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Feeding habits of the sesarmid crab *Perisesarma bidens* (De Haan) in the mangroves of the Ryukyu Islands, Japan

M. Sirajul Islam* and Tsuyoshi Uehara
Department of Marine and Environmental Sciences, University of the Ryukyus, Okinawa 903-0213, Japan
*Corresponding and present address: Department of Environmental Science and Resource Management, Mawlana Bhashani Science and Technology University, Tangail-1902, Bangladesh

Abstract

Feeding habits of the sesarmid crab *Perisesarma bidens* (De Haan) was investigated in the mangroves of the Ryukyu Islands, Japan. Stomach content analysis showed that their diet consists mainly of mangrove leaves fragments, with small amounts of animal, algae and sediment matters, indicating that *P. bidens* is primarily detritivorous. The consumption rate of *P. bidens* was investigated under laboratory conditions by offering three different types of *Kandelia candel* mangrove leaves. Crab survived by eating green, yellow or brown leaves, preferring brown to either green or yellow leaves. Consumption rate of brown leaves was significantly higher when crabs were provided with green, yellow and brown leaves together, than when provided separately. It is considered that the brown leaves have a soft tissue, which is easily torn by the crab chelae and have apparently low C/N ratio. The C/N ratio of faeces, which indicated lower value than that of burrow leaves or sediments, derived from the symbiosis of bacteria in the stomach. The C/N ratio showed that sediments had C/N ratios 2/3 times lower than leaves sequestered in the burrow, indicating that mangrove sediments could have higher nutritional value than mangrove leaves. *Perisesarma bidens* showed significant consumption rates of mangrove detritus, therefore, it may have the important role as the grazer of mangrove detritus in view of the nutrient cycle in the mangroves.

Key words: Mangrove leaves, Sesarmid crab, C/N ratio

Introduction

The sesarmid crabs are diverse and abundant in mangroves: they affect the soil chemistry and primary productivity, mangrove zonation and colonization, food web dynamics, nutrient retention, litter decomposition, and offshore export of mangrove production (Smith *et al.* 1989, Skov and Hartnoll 2002, Camilleri 1992, Sheaves and Molony 2000). About fifty species of sesarmid crabs have been reported to be predominantly associated with mangrove ecosystems (Islam *et al.* 2002). Although most sesarmid crabs are opportunistic scavengers, many have essentially detritivorous as they feed on dead leaves that have fallen off the mangrove, in particular members of the family Sesarmidae, which are important components of mangrove ecosystems in the Indo-West Pacific, Africa, the Caribbean and South America (Schoth *et al.* 1968).

The crab *Perisesarma bidens* (De Haan) is most common and typically associated with mangroves in tropical and subtropical estuaries and coastal lagoons in the Indo-West Pacific, being known from the Bay of Bengal to the Andaman Islands, Sri Lanka, India, Malay Archipelago, the Philippines, Hong Kong, Taiwan, Korea, and Tokyo Bay to Kyushu and the Ryukyu Islands of Japan (Sakai 1976, Dai and Yang 1991). This species live in burrow constructed in the edges or within the mangroves or in the reed marsh higher than ordinary high water mark, and among the roots, trunk, and lower branches of mangrove trees. This crab is commonly occurred in the mangroves of the Ryukyu Islands, Japan (Islam *et al.* 2000, 2002). The peak spawning season of this crab is early June to early August every year.

Stomach contents are the primary means of verifying the natural diets of many crustaceans that feed on macroscopic food, although the mouthparts and gastric mills of the crabs generally reduce the food to small fragments (Robertson 1991). In many cases, absolute or relative quantities of food ingested are difficult to measure, and the type of food is difficult to identify (Smith *et al.* 1989). To date methods for stomach contents analysis of crustaceans have been poorly documented in the literature. Williams (1981) established a method for analyzing the natural diet of portunid crabs. Stomach contents of varunid and sesarmid crabs were analyzed to get an idea about their natural diets by Mia *et al.* (2001) and Islam *et al.* (2002). Multiple field and laboratory studies leave no doubt that sesarmids ingest mangrove leaves. Leaves often comprise more than 85% of sesarmid stomach contents (Dahdouh-Guebas *et al.* 1999), and sesarmids may remove 79 to 95% of mangrove leaf fall from the forest floor (Sheaves and Molony 2000). The easiest method is the frequency of occurrence method which involves the examination of stomach contents visually, or with a microscope, with the different food items sorted and identified in each stomach. The percentage of stomachs an item is found in is used as a measure of its importance in the diet.

