

Feeding Ecology of Green Turtles (*Chelonia mydas*) from Shoalwater Bay, Australia

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Understanding the habitat usage and dietary requirements of a species is fundamental to its conservation. Although the diet of green turtles (*Chelonia mydas*) has been characterised for many populations around the world (reviewed by Bjorndal 1997), it is important to characterise the feeding ecology of distinct foraging populations in order to manage each effectively. Green turtles have a unique life history in terms of their foraging ecology. As small turtles they inhabit the open ocean, feeding omnivorously on pelagic material (Bolten 2003), but at approximately five to ten years of age green turtles in the Western Pacific recruit to an inshore neritic habitat and become primarily herbivorous feeding predominantly on seagrass and / or macroalgae (Bjorndal 1997; Limpus *et al.* 2005). Diet in green turtles is primarily driven by availability of a prey (Garnett *et al.* 1985), but some level of selectivity in feeding has also been demonstrated (Bjorndal 1985; Brand-Gardner *et al.* 1999; Fuentes *et al.* 2006). In Moreton Bay, Australia immature green turtles were found to select plants with higher concentrations of nitrogen and lower levels of fibre (Brand-Gardner *et al.* 1999) and in the Caribbean turtles have been observed to crop *Thalassia testudinum* to maintain new shoots that are higher in nitrogen and lower in lignin (Bjorndal 1985). Both these examples demonstrate a potential nutritional advantage through selective grazing, however, green turtles do not necessarily feed on either seagrass or algae to the exclusion of the other. Mixed diets are common (Bjorndal 1997) and sometimes also include mangrove (Limpus & Limpus 2000). Small amounts of animal material have often been described in green turtle diet, although these were initially thought to be incidental ingestions where animals were associated with benthic foods (Brand-Gardner *et al.* 1999; Mortimer 1981; Read & Limpus 2002). Recent studies have demonstrated green turtles in neritic habitats also target and consume significant amounts of gelatinous animal material from the water column (Arthur *et al.* 2007; Heithaus *et al.* 2002; Seminoff *et al.* 2006b), although the nutritional value that animal material contributes to metabolic activity is currently not known.

Shoalwater Bay is a shallow embayment in Central Queensland, Australia. It provides suitable foraging habitat for a large resident green turtle population (Limpus *et al.* 2005). Although never quantified, turtles in Shoalwater Bay have been reported to forage on seagrass, macroalgae, mangrove leaves when accessible and mangrove fruits when available (Limpus & Limpus 2000; Limpus *et al.* 2005). Here we quantify the diet of resident green turtles and opportunistically examine the digestive processes and foraging behaviour through a feeding history of one adult female that was found freshly dead at the site using nutrient and stable isotope analysis to address the physiological and biochemical processes that may be involved in digestion.

Shoalwater Bay (22°20S, 150° 12E) is located in the central section of the Great Barrier Reef Marine Park, Queensland, Australia. The maximum water depth in the bay is 11 m and a 7 m tidal range creates vast intertidal seagrass beds with mangroves on the landward fringe. Rocky reefs surrounding headlands provide substrate for macroalgal attachment (Lee Long *et al.* 1997).

Characterisation of the resident turtle population's diet was undertaken during three two-week sampling trips in winter (June-July) of 2002-2004. Turtles were captured using the turtle rodeo technique (Limpus & Reed 1985) and the habitat in which the turtle was first observed (seagrass flat, mangrove habitat or rocky reef) was noted at the time of capture. All turtles were either tagged immediately, or, in the case of recaptured turtles, their current tag was recorded. Turtles were weighed, their curved carapace (CCL) measured and they were sexed in accordance with Queensland Turtle Conservation Project protocol (Limpus *et al.* 1994). Based on laparoscopic observation of gonad maturity, turtles were assigned an age class of immature (small CCL < 65cm and large CCL > 65cm), pubescent or adult (Miller & Limpus 2003).

A random sub-set of turtles was selected for diet analysis and a diet sample was obtained from the lower oesophagus / crop using the stomach flush technique (Forbes & Limpus 1993). The content and relative volume of prey items was determined after the methods of Forbes (1999) and Read (2002). Briefly, a dissection microscope was used to visually identify all dietary material. The sample was then quantified using a marked eyepiece graticule where-by the prey item under each point was identified and the relative volume of each food type calculated as the proportion of diet (Channells 1981; Cribb 1983, 1996; Huisman 2000; Lanyon 1986). Diet data are presented as the mean (±SE) and the frequency of occurrence where the diet item is present and where it contributes >5% and >50% of the sample volume. This measure is important because some turtles feed on one type of food to the exclusion of others. As such, the average volume ± a measure of variation may not represent the true importance of the diet item to the minority of turtles that eat that item exclusively (Garnett *et al.* 1985).

