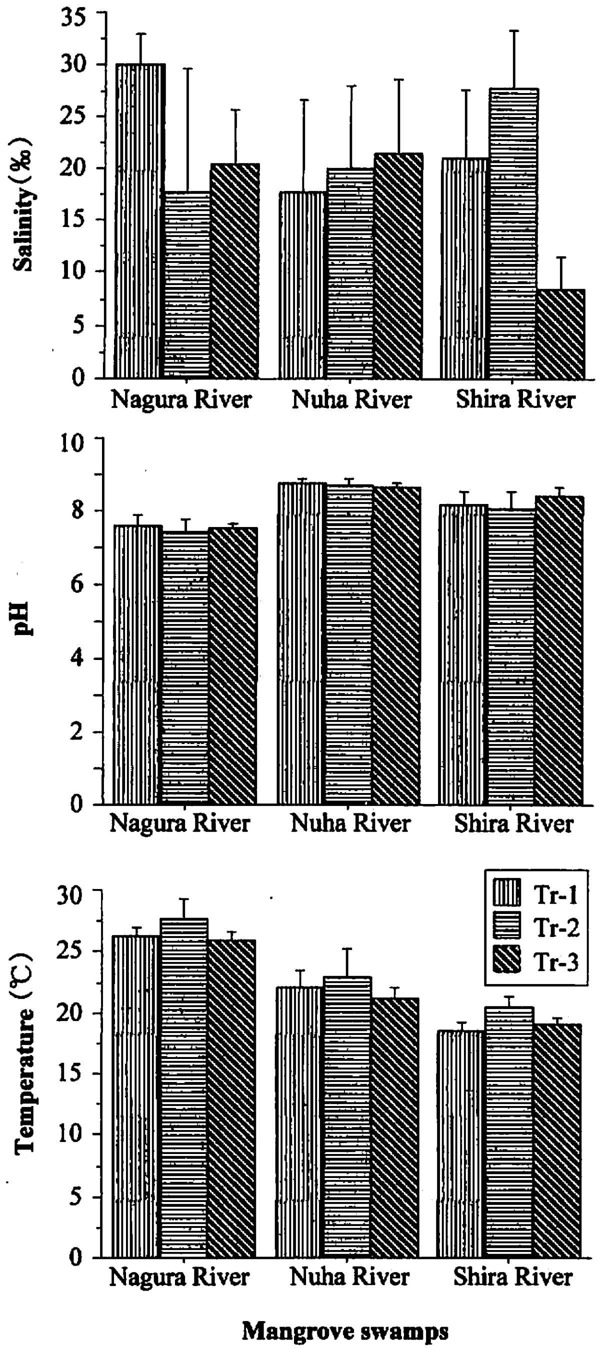

Fig. 7. Comparison of salinity, pH and tempera;ure level in the water of the Nagura, Nuha and Shira River in the Ryukyu Islands. Data indicate mean (±SD), N=5.

levels of Shira, Nuha and Nagura River were almost similar, ranged from 7.1-8.9, with a little variation in Nagura river. The two-factor ANOVA and Fisher's PLSD test detected significant differences (P<0.0001) among the pH levels recorded from the three different sites (Fig. 7). The water temperatures ranged from 18.6-20.4, 21.2-23.0 and 26.0-27.6℃ in the Shira, Nuha and Nagura rivers, respectively. A two-factor ANOVA and Fisher's PLSD test detected significant differences (P<0.0001) within the rivers and transects (Fig. 7).

Analysis of mangrove waters

The total organic carbon (TOC) ranged from 0.45-4.15ppm with an overall mean of 1.28ppm in the Shira, 0.25-2.74ppm with an overall mean of 1.52ppm in the Nuha, and 0.35-1.15ppm with an overall mean of 0.60ppm in the Nagura river (Figs. 8, 9, 10). The concentrations of TOC fluctuated throughout the study sites. A two-factor ANOVA and Fisher's PLSD test detected significant differences (P<0.0001) within stations, transects and their interactions in the Shira, Nuha and Nagura rivers (Figs. 8, 9, 10). The higher concentration of TOC was observed in Shira and Nuha rivers, although the lower concentrations in Nagura river, probably due to the heavy rainfall of that period (Fig. 11). Significant differences (P<0.0001, two-factor ANOVA and Fisher's PLSD test) were found among the rivers, and the interactions of rivers and stations (Fig. 11). When considered vegetated and un-vegetated areas, the quantity of TOC flowing into the mangrove area (vegetated) was markedly smaller than that observed in un-vegetated area, suggesting that it may accumulate by mangrove stands (Fig. 12). The outflow from the mangrove area at the river mouth was much higher than the inflow into the mangrove stand. The Fisher's PLSD and post hoc Tukey/Kramer tests detected significant differences (P<0.05) in TOC concentrations only between the Nagura and Nuha rivers when considered as vegetation (Fig. 12). The concentrations of dissolved inorganic nutrients in the three different sites are increase gradually to seawards (Figs. 13, 14, 15).

Analysis of mangrove sediments

The mangrove sediments C/N ratios ranged from 10.5-26.8 with an overall mean of 17.9 in the Shira, 9.4-14.8 with an overall mean of 12.8 in the Nuha, and 9.4-36.1 with an overall mean of 25.2 in the Nagura river (Figs. 16, 17, 18). A two-factor ANOVA, MANOVA and Fisher's PLSD tests detected significant differences (P<0.0001) in the C/N ratios between stations and transects of these rivers (Figs. 16, 17, 18). The C/N ratios were always higher in the sediments of Nagura river than those of Shira or Nuha river, indicating that the sediments of this area mostly consisted with sand or stone having less nutritional value (Fig. 19). The C/N ratios of Nuha river sediments were lower (12.8) than that of Shira or Nagura river, indicating higher nutritional value because of many organic matters decomposed there. A MANOVA test (Wilk's Lamda, Roy's Greatest Root, Hotelling-Lawley Trace and Pillai Trace) detected significant differences (P<0.0001) within