Freshly fallen (senescent) mangrove leaves have notably high C/N ratios several times greater than 17, a value suggested as a general maximum for sustainable animal nutrition (Russel-Hunter 1970, Twilley *et al.* 1997, Robertson 1988). Giddins *et al.* (1986) proposed that crabs might plaster leaves onto burrow walls to allow tannins to leach and increase the edibility of leaves. In addition, leaf nitrogen (N) content increases and C/N ratio decreases during breakdown, through microbial activity (Twilley *et al.* 1997, Cundell *et al.* 1979). Thus by not eating leaves immediately, but leaving them to age on the burrow wall, crabs might not only improve the digestibility of leaves but also decrease the C/N ratio of their diet (Giddins *et al.* 1986). Leaf material ingested by some sesarmid and xanthid crabs is incompletely digested, and much of it is returned to the environment in large faecal pellets, which contain more finely divided leaf materials (Misra *et al.* 1985). The aims of the present study were: to determine the diet of the crabs through an analysis of their stomach contents, the consumption rate of mangrove leaves, preference of different types of leaf, C/N ratios in leaves, sediments and faeces, and nutritional composition in the diet of *P. bidens*.

Materials and Methods

Study sites and experimental materials

Adult crabs of *Perisesarma bidens* were collected from two mangrove swamps: the Nuha River in the Okinawa Island (N=20) and the Shira River in the Iriomote Island (N=20), during April 2004 to March 2005 to analyze stomach contents.

Non-gravid, healthy adults of *P. bidens* and three types of *Kandelia candel* mangrove leaves (green, yellow, brown) were collected from the Nuha River mangroves at Okinawa Island, during July 2004, to examine the feeding habit and food choice of crabs under laboratory conditions.

For the analysis of C/N ratios, mangrove leaves and sediments were collected from the burrow of *P. bidens* at the Nuha and the Shira River mangroves between April 2004 and March 2005. Leaves and sediment samples were collected from at least ten to fifteen burrows per station. The three types of *K. candel* leaves were also collected from this area for analyzing their C/N ratios and nutritional composition. Faeces of *P. bidens* were collected both from field and laboratory to determine its C/N ratios during April 2004 to March 2005.

Stomach content analysis

Crabs were fixed in 10% formalin solution immediately after collection. Stomach content analysis took place within one month of sampling. The stomach was carefully removed from each crab and the contents washed into a Petri dish with distilled water. A drop of stomach contents was placed on a glass slide and examined with a binocular stereomicroscope (Nikon SMZ-10, x25). The nature of the diet was determined using the percentage occurrence method described by Williams (1981). This method gives a measure of the regularity with which a particular food item is eaten in the population sample, and is recommended when the diet includes several different food items. The occurrence of each different food item is recorded for each stomach, and results expressed as the frequency of each item among the stomachs constituting the population sample. Stomach contents were scored for the following different food item categories: plant materials, animal materials, algae, silt/clay, and unidentified materials.

Feeding behavior

Crabs (N=20 for each leaf type) were housed separately for two days in ventilated plastic containers containing 100ml of brackish water (15‰ salinity) to acclimate them to laboratory conditions. Each container was tilted slightly for drainage. Crabs were starved for 12 hours prior to the experiments, so that faecal production ceased. Leaves were divided into green, yellow and brown, on the basis of their color. Green and yellow leaves were handpicked from the trees, while brown leaves were taken from the forest floor. Each crab received only a single type of leaf. Each leaf was weighed at the beginning of the experiment and daily to the nearest of 0.001g, using an electric balance. A new leaf of the same type was added to each container when less than 0.03g of the previous leaf remained. All leaves were photocopied at the beginning of the experiment, so that the impact of feeding could be visualized. The carapace length (CL) and carapace width (CW), and body weight (BW) of all crabs was measured at the beginning of the experiment, and once a week to monitor growth. The experiment was conducted over a period of eight or more weeks. Water in all containers was changed on alternate days. The green, yellow and brown leaves of *K. candel* were provided together as food in order to investigate the leaf choice by the individuals of *P. bidens* separately. The experiment was conducted over a period of eight or more weeks. Growth changes of crabs by body weight and leaf consumption rates were monitored as described in the above experiment.

C/N ratio of burrow leaves and sediments

Collected leaves were rinsed with distilled water and dried in an oven at 60^0C with air circulation for 2 days. Dried samples were ground with a mortar and pestle. Ground samples were stored in desiccators until analysing in a Shimadzu (NC 80 model) high-sensitivity C: N Analyser. For each sample, 3 replicates of 0.1g dry weights were placed in ceramic sample boats and ignited at 830^0C for 1 minute. The connected Chromatopac recorder printed out the carbon (C) and nitrogen (N) amounts as detected by the Sumigraph Detector.