A non-metric multidimensional scaling approach was used to determine whether there was an effect of the sampling year, sex, age class or habitat in which the turtle was captured on the composition of diet. Using Primer 6 (V6.1.11, Primer-E Ltd. Plymouth), proportional data were transformed using the 4th square root to ameliorate the magnitude of the most common diet items and a Bray-Curtis similarity matrix was established for all samples. A one-way analysis of similarity (ANOSIM) was used to assess the effect of sex and sampling year on diet composition (Clarke & Gorley 2006). Where a significant difference (p<0.05) was observed

for sampling year, a subsequent pairwise test was used to compare years. In addition, a similarity of percent contribution (SIMPER) analysis was undertaken to establish which diet items contributed the most to the difference between years. As there was an effect of year, each sampling period was considered separately to assess the effects of age class and habitat in which a turtle was captured on the composition of diet. A two-way crossed ANOSIM was used to examine the effect of age across habitats and the effect of habitat across age groups.

In July 2001 an adult female green turtle (CCL = 107.0 cm) was found freshly dead within the region described above for live turtles. A necropsy did not find a conclusive cause of death, however, the alimentary tract was full of food and the carcass was robust suggesting that the turtle had been foraging normally up until its death. The alimentary tract of this turtle was examined to assess longer-term feeding patterns than could be established by sampling the most recent feeding event in live turtles. Sub-samples of dietary material were collected from the crop (1), stomach (1) and at 1 m intervals along the small intestine (4) and large intestine (9). The composition of sub-samples was determined visually and in the small intestine, where it was possible to separate these components, the dry weight biomass of seagrass, mangrove leaves and mangrove propagules was determined to estimate the dominant ingested food source at different feeding periods. In addition, plant samples from the alimentary tract, as described above, and tissue samples from the pectoral muscle (6) of the dead turtle were collected and immediately frozen (-20 °C) for nutrient and stable isotope analysis. Prior to analysis samples were dried at 60 °C for 48 hrs and ground using a ball mill grinder. Turtle tissue samples were not lipid extracted.

To characterise the mechanical breakdown of ingested material through the digestive tract, the particle size distribution of the sub-sample from the crop and the lowest part of the large intestine (16 m) was determined. The sub-sample was sieved into the following categories: <1.0 mm; 1.0–3.5 mm; 3.5–5.0 mm; and >5.0 mm, and the dry weight biomass of each category determined. To investigate digestive processes along the alimentary tract the carbon (C) and nitrogen (N) content and the stable isotopic signature of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) were measured from bulk material within the alimentary tract, and in the small intestine seagrass and mangrove leaves were separated and analysed. Plant material was prepared following the methods of Grice *et al.* (1996). Nutrient and stable isotope analysis was undertaken at Griffith University Stable Isotope Analysis Laboratory using an Isoprime (GV Instruments) mass spectrophotometer coupled to a EuroVector EA 3000 elemental analyser with continuous helium carrier flow. Stable isotope ratios of $^{13}\text{C}:^{12}\text{C}$ and $^{15}\text{N}:^{14}\text{N}$ were expressed relative to PeeDee Belemnite (PDB) standard for C and N_2 in air for N. Totals for C and N were expressed as % dry weight (DW) of the material. To investigate the dominant assimilated food source(s), the C and N content and $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were also determined for turtle muscle tissue and for field sources of seagrass leaves and rhizomes + roots *A. marina* mangrove leaves, propagules and algae.