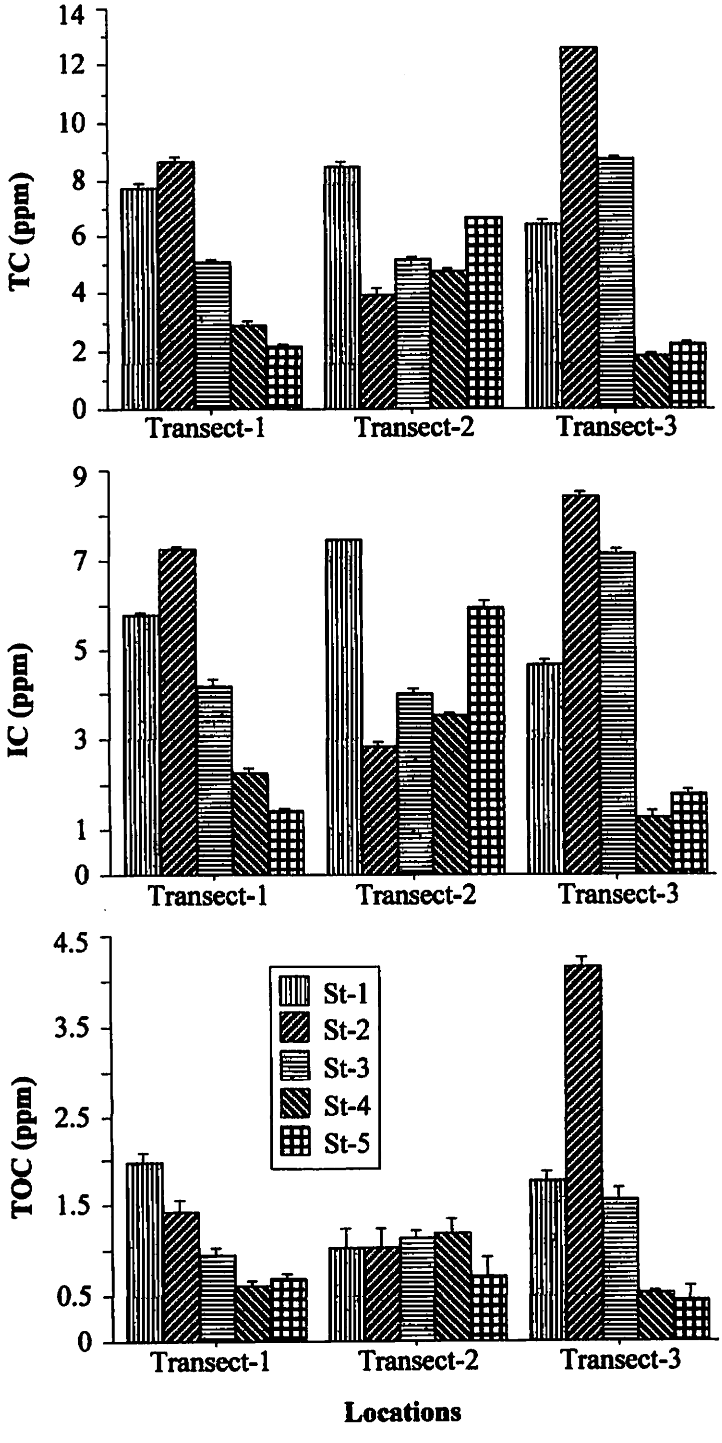

Fig. 8. Concentrations of total carbon (TC), inorganic carbon (IC) and total organic carbon (TOC) in the water of the Shira River mangrove swamp at Iriomote Island. Data indicate mean (±SD), N=3.

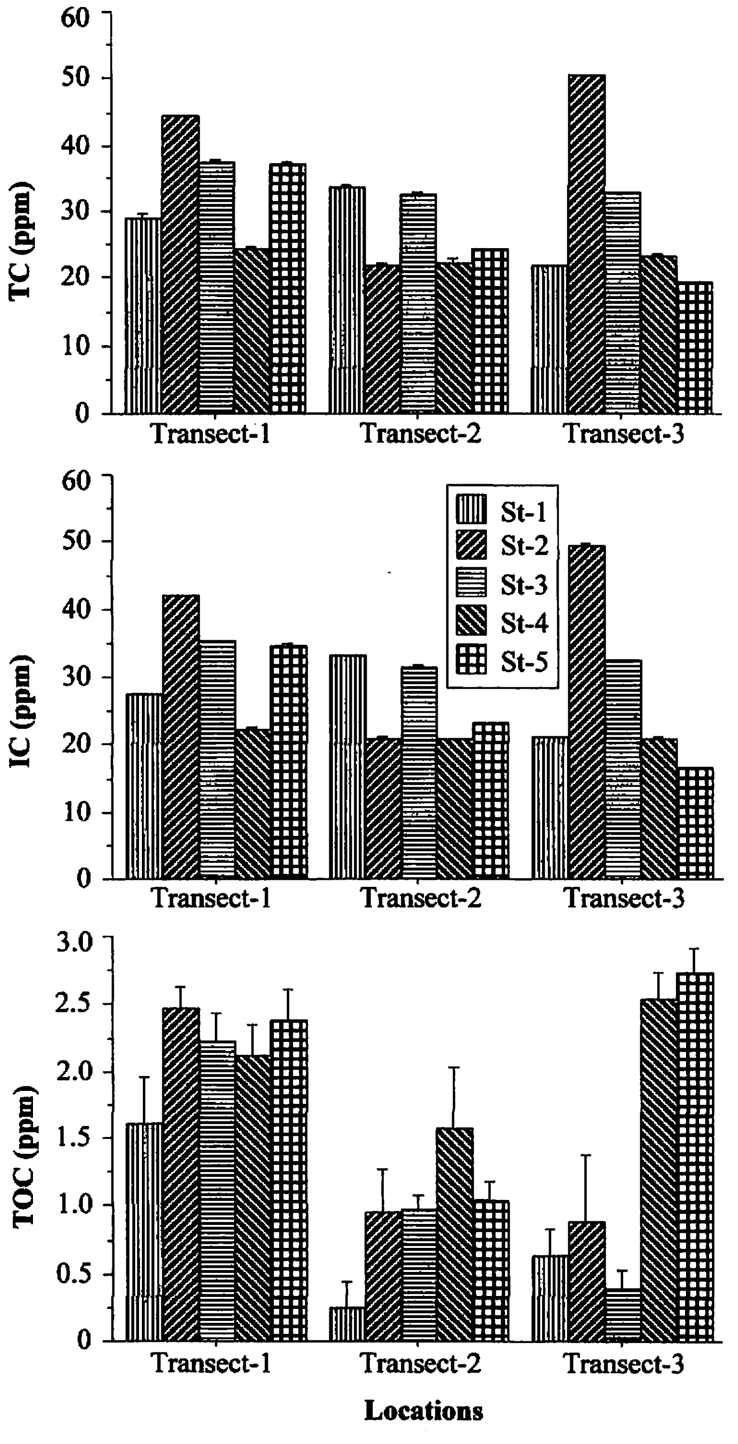

Fig. 9. Concentrations of total carbon (TC), inorganic carbon (IC) and total organic carbon (TOC) in the water of the Nuha River mangrove swamp at Okinawa Island. Data indicate mean (±SD), N=3.

