

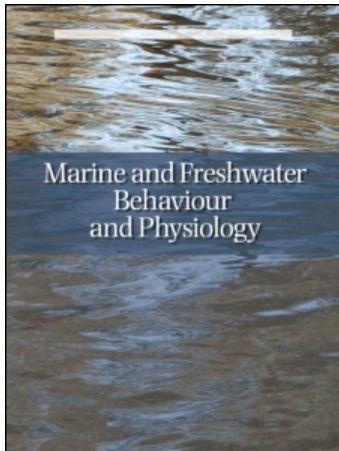
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Nutrient and energy consumption of captive mature dugong (*Dugong dugon*) consuming eelgrass at the Toba Aquarium

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Digestive efficiency and nutrient and energy consumption of the dugong (*Dugong dugon*) were determined during 1 year, using one male and one female captive animals fed eelgrass (*Zostera marina*) at the Toba Aquarium. The quantity of urine excreted was also estimated to evaluate ingestion of metabolic energy (ME), by measuring creatinine concentration of spot samples taken from the female. Estimated consumption rate of eelgrass was low at 0.82–0.99% dry matter (DM) of bodyweight, which was closely associated with its high nutritive value and digestibility as shown by 74% total digestible nutrients and 14.6% digestible crude protein on a DM basis. Consumption of gross energy and digestible energy averaged 10.4 Mcal per day and 9.6 Mcal per day, respectively. The female individual consumed 8.64 Mcal per day ME, calculated from urination of 26.21 per day and estimated from urinary creatinine concentration and an equation for urinary creatinine excretion and bodyweight.

Keywords: dugong; consumption rate; digestive efficiency; energy; eelgrass; *Dugong dugon*

Introduction

The dugong (*Dugong dugon*) is a member of the sirenians, totally aquatic herbivorous mammals, and is widely distributed throughout tropical Asian and Indian oceans, the western Pacific Ocean (Nishiwaki and Marsh 1985), and the subtropical coast of southern China (Morton 2001). This species mostly consumes sea grasses to meet its nutrient and energy requirements for maintenance, growth, and breeding, and ingests algae and invertebrates under some circumstances (Erftemeijer et al. 1993; Preen 1995a).

Dugongs ingest a variety of sea grasses, such as genus *Halophila*, *Halodule*, *Zostera*, *Syringodium*, *Enhalus*, *Thalassia*, and *Cymodocea*, which grow in their habitat (Johnstone and Hudson 1981; Marsh et al. 1982; Waldron et al. 1989; Preen 1995b). They eat the leaves, rhizomes, and root materials of sea grasses and digest them efficiently in their large capacity intestines and cecum (Murray et al. 1977; Lanyon and Marsh 1995; Goto et al. 2004b). From an analysis of feeding data recorded for captive dugongs, Goto et al. (2004b) reported that mature dugongs consume sea grasses of about 0.8% organic matter of

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bodyweight and over 90% of dry matter digestibility. Large numbers (10^9 – 10^{10} g⁻¹) of colony-forming bacteria utilizing starch, lactate, cellubiose, pectin, xylan and cellulose, and sulfate-reducing and methane-producing bacteria detected in the lower digestive tract are considered to contribute to a high total concentration of 10.5 mmol dL⁻¹ of acetate, propionate, and butyrate as microbial fermentation products *in vitro* (Goto et al. 2004a). The longer retention time of 7–10 days in the digestive tract would be also associated with the high digestibility of sea grasses (Lanyon and Marsh 1995).

Published studies on digestive organs (Marsh et al. 1977; Kamiya et al. 1979), feeding behavior (Heinsohn and Birch 1972; Heinsohn et al. 1977; Johnstone and Hudson 1981; Marsh et al. 1982; Erftemeijer et al. 1993; Anderson 1998; Masini et al. 2001), and ecology (Nishiwaki and Marsh 1985; Marsh 1995; Kataoka 1997) have contributed to the understanding of dugongs. Because of their special ecological niche, there is, however, interest in the nutritional physiology and metabolism of dugongs.

We have estimated the nutrient and energy consumption rates and digestive efficiencies of one male and one female dugong, and urination of the female, held captive in Toba Aquarium.

Materials and methods

Feeding trial of eelgrass

The *in vivo* digestibility of eelgrass (*Zostera marina*) was evaluated for two captive dugongs, a male (20 years old, 298 kg bodyweight) and a female (12 years old, 346 kg bodyweight). Consumption of dry matter (DM), total digestible nutrients (TDN), digestible crude protein (DCP), and gross energy (GE) and digestible energy (DE) were estimated for the two dugongs. Metabolic energy (ME) was also estimated for the female.