Sediment samples were 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 oven dried at 60^0C overnight. Dried samples were treated with diluted hydrochloric acid (HCl, 2N) overnight to remove carbonates and bicarbonates. Acid treated samples were oven dried again, ground using a mortar and pestle, and stored in a desiccators prior to analysis in a Shimadzu (NC 80 model) high-sensitivity C: N Analyser, as described for the leaf samples above.

C/N ratio of fresh leaves and faeces

Faeces were collected from crabs both in the field and laboratory (the latter supplied with green, yellow and brown leaves separately), oven dried at 60^0C overnight and analysed as described for the leaf samples.

Nutritional composition of leaves, sediments and waters

To assess the nutritional composition of mangrove leaves, samples of each type of leaf (green, yellow and brown) were analyzed by the Okinawa Environmental Technology Association, Japan. The amounts of energy and carbohydrate in 100g wets and dry leaf sample were assessed. The amount of carbohydrate and energy were estimated by the following equations: Carbohydrate = 100 - (Water + Ash + Fat + Protein), Energy = (Protein x 4) + (Fat x 9) + (Carbohydrate x 4). The concentrations of K^+, Na^+, NH_4^+, NO_2^-, NO_3^-, PO_4^{-2} and SO_4^{-2} were measured by spectro-photometer (DR/2000, HACH).

Statistical analysis

Comparative data on stomach fullness, food consumption and growth rate, and C/N ratios of leaves, sediments and faeces were analyzed using multiple analyses of variance (MANOVA) on the statistical package Stat View 5. A two-factor ANOVA was used to evaluate differences between sites and treatments of the experiments. Fisher's PLSD, Wilk's Lambda, Roy's Greatest Root, Hotelling-Lawley Trace and Pillai Trace indicated where there were significant differences in the mean. Mean values are reported with 95% confidence intervals and 5% significance levels.

Results

Stomach contents

The diet of *Perisesarma bidens* consisted mainly of mangrove leaf fragments, complemented with some sediment materials (Fig. 1). Plant materials were the most common in all cases. The second most common category was clay or mud, which was also higher in winter than in summer. Relatively small amounts of animal matters were found in most of the individuals, during both the summer and winter seasons. Unidentified materials were also found in both seasons. No significant differences were detected between summer and winter diets ($P>0.05$, Fisher's PLSD).

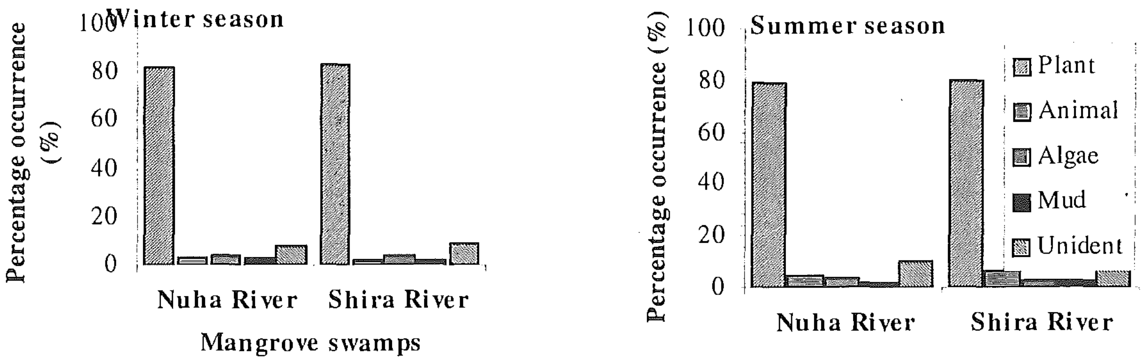


Fig. 1. Stomach contents of *Perisesarma bidens* (De Haan), collected from two different mangrove swamps. N=15.

Feeding behavior

Crabs were survived during experimental period, indicating that a diet of only green, yellow or brown leaves of *Kandelia candel* is sufficient for survival for an eight weeks period. Feeding commenced at varied parts of the leaves supplied (Fig. 2). Green leaves were consumed at the least and brown leaves to the most. Crabs preferred to feed on brown to yellow or green leaves, and also grew fastest on brown leaves than other two types of leaves ($P<0.0001$, Fisher's PLSD). When given alternatives, crabs preferred brown to yellow, and yellow to green leaves. The average weekly consumption rate of brown leaves was higher than that of green or yellow leaves during the course of experiment, as were weight changes ($P<0.0001$, Fisher's PLSD).