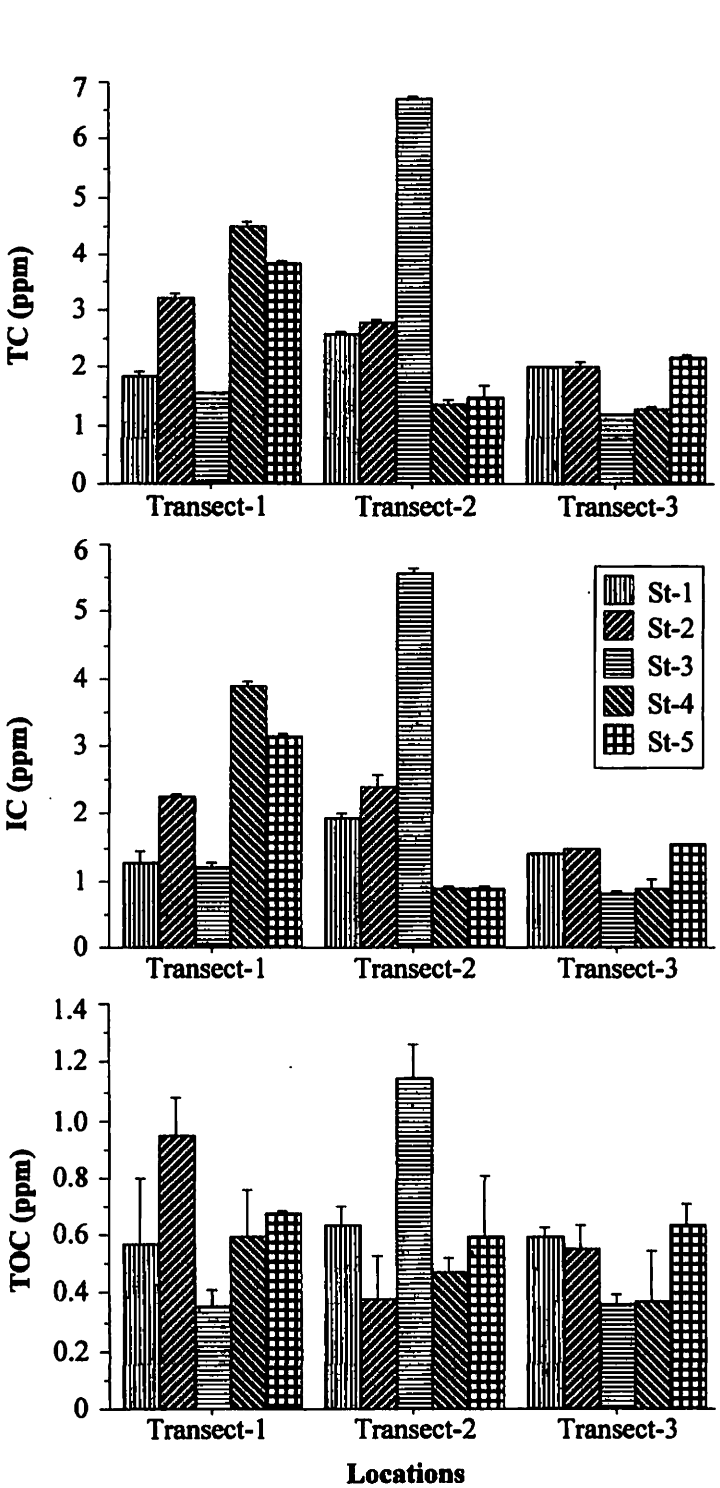

Fig. 10. Concentrations of total carbon (TC), inorganic carbon (IC) and total organic carbon (TOC) in the water of the Nagura River mangrove swamp at Ishigaki Island. Data indicate mean (±SD), N=3.

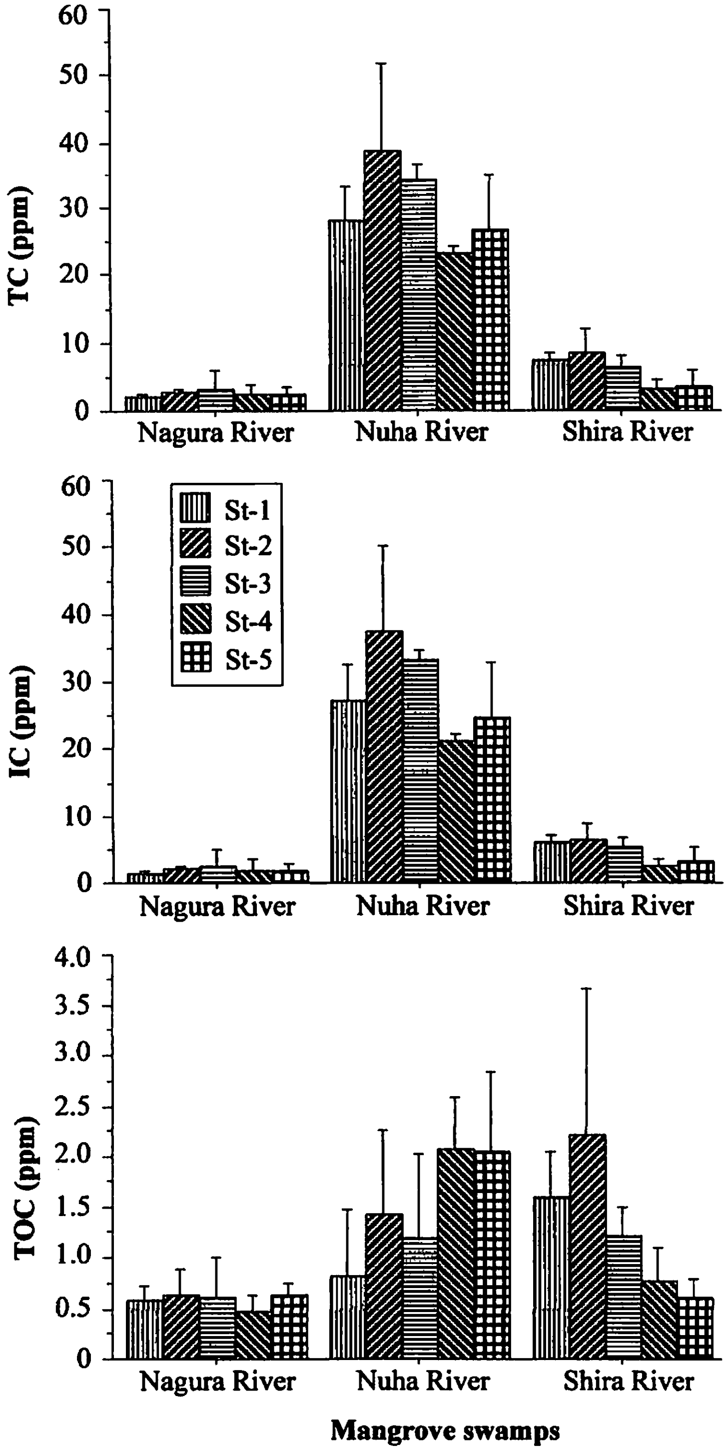

Fig. 11. Comparisons of total carbon (TC), inorganic carbon (IC) and total organic carbon (TOC) contents in the waters of the Nagura, Nuha and Shira River mangrove swamps at the Ryukyu Islands. Data indicate mean (±SD), N=9.