A t-test (Statistica V6.1, Statsoft Inc., Tulsa, USA) was used to test for significant differences in %C and %N content of seagrass and mangrove collected in the field with samples collected from the small intestine of the dead turtle. To assess the assimilation of nutrients from potential food sources into turtle muscle tissue the SISUS (Stable Isotope Sourcing Using Sampling) mixing model

Diet Item	Frequency (%)	Mean (+/- SE)	Frequency	
			>5%	>50%
<i>Cymodocea serrulata</i>	18.5	1.0 (0.4)	4.7	0.7
<i>Halodule</i> spp.	93.4	26.9 (2.2)	74.7	17.1
<i>Halophila ovalis</i>	41.1	T	2.7	0
<i>Zostera muelleri</i>	97.2	58.6 (2.7)	88.3	63.5
Total seagrass	100	85.5 (1.9)	100	88.6
<i>Aglaothamnion</i> spp.	0.7	T	0	0
<i>Amphiroa</i> spp.	0.7	T	0	0
<i>Bostrychia tennella</i>	3.4	T	2.1	0.7
<i>Centroceras</i> spp.	1.3	T	0	0
<i>Cerium</i> spp.	8.9	T	0	0
<i>Chondria</i> spp.	0.7	T	0	0
<i>Codium spongiosum</i>	0.7	T	0	0
<i>Coelarthrum</i> spp.	2.1	T	1.7	0
<i>Dasya</i> spp.	1.4	T	0.7	0
<i>Hypnea</i> spp.	58.9	2.7 (0.6)	16.4	0.7
<i>Gracilaria</i> spp.	23.3	4.1 (1.1)	10.3	4.7
<i>Laurencia</i> spp.	9.6	T	3.4	0.7
<i>Melanamansia glomerata</i>	0.7	T	0.7	0
<i>Polysiphonia</i> spp.	15.1	0.1 (0.0)	0	0
<i>Pterocladia</i> spp.	0.7	T	0.7	0
<i>Tolyphoclada glomerulata</i>	2.7	T	0	0
Unidentified red algae	5.4	T	0.7	0
Total red algae	74.7	9.4 (1.7)	27.4	6.7
<i>Enteromorpha</i> spp.	0.7	T	0	0
Total green algae	2.1	T	0	0
<i>Colpomenia sinuosa</i>	0.7	T	0	0
Total brown algae	0.7	T	0	0
<i>Avicenna marina</i> fruit / leaves	12.3	1.4 (0.5)	6.2	0.7
Total mangrove material	12.3	1.4 (0.5)	6.2	0.7
<i>Lyngbya majuscula</i>	18.5	T	3.4	0
<i>Oscillatoria</i> spp.	1.3	T	0	0
Unidentified filamentous algae	6	T	0	0
Total filamentous cyanobacteria	24.7	T	3.4	0
Shell material	21.9	T	0	0
Unidentified crustacean	6.8	T	0	0
Unidentified egg mass	4.1	1.3 (0.8)	3.4	1.4
Unidentified sponge	1.3	T	0.7	0
Total animal material	31.5	1.7 (0.8)	3.4	1.4
Unidentified material	72.6	1.5 (0.2)	6.7	0

Table 1. The diet of green turtles in Shoalwater Bay, Australia in winter 2002-04. Frequency = percentage of samples in which the diet item was observed. T = trace or mean <1% of the overall relative volume. The frequency >5% and >50% represents the percent of samples observed where the relative volume of the diet item was greater than 5% and 50% of the total volume of the sample respectively (n=146).

Ingested material	Proportion of material in alimentary tract (%)			
	4 m	5 m	6 m	7 m
Seagrass	85	97	35	48
Mangrove leaves	13	3	65	52
Mangrove propagules	2	0	0	0

Table 2. The percentage of seagrass leaves, mangrove leaves and propagules based on dry weight biomass in sub-samples from 1 m intervals along the small intestine.

was employed. SISUS is a Bayesian mixing model and software package for source partitioning using stable isotopes (Erhardt 2008). The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of six potential source diet items were included in the model: red algae (3), seagrass shoots (3), seagrass rhizome + roots (2), mangrove epicormic shoots (2), mangrove leaves (4) and mangrove propagules (3). These were compared with $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of turtle muscle from one individual (6) assuming a constant discrimination of +0.17‰ for $\delta^{13}\text{C}$ and +2.8‰ for $\delta^{15}\text{N}$ for all food types (Seminoff *et al.* 2006a), 100% source assimilation for all sources and a source concentration as determined by %C and %N analysis. No additional linear constraints were applied to this model.