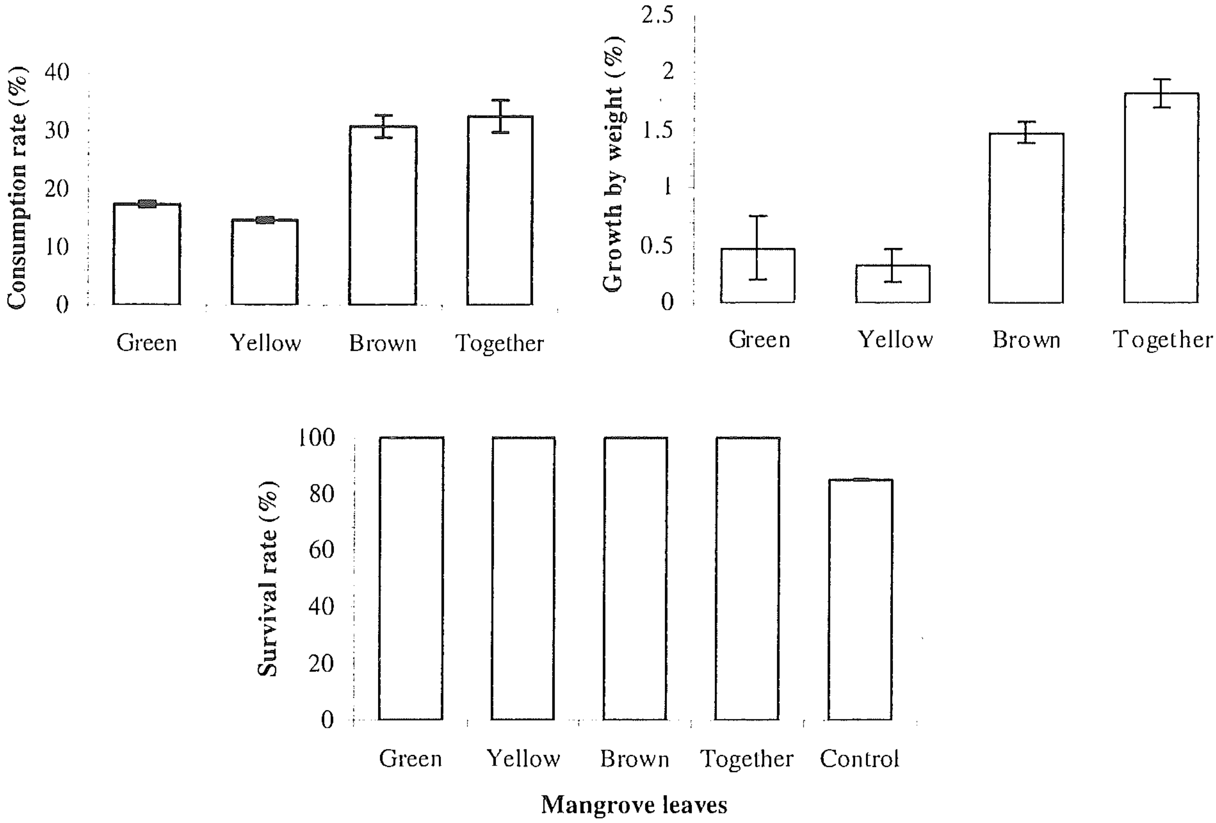


Fig. 2. Consumption, growth and survival rate of *Perisesarma bidens* (De Haan) when fed on green, yellow and brown leaves of *Kandelia candel*, separately and together. Data indicate mean (±SD) of eight weeks experiments, N=24. Significant differences ($P<0.0001$, Fisher's PLSD, 5% significance level) were found among three types of leaves supplied except survival rate.

C/N ratios

C/N ratios were always higher in leaves taken from burrows in the Shira River (60.01) than those taken from the Nuha River (43.89) sites (Fig. 3). The C/N ratio in burrow sediments of the Nuha River (20.76) was lower than in the Shira River (23.31) sites (Fig. 4). Significant differences ($P<0.0001$, Fisher's PLSD) were found among C, N and TOM contents and C/N ratios of burrow leaves and sediments between the Nuha and the Shira River sites. C/N ratios were always higher in green fresh leaves than in yellow or brown leaves ($P<0.0001$, Fisher's PLSD) (Fig. 5). The C/N ratio was lower in natural faeces than in faeces produced under laboratory conditions ($P<0.0001$, Fisher's PLSD) (Fig. 6).