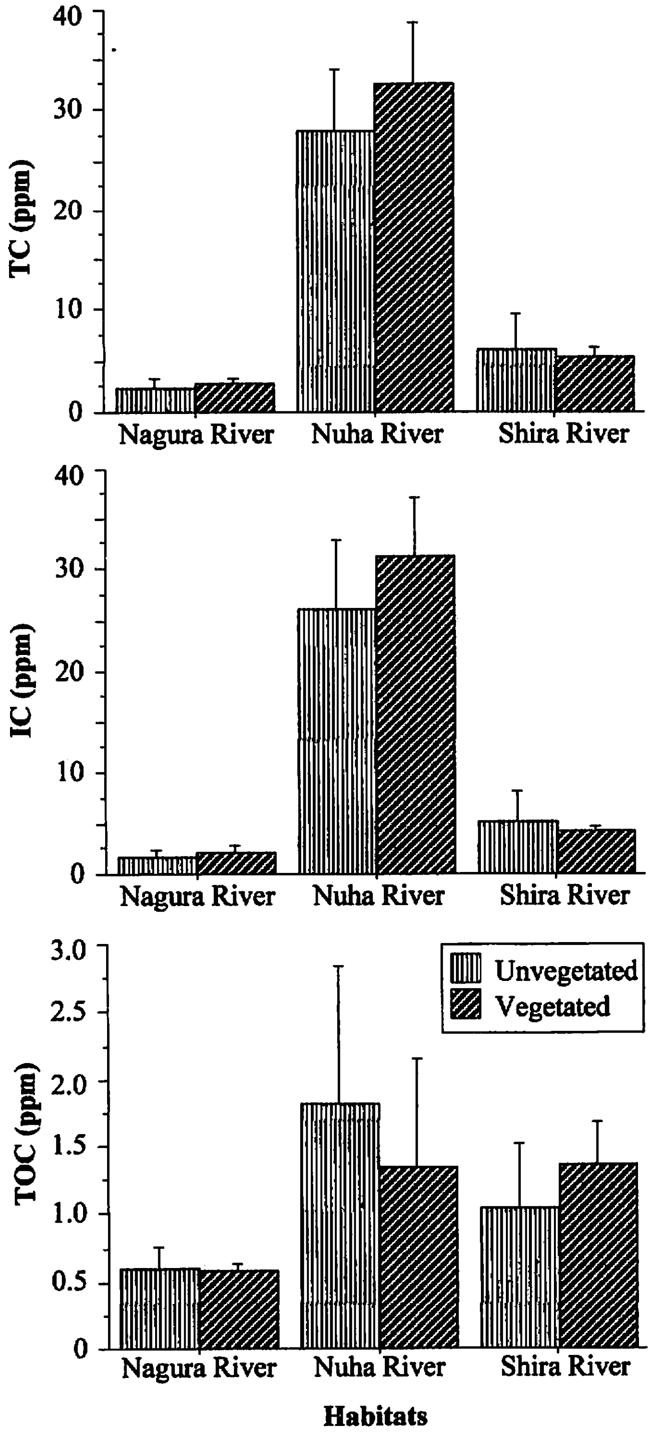

Fig. 12. Coparisons of total carbon (TC), inorganic carbon (IC) and total organic carbon (TOC) contents in the waters of the Nagura, Nuha and Shira River mangrove swamps at the Ryukyu Islands. Data indicate mean (±SD), N=6.

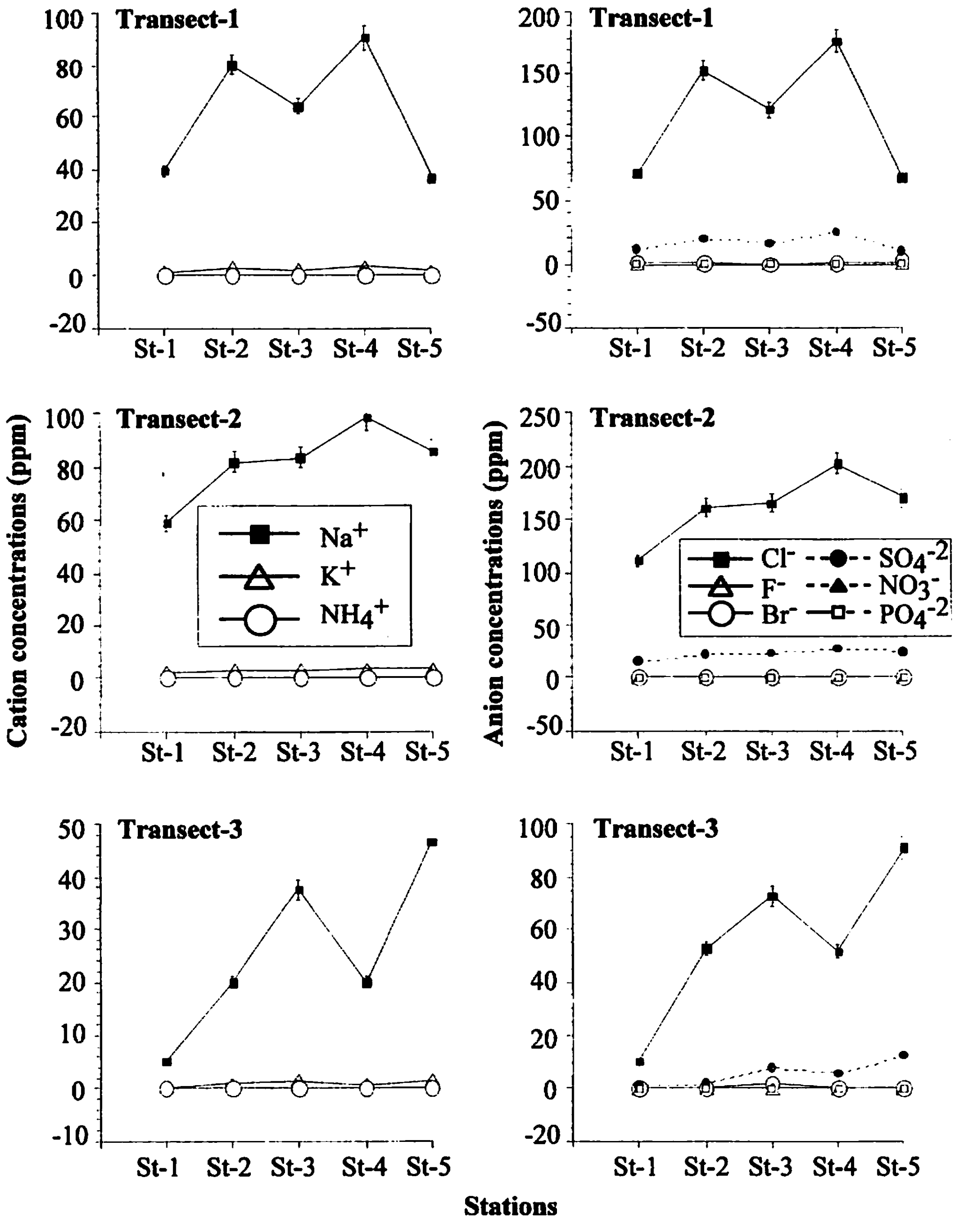

Fig. 13. Concentration of dissolved inorganic nutrients (cations and anions) in the three different transects of the Shira River mangrove swamp at Iriomote Island. Measurements were carried out at low tide in December 2000.