One-hundred and forty six green turtles (CCL = 39.9 – 115.6 cm) were stomach flushed in Shoalwater Bay in winter 2002-2004. During this time, green turtles in Shoalwater Bay were primarily consuming seagrass and the most common species found in diet samples were *Z. muelleri* and *Halodule* sp. (Table 1). *Halophila* sp. and *C. serrulata* were also present, but in fewer diet samples and in smaller quantities. Red alga was also common, found in 74.7% of samples, but only contributing a mean relative volume of 9.4% and this was generally made up of *Hypnea* sp. and *Gracilaria* sp. Although red algae wasn't a dominant food type overall, some samples were predominantly red algae. In 6.7% of samples examined, red algae made up more than half the relative volume of the diet sample. The low overall mean proportion of red algae in diet is due to the fact that while some turtles ate a lot of red algae many had not consumed any. Green and brown algae species were rarely found and only constituted trace amounts of diet samples. The fruit of the mangrove *A. marina* was often found in diet samples in 2003 and 2004, but only in two samples in 2002. Overall, it only contributed a small amount to diet, but one sample contained more than 50% mangrove material. Conversely, the cyanobacteria

Particle size	Proportion of dietary material (%)	
	Crop	Large intestine
> 5 mm	86	5
3.5 – 5 mm	1	17
1 – 3.5 mm	10	65
< 1 mm	3	13

Table 3. The particle size distribution of sub-samples from within the crop and the lower end of the large intestine in the green turtle.

L. majuscula was common in green turtle diets in 2002, but not in other years, and when present only constituted an average of 2.9% of volume. Animal material was often found in samples, but generally only in small amounts, most commonly as tiny gastropod shells, which did not constitute a large proportion of the diet. The only exception to this occurred in 2002 when the majority of the diet samples from two adult females were found to be unidentified gelatinous egg masses.

There was not a significant difference in the composition of diet samples collected from male and female turtles (ANOSIM: Global R = 0.009, p = 0.373), however, there was a significant difference between sampling years for both sexes combined (ANOSIM: Global R = 0.134, p = 0.001). The SIMPER analysis showed 2003 and 2004 samples were the most similar (Dissimilarity 38.6%) compared with 2002, which had dissimilarity of 44.9% to 2003 and 43.5% to 2004. The diet items that contributed most to this dissimilarity were *Halodule* sp. *Z. muelleri*, *L. majuscula*, *Hypnea* sp. *Halophila* sp., *Gracilaria* sp. and *C. serrulata*. As the year of capture led to significant differences in the composition of diet, we examined the effects of age classification and habitat in which the turtle was captured for each year separately. In all three sampling events there was not a significant difference in the composition of turtle diet between age groups (considered across habitat types) or across habitats (as observed across age groups) using a two-way crossed ANOSIM model. Throughout the alimentary tract of the dead turtle the following organisms were observed: leaves of the seagrass species *H. uninervis*, *Z. muelleri*, *H. ovalis*; leaves and propagules of the mangrove *A. marina*; unidentified red sponge; and unidentified solitary ascidian. Seagrass was observed from all sub-samples along the alimentary tract, whereas mangrove leaves and propagules, and the red sponge were found in the small and large intestine and the solitary ascidians were only found in the large intestine. Although seagrass was ubiquitous throughout the gut, mangrove and algae were not evenly dispersed and were found as clumps amongst the seagrass. Mangrove leaves were the dominant component of the sub-sample in the small intestine at 6 and 7 m (65% and 75% of the DW respectively), whereas at 4 and 5 m seagrass was the dominant component (85 and 97% respectively, Table 2).

There was obvious breakdown of the ingested plant material along the alimentary tract. In the crop and small intestine plant material was in small pieces but readily identifiable, however, in the large intestine only the veins of mangrove leaves and very small pieces of seagrass leaves were identifiable and these were surrounded by unidentifiable viscous green digesta. In comparison, the animal material, sponges and ascidians were intact and appeared undigested. There was a greater proportion of smaller particles at the end of the alimentary tract compared with the crop. In the crop, 86% of the material was greater than 5 mm diameter, whereas at the end of the lower intestine only 5% of the material was greater than 5 mm. The percentage of particles less than 1 mm increased from the crop to the end of the lower intestine, 4-13%. The dominant particle size at the end of the digestive tract was 1-3.5 mm (Table 3).