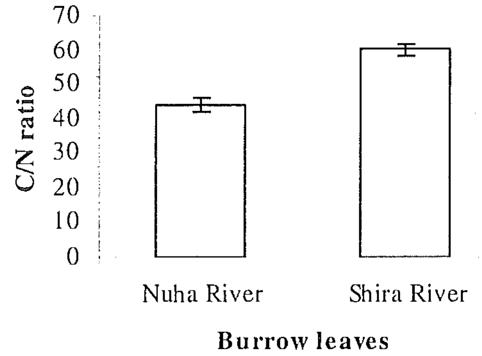
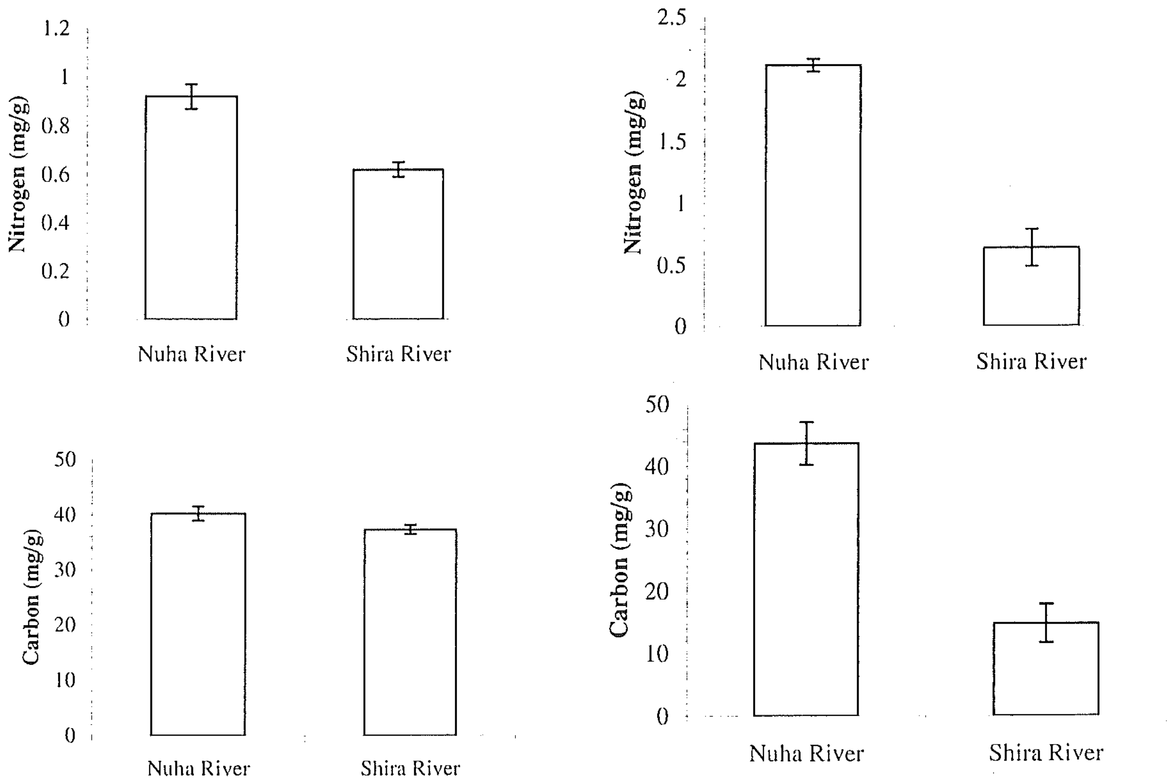


Fig. 3. Concentrations of C and N contents, and C/N ratios in burrow leaves of *Perisesarma bidens* (De Haan) from two different mangrove swamps. Data indicate mean (±SE), error bars = 95% confidence interval, N=15. Significant differences ($P<0.0001$, Fisher's PLSD, 5% significance level) were found between two mangroves.



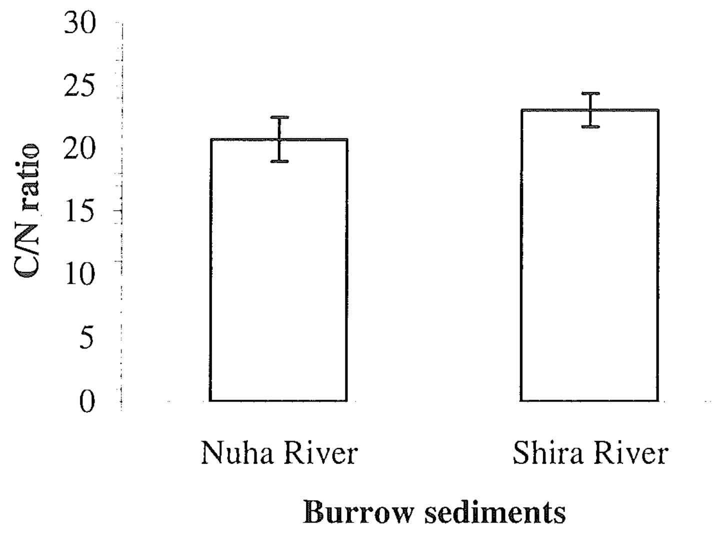


Fig. 4. Concentrations of C and N contents, and C/N ratios in burrow sediments of *Perisesarma bidens* (De Haan) from two different mangrove swamps. Data indicate mean (±SE), error bars = 95% confidence interval, N=15. Significant differences (P<0.0001, Fisher's PLSD, 5% significance level) were found between two mangroves.