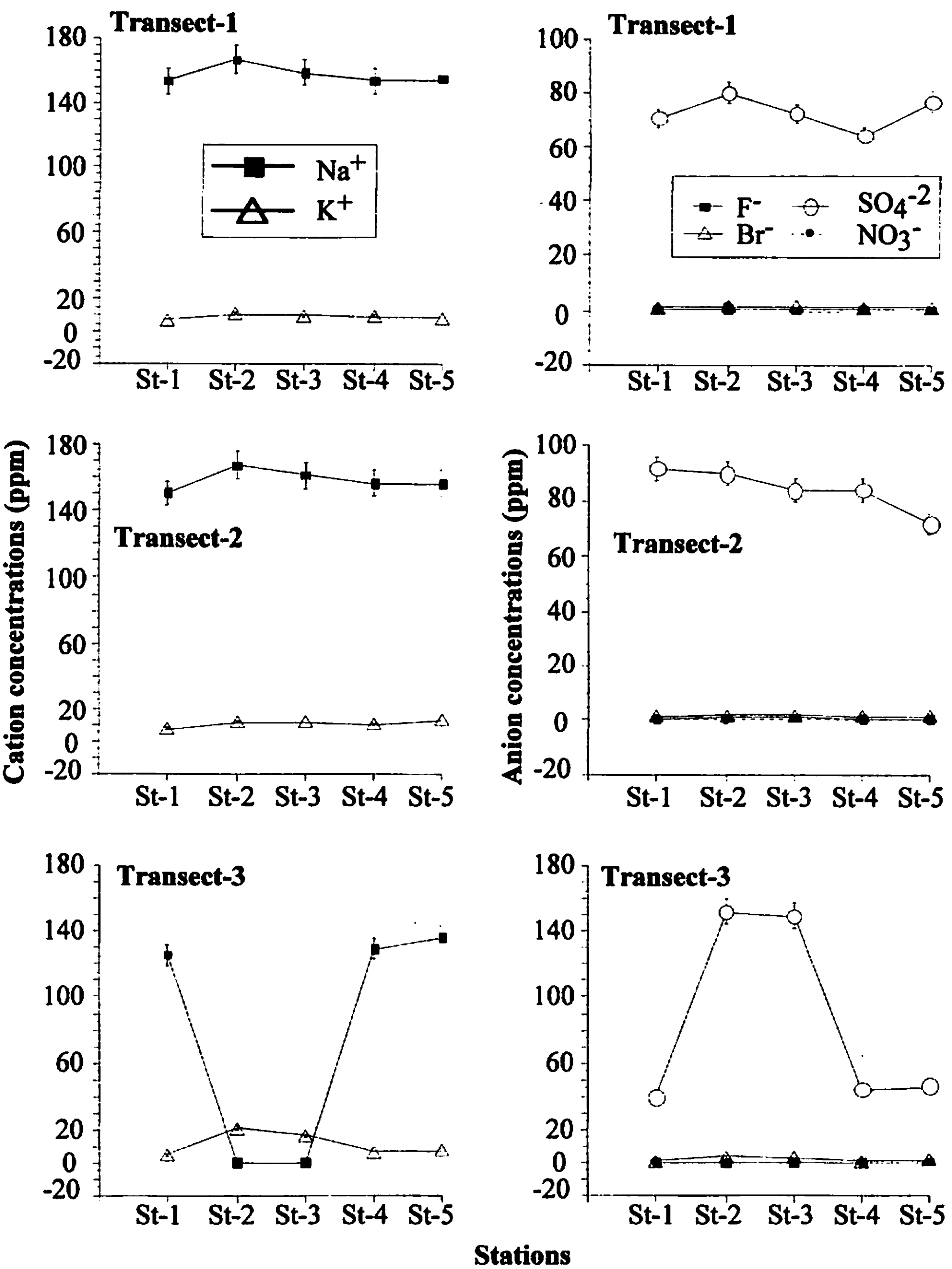

Fig. 14. Concentration of dissolved inorganic nutrients (cations and anions) in the three different transects of the Nuha River mangrove swamp at Okinawa Island. Measurments were carried out at low tide in August 2001.

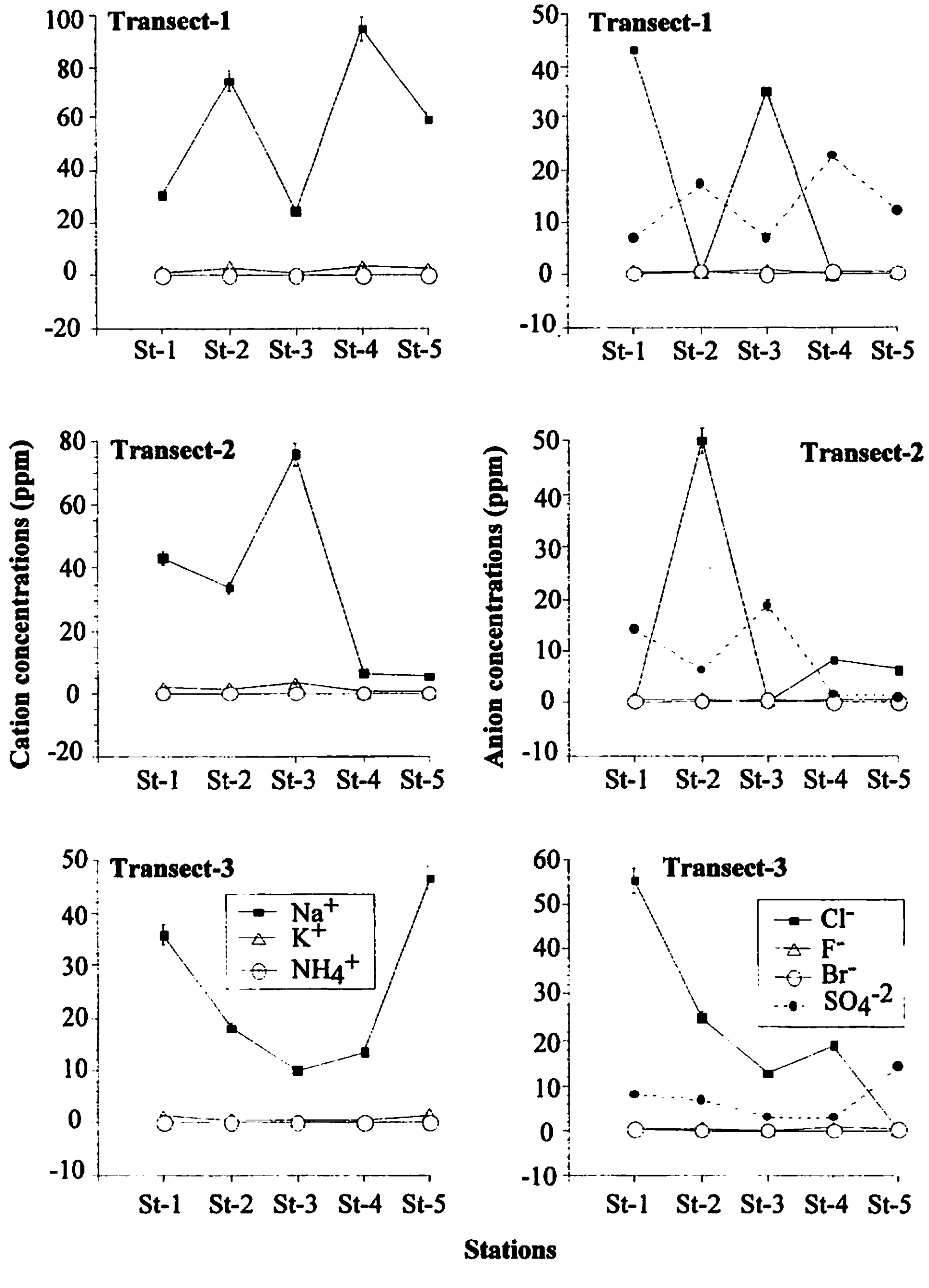

Fig. 15. Concentration of dissolved inorganic nutrients (cations and anions) in the three different transects of the Nagura River mangrove swamp at Ishigaki Island. Measurments were carried out at low tide in September 2002.