A 10-day feeding trial was conducted every month between May 1999 and April 2000. Whole eelgrass (tops and roots) of standard quality was transported by aircraft every 5 or 6 days from Moppo Bay, South Korea, and kept at 5°C until fed. It was weighed and supplied in excess of feeding requirements twice a day, in the morning and afternoon. Eelgrass was anchored to metal net plates of 1.0 m × 1.5 m to prevent it from scattering in the tank and to allow the animal to feed at one position on the bottom of the aquarium. During feeding trials the male and female dugongs were kept separately in aerated aquaria of 12 m (length) × 6 m (width) × 3 m (depth) and 10 m × 6 m × 3 m, respectively, under public exhibition conditions (Goto et al. 2004b).

Leftover feed was collected and weighed before the next feeding to measure the consumption of fresh eelgrass. All feces that floated or sank in the aquarium were immediately collected and weighed. Urinary samples were collected only from the female two or three times each 10-day experimental period, in the afternoon between the morning and evening feeding. To avoid contamination with pool water, the urine sample was taken by floating the female on her back while applying fingertip pressure to the urogenital area (as shown in Figure 1, Goto et al. 2004a).

Samples of eelgrass and feces were dried at 60°C in a forced-air oven, milled to pass a 1-mm sieve, and kept at room temperature until analysis. Urinary samples were immediately divided into two portions and kept until analysis; one half was stored at -80°C for creatinine determination and the other half was dried at 60°C for calorimetric determination. Calorimetric analysis excluded urinary samples taken in July and December 1999 and April 2000 because sample volumes were too low.

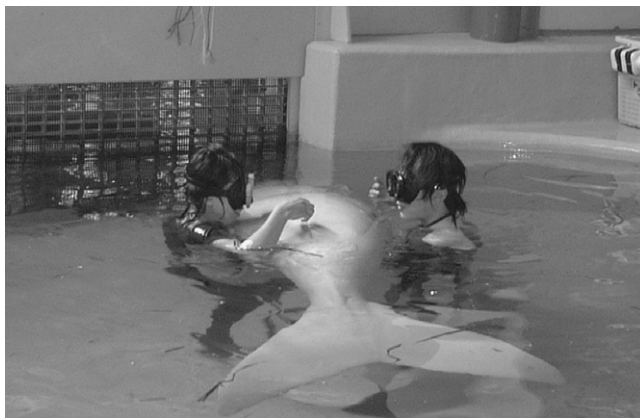


Figure 1. Method for collecting urinary samples from a female dugong by floating it on its back.

Chemical analysis

Organic matter (OM), crude protein (CP), crude fiber (CFib), crude fat (CFat), crude ash (CAsh), and nitrogen-free extract (NFE) of eelgrass and fecal samples were determined according to the procedure of Association of Official Analytical Chemists (1990), and neutral detergent fiber (NDF) was determined according to the procedure of Van Soest et al. (1991). TDN and DCP of eelgrass were estimated using chemical composition and digestibility of feed components, as the digestible CAsh content was excluded. Energy content of dried samples of eelgrass, feces, and urine was determined by an adiabatic bomb calorimeter (Shimazu, Japan).

Concentration of urinary creatinine (UC; mg dL^{-1}) was determined according to the procedure of Taussky (1954). Urinary excretion (U; L) of the female was then estimated according to an equation for urinary creatinine excretion and bodyweight (urinary excretion of 24 mg creatinine per kg of bodyweight as determined for cattle and sheep, $U = (346 \times 24)/UC \times 10$).

Results

Eelgrass consumption by each of the two dugongs was constant throughout the experimental period. The male and female consumed 2.4 and 3.44 kg DM/day (Table 1), accounting for consumption rates of 0.82 and 0.99% of bodyweight, respectively. Eelgrass fed contained high protein, minerals, and nonstructural carbohydrate but low cell wall components, as shown by the average compositions of 78.1% OM, 16.3% CP, 16.2% CFib, 21.9% CAsh, 1.1% CFat, 45.5% NFE, and 44.5% NDF on a DM basis (Table 1). Eelgrass also had high digestibility of 93.5% OM, 94.8% NDF, and 90.5% CP, accounting for concentrations of 73.1% TDN and 14.3% DCP, respectively (Table 1).