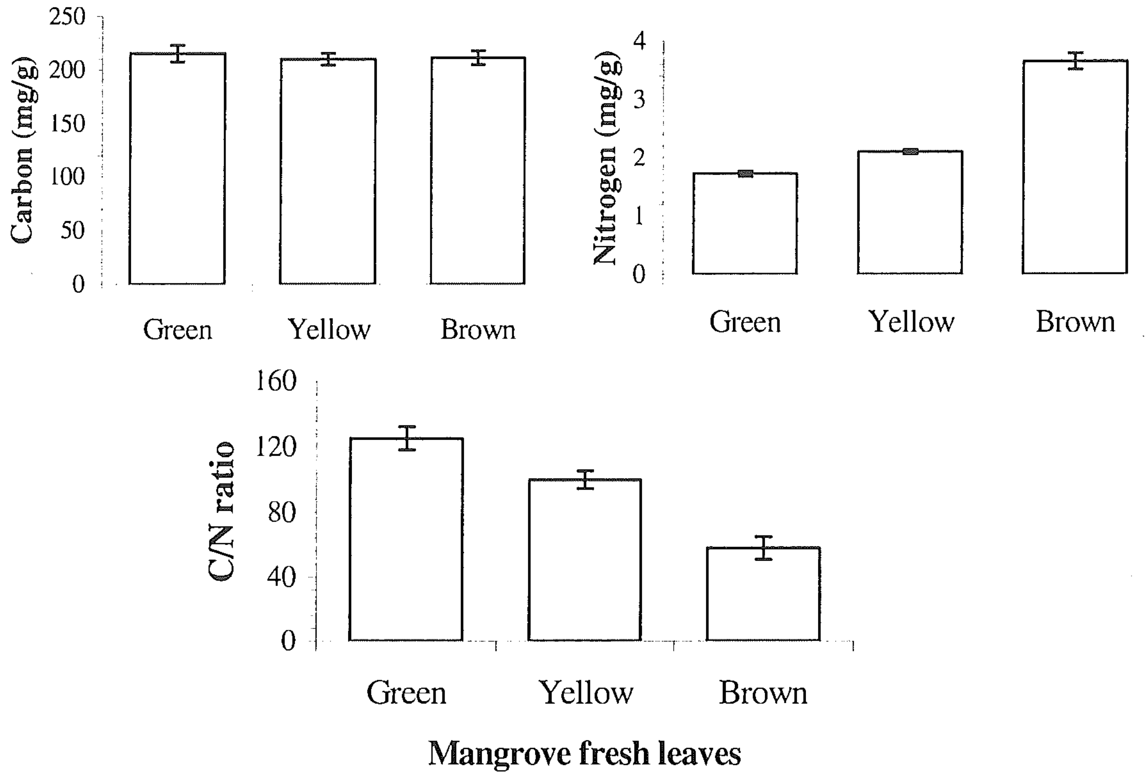


Fig. 5. Concentration of C and N contents, and C/N ratios in fresh leaves of *Kandelia candel* mangrove. Data indicate mean (±SE), error bars = 95% confidence interval, N=15. Significant differences (P<0.0001, Fisher's PLSD, 5% significance level) were found among three types of leaves.