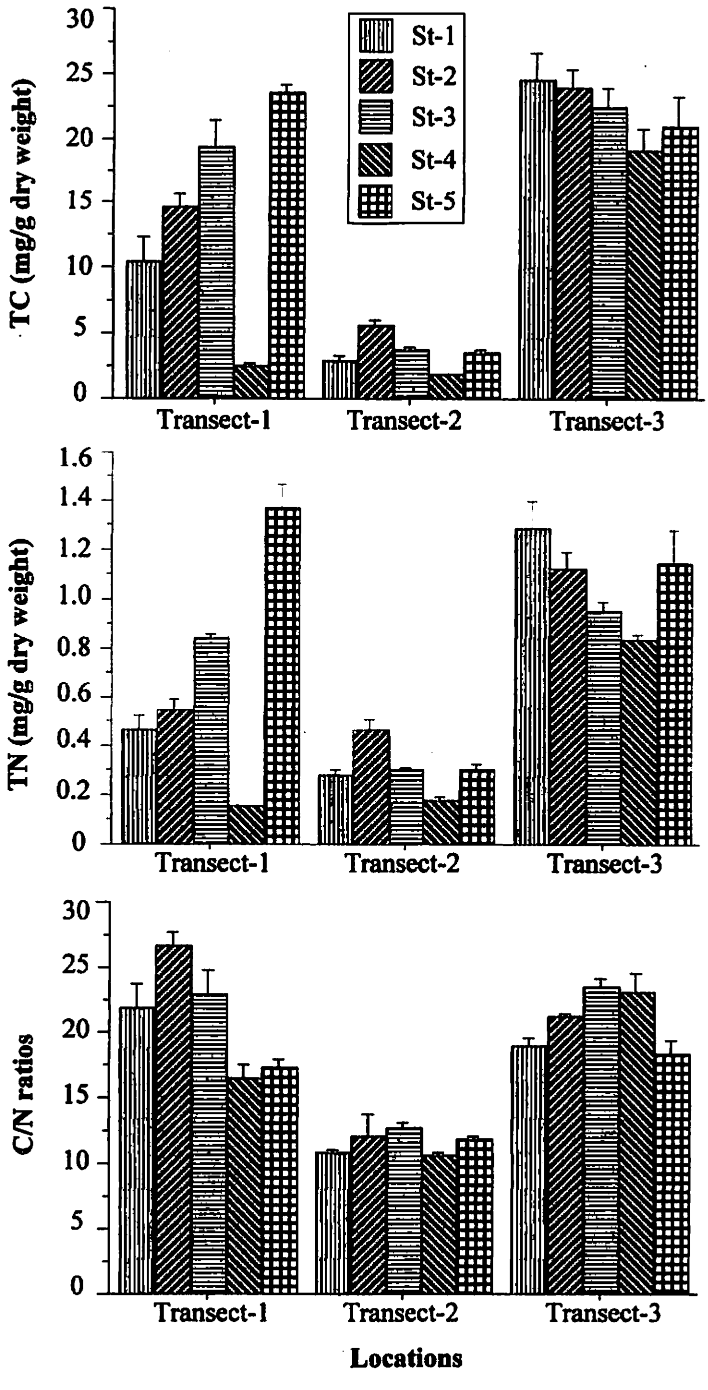

Fig. 16. Concentrations of total carbon (TC) and total nitrogen (TN) contents and C/N ratios in the sediment of the Shira River mangrove swamp at Iriomote Island. Data indicate mean (±SD), N=3.

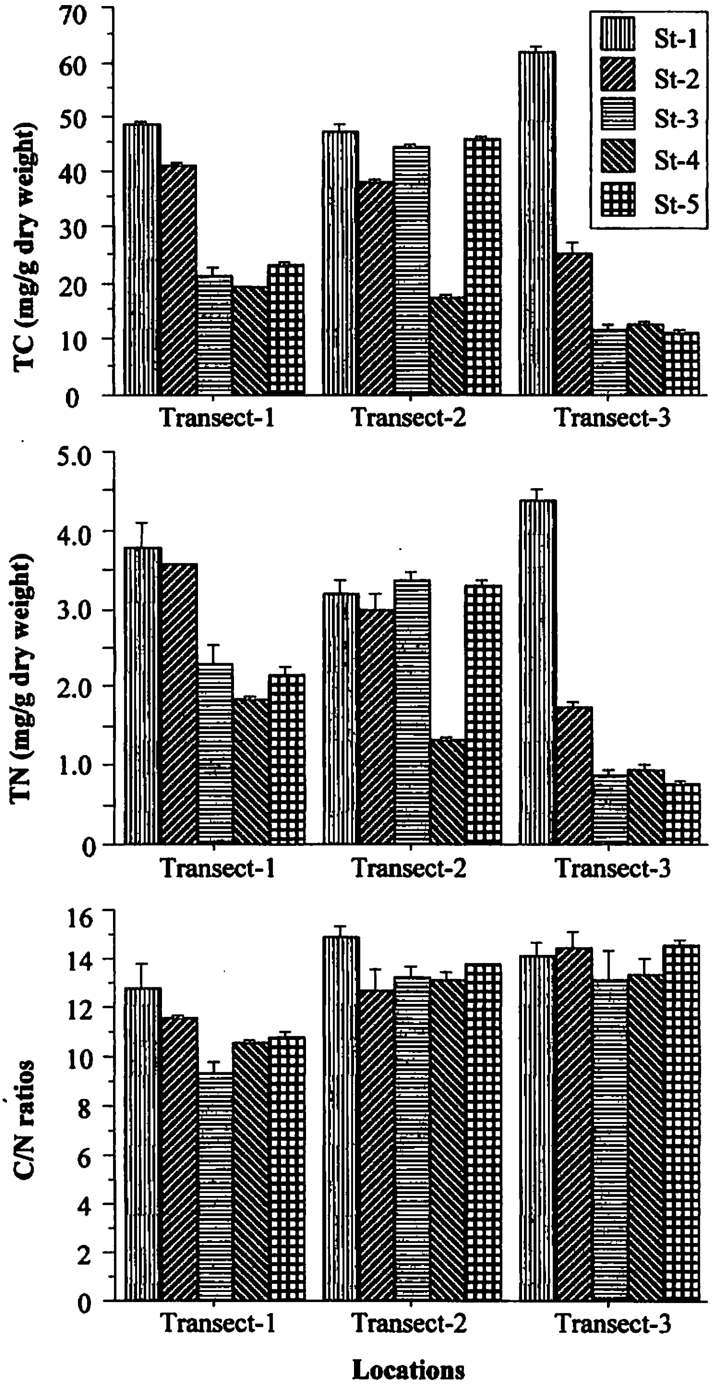

Fig. 17. Concentrations of total carbon (TC) and total nitrogen (TN) contents and C/N ratios in the sediment of the Nuha River mangrove swamp at Okinawa Island. Data indicate mean (±SD), N=3.