Carbon content of fresh field samples was greater in mangrove leaves compared with seagrass leaves (Figure 1). There was no significant difference in the %C (T-test: t = -1.01, df = 6, p = 0.35) and %N (T-test: t = -0.11, df = 6, p = 0.97) composition of ingested seagrass material in the small intestine compared with samples collected in the field. However, the %C (T-test: t = 3.18, df = 6, p =

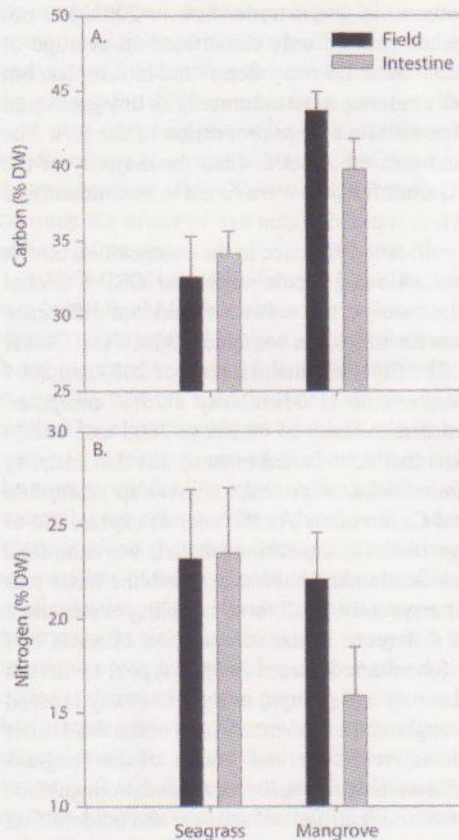


Figure 1. Comparison of carbon (A) and nitrogen (B) content of seagrass and mangrove leaves collected in the field and from the small intestine of an adult green turtle in Shoalwater Bay. Average + SD.

0.02) and %N (T-test: $t=3.42$, $df=6$, $p=0.01$) of mangrove leaves was significantly lower in the small intestine compared with samples collected in the field (Figure 1). Within the gut, %C was lower in the large compared with the small intestine (Figure 2). The N content of ingested material in the large intestine was higher (average 3.6 ± 0.2) than in the small intestine (average 2.0 ± 0.2 ; $p < 0.001$). The N content of mangrove leaves decreased through the small intestine, and the N content of the composite large intestine material increased towards the lower end of the large intestine (Figure 2). The $\delta^{13}C$ of mangrove leaves became more negative through the small intestine and was consistent through the large intestine. The $\delta^{15}N$ value was enriched in stomach contents (6.2 ‰) compared with all other locations along the alimentary tract (0.7 - 2.6 ‰; Figure 2).

The $\delta^{13}C$ signatures of available food sources were all distinct: seagrass (mean = -10.4 ‰), algae (mean = -14.1 ‰) and mangrove (mean = -26.6 ‰; Figure 3). However, potential food sources had similar $\delta^{15}N$ signals (0.0 - 1.5 ‰), except seagrass roots (-1.6 ‰). Turtle tissue was found to have $\delta^{13}C$ signature (-10.5 ‰) that was similar to that of seagrass (-10.4 ‰), whereas the $\delta^{15}N$ signature (3.0 ‰) was enriched by 1.4 - 3.3 ‰ when compared with the average seagrass (-0.3 ‰), mangrove (0.7 ‰) and algae (1.6 ‰) values (Figure 3). The SISUS mixing model found the feasible source contribution of seagrass leaves to be highest with a mean of 81.4% (SD $\pm 1.4\%$) followed by seagrass roots ($16.1 \pm 0.5\%$),

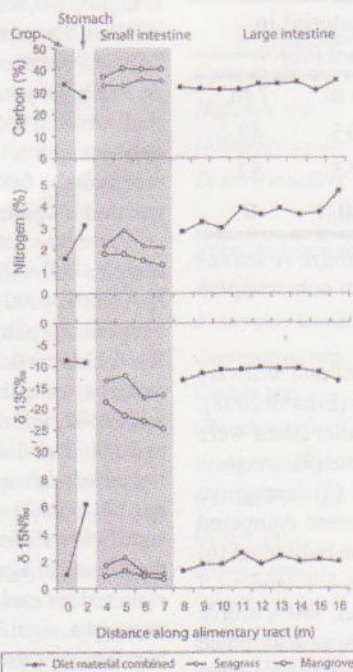


Figure 2. Carbon and nitrogen content and $\delta^{15}N$ and $\delta^{13}C$ (‰) of diet material collected along the alimentary tract of an adult green female turtle found freshly dead in Shoalwater Bay, winter 2001.

red algae ($1.4 \pm 1.1\%$), mangrove propagules ($0.3 \pm 0.3\%$) and mangroves shoots and leaves ($0.3 \pm 0.2\%$).