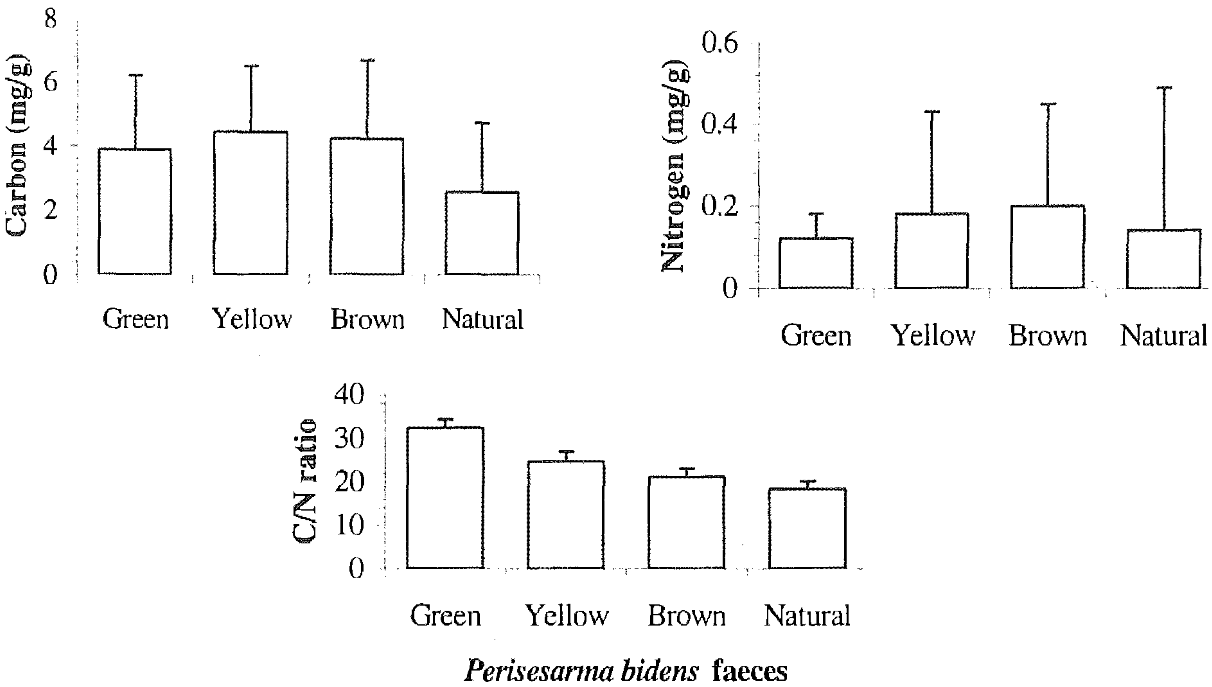


Fig. 6. Concentrations of C and N contents, and C/N ratios in faeces of *Perisesarma bidens* (De Haan) produced in the laboratory and the field. Data indicate mean (±SE), error bars = 95% confidence interval, N=15.

Nutritional compositions

Dry leaves were more nutritious than wet leaves in three different types (Fig. 7). The amount of carbohydrate and energy are always higher in brown leaves than that of yellow or green leaves (Fig. 7). The nutrients NH_4^+, NO_3^-, PO_4^{-2} and SO_4^{-2} are available in both mangrove habitats as well as in sediments and waters (Table 1).

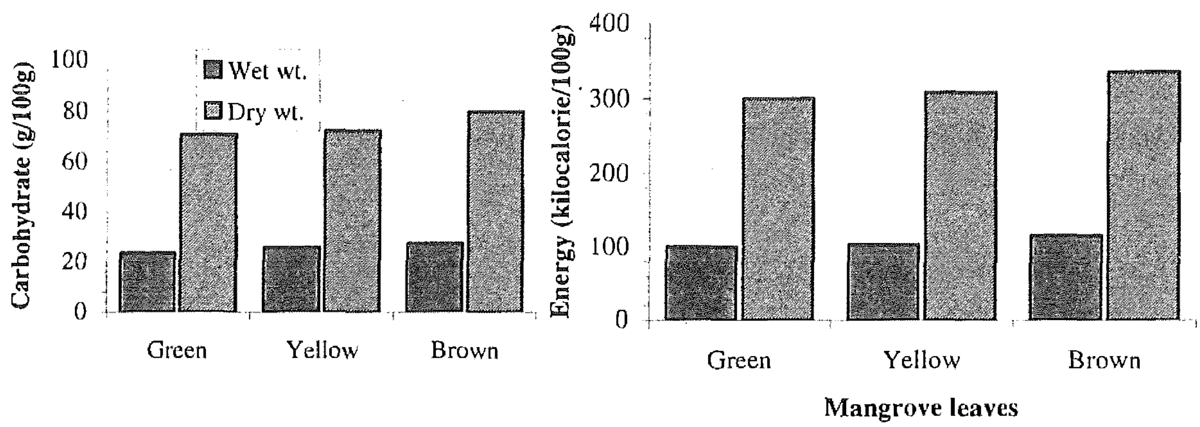


Fig. 7. Nutritional composition of *Kandelia candel* leaves in 100g wet and dry weights. Samples were originated from the habitat of *Perisesarma bidens* (De Haan) in the Nuha River mangroves on Okinawa Island. N = 5.

Table 1. Nutritional compositions of burrow sediments and waters

Sites	Nutrients						
	K^+	Na^+	NH_4^+	NO_2^-	NO_3^-	PO_4^{-2}	SO_4^{-2}
Sediments							
Nuha River	Nd	Nd	0.14	0.03	1.28	0.09	0.04
Shira River	Nd	Nd	0.12	0.03	1.30	0.08	0.04
Waters							
Nuha River	10.31	151.72	0.00	Nd	0.39	0.00	80.76
Shira River	2.11	57.19	0.03	Nd	0.34	0.08	14.95

Nd = not detected.