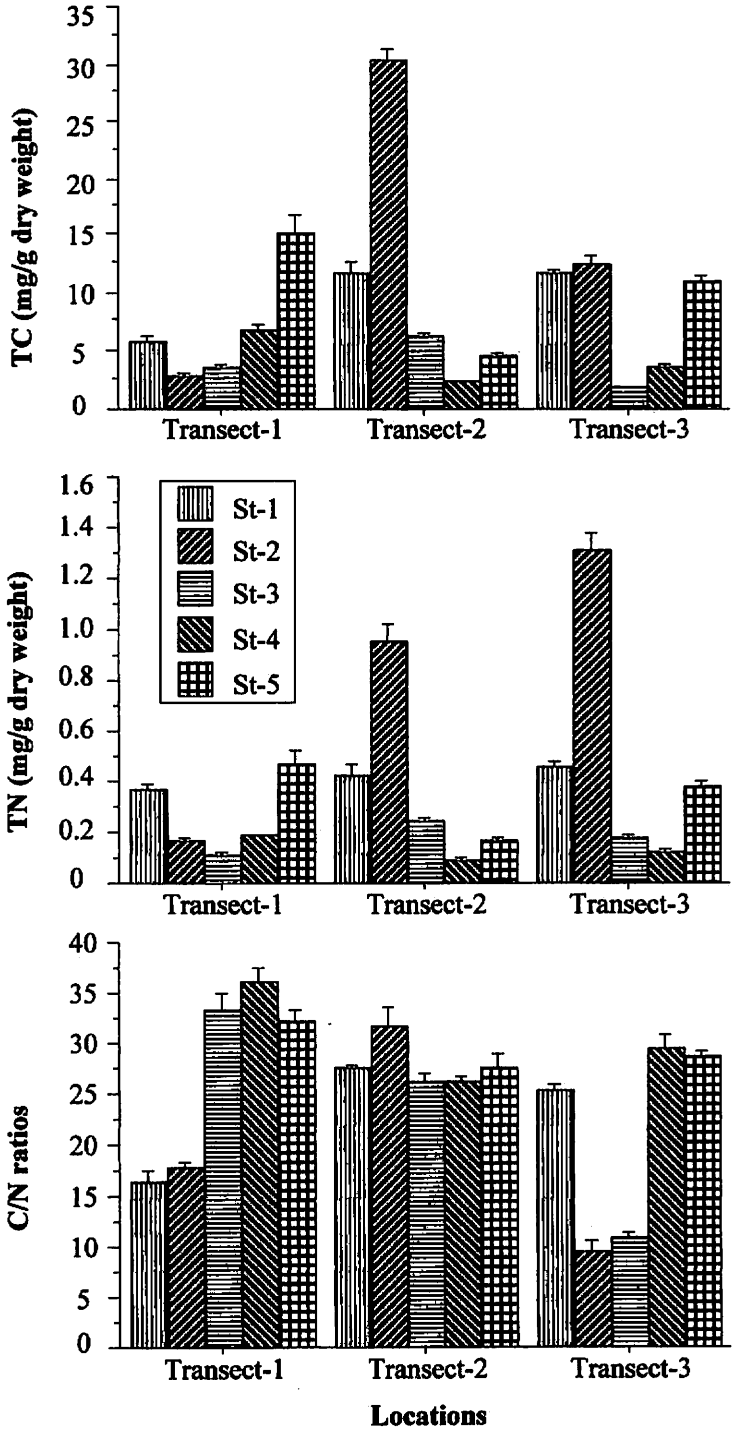

Fig. 18. Concentrations of total carbon (TC) and total nitrogen (TN) contents and C/N ratios in the sediment of the Nagura River mangrove swamp at Ishigaki Island. Data indicate mean (±SD), N=3.

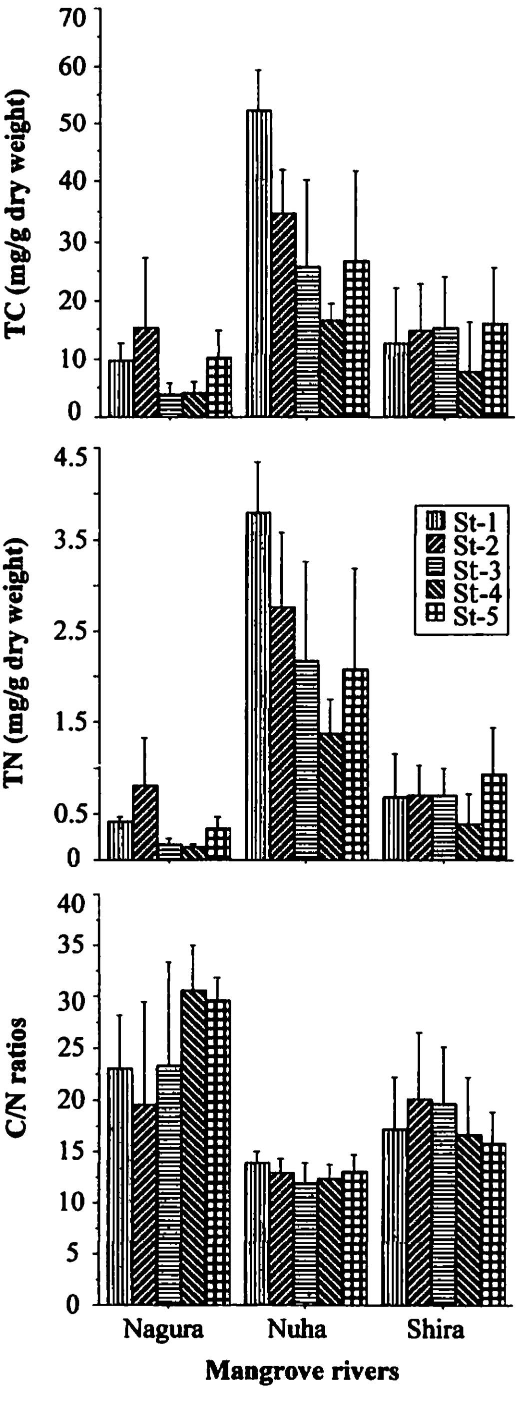

Fig. 19. Comparisons of total carbon (TC) and total nitrogen (TN) contents and C/N ratios in the sediments of the Nagura, Nuha and Shira River mangrove swamps at the Ryukyu Islands. Data indicate mean (±SD), N=9.

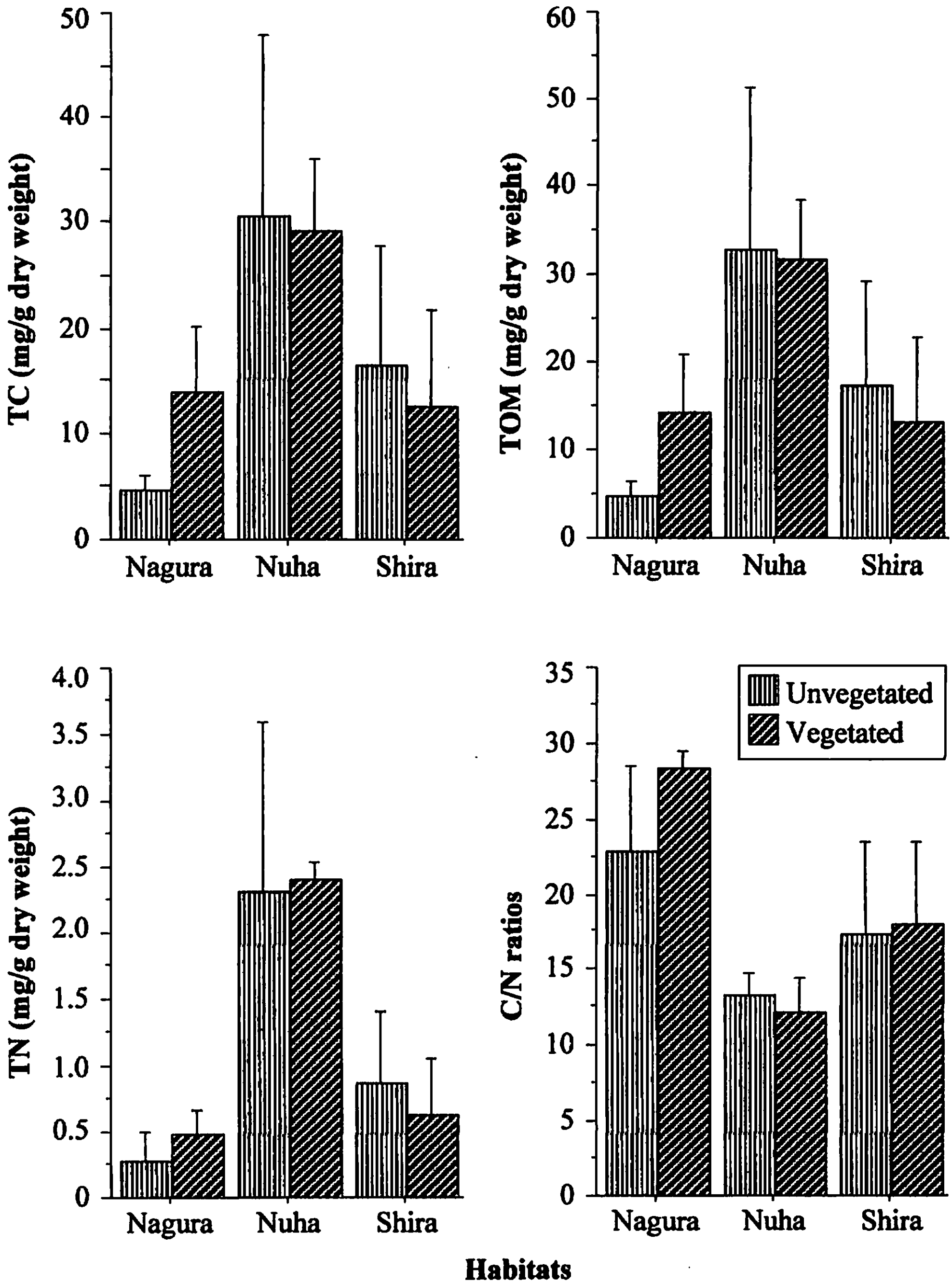

Fig. 20. Comparisons of TC, TN and TOM contents and C/N ratios in the sediments of the Nagura, Nuha and Shira River mangrove swamps at the Ryukyu Islands. Data indicate mean (±SD), N=6.

rivers, stations and their interactions, but two-factor ANOVA and Fisher'S PLSD test detected significant differences ($P<0.0001$) only within these rivers (Fig. 19). Virtually, there were no differences in the C/N ratios between vegetated and un-vegetated area, indicated that the surrounding areas of mangrove swamps also have nutritional value (Fig. 20). There was no significant difference ($P>0.05$, two-factor ANOVA and Fisher's PLSD) between the C/N ratios in the vegetated and un-vegetated part of these rivers (Fig. 20).