Average GE contents of eelgrass consumed by male and female dugongs was 2.98 and 3.01 kcal g^{-1} DM, respectively, over the experimental period. GE content of eelgrass fed varied less among months, ranging between 2.82 and 3.10 GE kcal g^{-1} DM in the male and 2.80 and 3.36 GE kcal g^{-1} DM in the female (Table 2). Feces had a higher GE content (yearly average 4.14 kcal g^{-1} DM) than eelgrass (3.00 kcal g^{-1} DM); the monthly average of the male and female individuals ranged between 3.35 and 5.05 kcal g^{-1} DM and between 3.70 and 4.38 kcal g^{-1} DM, respectively. The female's urinary samples had an average GE content of 35.1 cal mL^{-1} and a monthly range of 26.0–51.7 cal mL^{-1} .

Table 1. Voluntary intake, chemical composition, *in vivo* digestibility, and nutrient composition of eelgrass as given to the captive dugongs in Toba aquarium.

	Male	Female	Average
Voluntary intake (kg day ⁻¹ h ⁻¹)			
Fresh matter	20.6 ± 2.4	29.4 ± 3.1	25.0 ± 5.2
Dry matter (DM)	2.40 ± 0.35	3.44 ± 0.42	2.92 ± 0.65
Chemical composition of eelgrass			
Dry matter content (%)	11.7 ± 0.9	11.7 ± 0.9	11.7 ± 0.9
Feed composition (% DM)			
Organic matter	78.3 ± 1.2	77.9 ± 1.1	78.1 ± 1.3
Crude ash	21.7 ± 1.2	22.1 ± 1.5	21.9 ± 1.3
Crude protein	16.3 ± 3.2	16.4 ± 3.2	16.3 ± 3.1
Crude fat	1.2 ± 0.6	1.1 ± 0.5	1.1 ± 0.6
Crude fiber	16.1 ± 4.4	16.4 ± 3.2	16.2 ± 3.8
Nitrogen-free extracts	44.7 ± 2.7	46.2 ± 2.7	45.5 ± 2.7
Neutral detergent fiber	44.8 ± 4.9	44.2 ± 5.0	44.5 ± 4.8
<i>In vivo</i> digestibility of eelgrass (%)			
Dry matter	88.6 ± 8.2	85.9 ± 8.0	89.1 ± 8.0
Organic matter	92.9 ± 3.0	94.1 ± 2.3	93.5 ± 2.7
Crude ash	94.8 ± 2.6	95.9 ± 2.2	95.4 ± 2.4
Crude protein	89.6 ± 4.8	91.3 ± 3.1	90.5 ± 4.0
Crude fat	55.1 ± 31.7	64.0 ± 21.6	58.9 ± 27.5
Crude fiber	97.7 ± 0.8	98.2 ± 0.7	97.9 ± 0.8
Nitrogen-free extracts	93.7 ± 2.8	94.8 ± 2.1	94.3 ± 2.5
Neutral detergent fiber	94.4 ± 2.7	95.2 ± 2.5	94.8 ± 2.5
Nutrient composition (% DM)			
Total digestible nutrient*	72.9 ± 3.2	73.4 ± 2.8	73.1 ± 3.0
Digestible crude protein	14.6 ± 2.6	14.9 ± 2.7	14.3 ± 1.1

Notes: All values of voluntary intake, gross composition, *in vivo* digestibility and nutrient composition of eelgrass were expressed as averaged value obtained in the feeding trial between April 1999 and May 2000.

*Total digestible nutrient expressed as the content of digestible crude ash was excluded.

Concentrations of urinary creatinine averaged 36.9 mg dL⁻¹ of urine, and varied between 28.6 and 48.1 mg dL⁻¹ (Figure 2). The female dugong was estimated to excrete an average of 26.21 per day of urine, as calculated from creatinine values, ranging between 18.8 and 32.21 per day. Therefore, the quantities of fecal and urinary excretion and their GE contents gave similar estimates for energy excretion of the female dugong.

The male dugong ingested 1.75 kg TDN per day and 0.35 kg DCP per day, and 7.15 Mcal GE per day and 6.49 Mcal DE per day (Table 3). The female consumed 2.52 kg TDN per day and 0.52 kg DCP per day, and 10.4 Mcal GE per day and 9.60 Mcal DE per day. ME consumption of the female was also calculated as 8.64 Mcal ME per day, by simply employing yearly averages of urine quantity and urinary energy as ignored energy loss by methane emission from the lower digestive tract.