Discussion

The stomach contents of *Perisesarma bidens* shows that they are mainly detritivorous. This confirms the result of previous studies in related species of sesarmid crabs which are major players in leaf degradation and nutrient regeneration in mangroves (Islam *et al.* 2002, Dahdouh-Guebas *et al.* 1999, Smith *et al.* 1991). Silt and clay materials found in their stomach may have been incidentally eaten with leaf materials. More clay was found the stomachs during the winter than summer, where the crabs remaining in their burrows for extended periods, when they may consume clay to assuage their hunger. Only small amounts of animal material were found in stomach contents. This may be accidentally consumed together with the leaves, or when fallen leaves were insufficient in the crab surroundings. *Neosarmatium indicum* and *N. meinerti* descended from their burrows above the high tide mark to feed on mangrove leaves, which they took into their burrows (Dahdouh-Guebas *et al.* 1999, Islam *et al.* 2000). *Perisesarma bidens* showed the same activity in the Nuha River mangroves, where *Kandelia candel* is abundant, but little there is accumulation of leaf litter. This may be due to the presence of leaf-eating crabs like *P. bidens.* Based on the present study, it is concluded that the sesarmid crab *P. bidens* is detritivorous, and that there is no seasonal difference in its natural diet.

Consumption rate of brown leaves were higher than green or yellow leaves of *K. candel.* Therefore, *P. bidens* clearly preferred brown leaves to green or yellow. In a previous experiment of related species, *N. indicum* preferred brown leaves more than green or yellow ones (Islam et al. 2000). Giddins *et al.* (1986) reported that *N. smithi* consumed decayed leaves of *Ceriops tagal* much more than fresh and senescent leaves, which is consistent with the present findings. Micheli (1993) noted that *Perisesarma messa* and *N. smithi* did not exhibit a significant preference for newly fallen leaves of mangroves, and they consumed significantly more decayed leaves than senescent ones. The consumption rate of brown leaves by *Helice leachi* was significantly higher than that of green and yellow leaves (Lee 1998). It has been suggested that brown leaves have soft tissues that might be more easily torn by crabs.

Giddins *et al.* (1986) noted that *N. smithi* took leaves into their burrows several weeks before consuming. During this time, tannins were lost from the leaves through leaching, while nitrogen content increased through bacterial activity, resulting in a higher quality food. Since *P. bidens* do not come outside their burrow during daytime, they must emerge during low tide at night and pull down leaf particles into burrows. The green leaves of *K. candel* ranked last in the preference hierarchy of *P. bidens*.

Skov and Hartnoll (2002) investigated that C and N contents and C/N ratios of leaves in crab burrows and found that they do not differ significantly from those of freshly fallen leaves. The leaf-ageing hypothesis, that sesarmid crabs may plaster leaves to their burrow walls in order to improve leaf palatability and nutritional quality, has been discussed in the literature for more than 15 years (Giddins *et al.* 1986, Skov and Hartnoll 2002). Several papers, for instance, have noted how sesarmids in the field and in the laboratory may prefer to ingest aged leaves rather senescent leaves (Giddins et al. 1986, Skov and Hartnoll 2002). The majority of studies have recorded C/N ratios in mangrove leaves that far exceed the Russel-Hunter ratio of 17. Leaves, in general, take a very long time to reach their lowest C/N values, and in most cases the lowest C/N ratios of decayed leaves are still at least double the Russel-Hunter ratio (Skov and Hartnoll 2002). The sediments in the present study had C/N ratios 2/3 times lower than leaves, indicating that sediments could have higher nutritional value than leaves. Bacteria may certainly reach high densities in mangrove mud and are highly digestible by crabs (Alongi 1988). The C/N ratio of fresh faeces of *N. meinerti* was 49, which is higher than the present study (Skov and Hartnoll 2002).

Green leaves of *K. candel* contain more protein than yellow or brown leaves in both wet and dry conditions (Islam et al. 2002, Lee 1998). Since carbohydrates are the primary energy source, brown leaves contain more energy (Islam *et al.* 2002). The leaf material is originally high in carbohydrates, lipids and protein content (Bhosle *et al.* 1976). Organic matter and nutrients are thus conserved in the forest rather than being washed out to the sea (Camilleri 1992). Thus, *P. bidens* plays an important role in the energy flow pathway in the mangrove forest by providing food for detritus feeders. However, *P. bidens* feeds on mangrove leaves and egests them as small particles; these particles are then utilized by bottom-dwelling detritivores inside and outside the mangrove forest. For this reason, *P. bidens* may be regarded as an important species in the nutrient cycles of the mangrove ecosystem.

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