Discussion

The total organic carbon (TOC) concentrations in mangrove waters did not vary significantly among the Okinawan mangroves (Table 2). The TOC concentration in Nagura river mangrove swamp was lower than Shira or Nuha river mangrove swamps, reason may be these swamps mainly covered with sand or stone (un-vegetated area). Concentrations of dissolved inorganic nitrogen are usually dominated by ammonium-N in tropical mangrove waters (Alongi *et al.*, 1992). Most of the inorganic nutrients in

Table 2. Comparison of total organic carbon (TOC) in the water of the mangrove swamps of Okinawa Island.

Location	TOC				Reference
	Mean	*SD*	*Range*	*N*	
Shira River mangrove swamp (Iriomote Island)	1.28	0.90	0.45-4.15	45	Present study
Nuha River mangrove swamp (Southern Okinawa)	1.52	0.85	0.25-2.74	45	Present study
Nagura River mangrove swamp (Ishigaki Island)	0.60	0.23	0.35-1.15	45	Present study
Okukubi River mangrove swamp (Central Okinawa)	3.85	–	2.14-5.30	–	Iriondo (1999)

Note: Dash (–) indicates no data.

Table 3. Comparison of dissolved inorganic nutrients in the water of mangrove swamp in Okinawa Island.

Mangrove swamps	Dissolved inorganic nutrients							Reference
	NH_4^+	Br^-	Cl^-	F^-	NO_3^-	PO_4^{-2}	SO_4^{-2}	
Gesashi River (Northern Okinawa)	O	–	–	–	O	O	O	Watanabe (1993)
Nagura River (Ishigaki Island)	O	O	O	O	–	–	O	Present study
Nuha River (Southern Okinawa)	–	O	–	O	O	–	O	Present study
Okukubi River (Central Okinawa)	O	–	–	–	O	O	O	Iriondo (1999)
Shira River (Iriomote Island)	O	O	O	O	O	O	O	Present study

Note: circle (O) indicates present, dash (–) indicates absent.

mangrove water are presented in Okinawan mangrove, when compared with other mangrove region of the world (Table 3). The river discharge large amounts of suspended matter, originated from the soil erosion of forests and farmlands, which contains large amount of nutrients (Tanaka, 1995). Mangrove litter is effectively removed from the forest system by tidal flushing, while removal by grazing and decomposition is minor (Boto and Bunt, 1981). A large volume of mangrove forest litter accumulates in the river sediments, especially in the deeply scoured creek bottom immediately adjacent to the river basin (Tanaka and Choo, 2000). Newell *et al.* (1995) reported that the mangrove forests and their creek system support not only near-shore production by mangrove derived detritus food chains but also high phytoplankton biomass in estuarine waters by the fact that nutrient supply in the mangrove estuary is considerably affected by out-welling from sediments of the mangrove swamp and creek.

Mangroves play a more important role than rivers in marine carbon budgets (Dittmar *et al.*, 2001). Output sources from the mangrove forest include tidal flushing and sedimentation within the mangrove forest. Nitrogen can possibly enter the mangroves through the fixation of atmospheric N by cyanobacteria growing on sediments and on timber lying on the forest floor, by tidal flushing and rainfall runoffs and ground water outflow from the mountain barrier bordering the forest (Mfilinge *et al.*, 2002). Mangrove swamps trap 99% of land derived sediments brought in by runoff in the wet season before they enter into the ocean by out-welling due to chemical and biological processes (Alongi *et al.*, 1992). Skov and Hartnoll (2002) examined the feeding behaviour of some sesarmid crabs and found mud feeding clearly predominated. Several studies have noted that mangrove sesarmid crabs may feed on mud (Robertson, 1986; Camilleri, 1992; Kwok and

Table 4. Comparison of the mangrove sediment C/N ratios from the literature records and the present study.

Location	C/N ratio				Reference
	Mean	*SD*	*Range*	*N*	
Okukubi River mangrove swamp (Central Okinawa)	15.62	1.12	13.62−17.67	−	Iriondo (1999)
Mantang mangrove swamp (West Malaysia)	18.85	−	11.56−26.13	9	Tanaka and Choo (2000)
Maruhubi mangrove swamp (Zanzibar, Tanzania)	19.60	1.00	17.10−23.20	15	Skov and Hartnoll (2002)
Shira River mangrove swamp (Iriomote Island)	17.93	4.72	10.52−26.82	45	Present study
Nuha River mangrove swamp (Southern Okinawa)	12.81	1.64	9.43−14.84	45	Present study
Nagura River mangrove swamp (Ishigaki Island)	25.24	7.93	9.41−36.13	45	Present study

Note: Dash (−) indicates no data.

Lee, 1995; Skov and Hartnoll, 2002). The C and N content of mangrove sediments were measured and the mean sediment C/N ratio was 25.24 at Nagura, 12.81 at Nuha and 17.93 at Shira sites (Table 4). Lower values of C/N ratio indicate more nutritious, so the Nuha river mangrove swamp is highly rich with organic nutrients. These are very similar to those of sites in Tanzania and Kenya (Skov and Hartnoll, 2002; Rao *et al.*, 1994), and are higher than C/N ratios in mangrove sediments from Taiwan, Papua New Guinea, Brazil and India (Alongi *et al.*, 1993; Cheng and Chang, 1999), and lower than those of some north Australian mud (Boto and Wellington, 1984). The sediments in the present study had C/N ratios 4 times lower than mangrove leaves, indicating that sediments could have higher nutritional value than leaves (Alongi, 1988; Islam, 2003). We do not know what proportion of the C and N of the sediment digested by the mangrove sesarmid crabs. However, stable isotope studies from Tanzania and India indicated that mangrove sediment was an important dietary source for sesarmid crabs. Robertson (1986) suggested that sesarmid crabs forage bacteria from the mud surface. Bacteria may certainly reach high densities in mangrove mud and are highly digestible by sesarmid crabs feeding on sedimentary bacteria (Alongi, 1988).

Recent research on Indo-Pacific mangroves has confirmed the significant role played by sesarmid crabs in the structure and function of these ecosystems. Through the feeding activities of the sesarmid crabs, large proportions of organic matter production are recycled within the forest (Lee, 1998). The sesarmid crabs processed organic matter could also form the basis of a coprophagous food chain involving small invertebrates, or be re-exported as micro-particulates (Lee, 1997). Bioturbation by the crabs also results in changes in surface topography, particle size distribution and degree of aeration. Growth and reproduction of the crabs may in turn be influenced by the associated mangrove species, mainly through the provision of food. The semi-terrestrial and air-breathing habit of the sesarmid crabs probably makes them tolerant of deoxygenation caused by organic enrichment, but development of the landward mangroves will strongly affect survival of the crabs.

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