Discussion

The quantity of nutrients and energy required by an individual is generally a function of body size, activity level, reproductive state, and thermoregulatory cost, whether or not the animal is actively growing (Owen-Smith 1988). Due to the difficulties of studying free-ranging animals, data on their nutritional and energetic requirements are often lacking for

Table 2. Gross energy of eelgrass, feces, and urine of the captive dugongs in Toba aquarium.

Year	Month	Gross energy					
		Eelgrass (kcal g ⁻¹ DM)		Feces (kcal g ⁻¹ DM)		Urine (cal mL ⁻¹)	
		♂	♀	♂	♀	♀	
1999	5	2.87 ± 0.01	2.91 ± 0.03	4.19 ± 0.01	4.21 ± 0.01	26.0 ± 4.3	
	6	2.82 ± 0.01	2.80 ± 0.01	4.09 ± 0.09	3.83 ± 0.19	36.2 ± 3.8	
	7	2.87 ± 0.03	2.96 ± 0.06	3.47 ± 0.08	3.70 ± 0.17	ND	
	8	2.99 ± 0.02	2.93 ± 0.05	3.95 ± 0.03	4.03 ± 0.05	51.7 ± 4.8	
	9	3.07 ± 0.00	3.06 ± 0.01	4.05 ± 0.14	3.94 ± 0.08	32.5 ± 4.1	
	10	3.05 ± 0.00	3.06 ± 0.01	4.61 ± 0.17	4.12 ± 0.34	31.3 ± 2.8	
	11	3.03 ± 0.01	3.00 ± 0.02	3.35 ± 0.29	4.17 ± 0.58	29.6 ± 4.3	
	12	3.10 ± 0.08	2.89 ± 0.15	4.22 ± 0.05	4.38 ± 0.11	ND	
	2000	1	2.93 ± 0.15	3.36 ± 0.31	4.00 ± 0.13	4.36 ± 0.25	42.3 ± 6.9
		2	2.96 ± 0.04	3.06 ± 0.07	4.47 ± 0.05	4.33 ± 0.10	ND
		3	3.10 ± 0.01	3.11 ± 0.01	5.05 ± 0.27	4.29 ± 0.54	31.4 ± 5.4
		4	2.93 ± 0.01	2.97 ± 0.02	4.24 ± 0.02	4.30 ± 0.04	ND
Average of a year		2.98 ± 0.10	3.01 ± 0.14	4.14 ± 0.46	4.14 ± 0.22	35.1 ± 8.2	

Note: ND: No data.

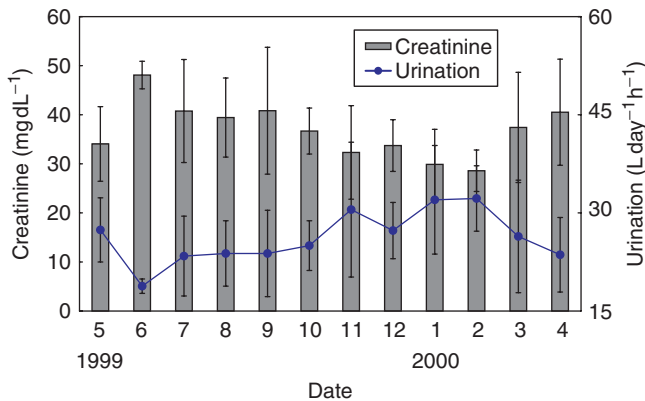


Figure 2. Urinary creatinine concentration and estimated urination in a mature female dugong held captive in the Toba Aquarium.

a particular species. These difficulties are certainly true for marine herbivores such as dugong and manatees. Details of the bioenergetics even in captive animals may therefore improve our understanding of the nature of the survival mechanisms of free-ranging wildlife, together with detailed observations of variations of dominated sea grass community and its seasonal change such as biomass and compositional percentage, and associated foraging habit in their habitat. In this study, the consumption rate, digestive efficiency, and nutrient and energy intake of mature dugongs were evaluated in feeding and digestion trials with two captives fed on a standardized diet.

Long-term feeding and digestion trials can provide consistent and reliable data on nutrient and energy consumption of captive wild animals. In this study, eelgrass consumption of the male and female dugongs observed with data collected monthly, was 0.82 and 0.99% DM of body weight, respectively, in broad agreement with a 20-year

Table 3. Nutrient and energy intake of the captive dugongs in Toba aquarium.

Year	Month	Nutrient intake (kg day ⁻¹ h ⁻¹)						Energy intake (Mcal day ⁻¹ h ⁻¹)					
		TDN*		DCP		GE		DE		ME			
		♂	♀	♂	♀	♂	♀	♂	♀	♂	♀		
1999	5	1.61 ± 0.23	2.24 ± 0.45	0.25 ± 0.05	0.38 ± 0.09	6.67 ± 0.73	9.11 ± 0.03	5.70 ± 0.06	8.40 ± 0.01	7.44 ± 0.01			
	6	1.27 ± 0.26	2.00 ± 0.51	0.18 ± 0.04	0.30 ± 0.09	4.73 ± 0.86	7.36 ± 0.01	4.32 ± 0.37	6.93 ± 0.19	5.98 ± 0.19			
	7	1.59 ± 0.30	2.45 ± 0.61	0.22 ± 0.04	0.33 ± 0.08	6.08 ± 0.48	9.59 ± 0.06	5.73 ± 0.44	9.10 ± 0.17	8.15 ± 0.17			
	8	1.99 ± 0.09	2.24 ± 0.17	0.34 ± 0.02	0.39 ± 0.03	7.80 ± 0.60	8.66 ± 0.05	7.49 ± 0.45	8.22 ± 0.05	7.26 ± 0.05			
	9	2.24 ± 0.10	2.52 ± 0.20	0.43 ± 0.01	0.46 ± 0.02	9.00 ± 0.76	10.1 ± 0.01	8.68 ± 0.31	9.76 ± 0.08	8.80 ± 0.08			
	10	2.15 ± 0.24	2.83 ± 0.48	0.45 ± 0.06	0.61 ± 0.11	8.70 ± 0.89	11.4 ± 0.01	8.14 ± 0.85	10.9 ± 0.04	9.96 ± 0.04			
	11	1.79 ± 0.32	2.70 ± 0.64	0.39 ± 0.05	0.54 ± 0.10	7.39 ± 0.61	11.1 ± 0.02	6.92 ± 0.95	10.3 ± 0.58	9.29 ± 0.58			
	12	1.79 ± 0.29	2.62 ± 0.59	0.38 ± 0.06	0.55 ± 0.12	7.48 ± 0.23	10.8 ± 0.15	6.93 ± 0.80	9.27 ± 0.11	8.31 ± 0.11			
	2000	1	1.91 ± 0.43	3.13 ± 0.86	0.46 ± 0.11	0.77 ± 0.22	7.97 ± 0.31	14.0 ± 0.13	6.89 ± 0.79	13.2 ± 0.25	12.23 ± 0.25		
		2	1.53 ± 0.34	2.50 ± 0.68	0.38 ± 0.10	0.67 ± 0.20	6.59 ± 0.04	10.9 ± 0.07	5.57 ± 0.87	9.64 ± 0.10	8.69 ± 0.10		
		3	1.69 ± 0.36	2.69 ± 0.71	0.42 ± 0.09	0.68 ± 0.19	7.25 ± 0.15	11.7 ± 0.01	6.24 ± 0.38	10.6 ± 0.54	9.64 ± 0.54		
		4	1.41 ± 0.32	2.31 ± 0.64	0.33 ± 0.09	0.57 ± 0.17	6.13 ± 0.78	10.1 ± 0.02	5.24 ± 0.66	8.85 ± 0.07	7.90 ± 0.07		
Average of a year		1.75 ± 0.10	2.52 ± 0.26	0.35 ± 0.03	0.52 ± 0.12	7.15 ± 1.19	10.4 ± 1.70	6.49 ± 1.26	9.60 ± 1.58	8.64 ± 1.58			

Notes: DM, Dry matter; TDN, Total digestible nutrient; DCP, Digestible crude protein; GE, Gross energy; DE, Digestible energy; ME, Metabolic energy (DE - average of urine GE).
 *TDN was noted in Table 1.

feeding record for the same individuals analyzed in our laboratory (Goto et al. 2004b). This was also consistent with the findings that a West Indian manatee consumed 0.9% DM of body weight of water hyacinths. The lower consumption of sea grasses was closely associated with the higher digestibility of most feed components, including 93.5% OM and 90.5% CP. The higher digestibility of the eelgrass was also consistent with a cell wall digestibility of over 90% of sea grasses, as shown by analysis of proximal colon contents of a netted dugong (Murray et al. 1977) and 82.6–91.4% for a netted manatee (Lomolino and Ewel 1984; Burn 1986; Burn and Odell 1987). An estimation of comparative consumption of GE and DE also indicated that the eelgrass was of a high metabolic efficiency similar to various cereal grains fed to cow, sheep, and horses, and that would be clearly higher than grasses. Thus the data obtained in this study indicate that the dugong can maximize nutrient and energy intake by grazing sea grasses.

Most terrestrial herbivores show relatively high feed consumption as follows; horse 2.3–2.8% (Arabian geldings, Crozier et al. 1997), Asian elephant (*Elephas maximus*) 1.4–1.8% (Clauss et al. 2003), red kangaroo (*Macropus rufus*) 1.8% (Munn and Dawson 2003), and springbok (*Antidorcas marsupialis*) 2.4% (Milewski and Diamond 2000). An exception is the Indian rhinoceros (*Rhinoceros unicornis*), at 0.6–0.9% (Clauss et al. 2005). The horse, Indian rhinoceros, and Asian elephant also show DM digestibilities of 44–58, 52.8, and 34.2%, respectively. The DM digestibility derived mainly from farmed animals was reported to be 71.6% for cows fed alfalfa, 61% for goats fed alfalfa and timothy, 57% for alpaca fed smooth bromegrass (*Bromus inermis*), and 53% for llama fed smooth bromegrass (Sponheimer et al. 2003). Marine herbivores such as dugong and manatee are therefore characterized by a lower feed consumption rate in relation to body weight and a higher digestive ability compared with terrestrial nonruminant and/or ruminant herbivores.

In this study, the nutrient and energy consumption of male and female dugongs were estimated 0.58 and 0.73 kg of TDN, 0.12 and 0.15 kg of DCP, 2.4 and 3.0 Mcal of GE, and 2.2 and 2.8 Mcal of DE per 100 kg bodyweight, respectively. The higher consumptions of a female were not in this study discussed either with individuality, or differences of age and/or sex, because of small sample size of the two animals. Concentrations of urinary GE and urinary energy loss of the dugong estimated throughout the year, also showed incomparable information for bioenergetics at the first time in the world. Since estimation of comparative ME consumption of a female was, however, made here without measurement of energy loss as methane from the lower digestive tract, this may contribute to a part of understanding inherent nutrition and physiology of the dugong. Further research is therefore needed to determine the amount of methane production by dugong, because energy loss as methane from the lower digestive tract of herbivores cannot be negligible as shown by a 2–12% of gross energy intake for sheep and cattle (Johnson and Johnson 1995). There are very few reports for wild ruminants and other herbivorous fauna, except that of 1.5–3% for elephant and horse (Crutzen et al. 1986; Vermorela et al. 1997).

The dugong has a relatively large intestine and cecum capacity compared with other mid-sized herbivores (Marsh et al. 1977; Kamiya et al. 1979). Kamiya et al. (1979) reported that the dugong has a long colon, 8.6–11.5 times longer than its body size. The dugong's digestive system differs from that of other nonruminant herbivores, which assimilate more nutrients per unit time at a higher passage rate of feed in the digestive tract (Faverdin et al. 1995). The long retention time of 7–10 days in the digestive tract has been discussed in relation to the high digestibility of sea grasses (Lanyon and Marsh 1995). Additionally, the higher nutritional content of sea grasses can be attributed to the high digestive efficiency of dugong. This is shown by the low neutral detergent fiber content of eelgrass (Goto et al. 2004a). In the wild, dugongs prefer a variety of sea grasses and only eat algae if sea grasses are scarce

(Johnstone and Hudson 1981; Marsh et al. 1982; Waldron et al. 1989; Preen 1995b). Short-chain fatty acids such as acetate, propionate, and butyrate were previously detailed as products of the microbial degradation of sea grass fibers in the cecum and proximal colon (Murray et al. 1977; Goto et al. 2004a) and as the major energy source for maintenance and growth. The microflora in the digestive tract of dugong, digestive function and capability of the sensitivity or resistance of cell walls of sea grasses to microbial digestion, and their relationship therefore require further clarification. This may vary among the different species of sea grasses grazed by dugongs in the wild.

In conclusion, the results in this study suggest that the dugong have evolved a preference for sea grasses because they maximize growth and energy maintenance. Further research to determine oxygen consumption and metabolic rate of the captive dugong would therefore be interesting in order to clarify the basal requirement of nutrients and energy.

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