Green turtles in Shoalwater Bay appear to be primarily herbivorous, but opportunistic in their foraging behaviour. All turtles considered in this study ingested seagrass, but many also consumed mangrove material and red algae. Only two turtles were determined via stomach lavage to have consumed significant amounts of animal material. However, the authors acknowledge the potential for pelagic gelatinous animal material to be overlooked using this sampling technique (Arthur *et al.* 2007). The composition of green turtle diets was found to be significantly different between sampling years, primarily due to the quantity of the seagrass *Halodule* sp. in the diet and the presence of *L. majuscula*. This suggests that although turtles predominantly consume seagrass, the abundance of each seagrass species may vary from year to year. Similarly, when ephemeral blooms of *L. majuscula* grew over the seagrass in 2002 turtles were observed to consume small amounts, but this was obviously not a preferred food (Arthur *et al.* 2006).

Zostera muelleri was the most commonly encountered species in diet samples (97.2%) and contributed the greatest mean volume (58.6% ; Table 1). *Halodule* spp. also contributed significantly to diet while *H. ovalis* and *C. serrulata* contributed only small amounts. These findings may reflect the abundance of these species in the Western Bight of Shoalwater Bay. Both *Z. muelleri* and *Halodule* spp. are abundant in the area, and although *Halophila* spp. is present, it is not as common as *Z. muelleri* and *Halodule* spp. (Kay 2003; Lee Long *et al.* 1997). Interestingly, *C. serrulata* was not noted to be present in Shoalwater Bay in 1997 seagrass surveys, however, it was found in surveys conducted in 2002 where it was recorded very occasionally and made up less than 0.1% of seagrass present (Kay 2003). In Moreton Bay, *H. ovalis* was described to be the preferred species for green turtle consumption when compared with *Halodule uninervis* and *Z. muelleri* and this was attributed to the lower fibre content of this species (Brand-Gardner *et al.* 1999). Although selectivity was not examined in the current study, the frequency but low contribution of *H. ovalis* in diet samples suggests that turtles may consume it when available, but as there was less present in the environment it did not contribute significantly to overall diet.

Red algae and mangrove material were both commonly observed in green turtle diet samples. Although common, they did not contribute as much volumetrically to diet as the seagrasses (Table 1). Red algae may provide an alternate food source when seagrass is limited, and could potentially provide a nutritional advantage for those turtles able to access areas in which the algae grows (Brand-Gardner *et al.* 1999). Similarly, mangrove fruit has previously been documented in the diet of green turtles from Shoalwater (Limpus & Limpus 2000) and Moreton Bays (Read & Limpus 2002), and in Western Australia an adult green turtle was observed feeding on the

leaves of *A. marina* (Pendoley & Fitzpatrick 1999). Brand-Gardner *et al.* (1999) suggested that green turtles preferentially consume diet items of greater nutritional value. In this study mangrove leaves from the field had higher C content than seagrass, but N content was similar (Figure 1). It is not known whether mangrove material and red algae confer other nutritional advantages, however, the behavioural adaptation required to feed on these items is consistent with that of an opportunistic and versatile forager.

The continuous presence of seagrass throughout the alimentary tract interspersed with clumps of mangrove material in the single adult female that was found dead during this study is suggestive of transitory feeding behaviour where the turtles move up into the mangroves with the high tide and forage on mangrove propagules and leaves whilst they are accessible at the top of the tide and then move back to the seagrass beds with the receding tide. This supports observations made by Limpus & Limpus (2000) where they describe alternating bands of seagrass and mangrove material through the gut of another deceased turtle from this region.

Although we were only able to sample one dead animal through the entire alimentary tract, the diversity of food in the most recent feeding events observed in the live turtles reflects the diversity of foods observed through the entire digestive tract of the dead turtle. Based on estimates of digesta time of green turtles this could reflect 6-30 days of feeding (Amarocho & Reina 2008; Brand-Gardner *et al.* 1999) and begs the question as to whether all turtles always feed on a variety of items or whether they have a preference for certain food types. Based on the SISUS mixing model, the stable isotopic signature of muscle tissue from the dead turtle suggests that even though she consumed multiple food items, seagrass was the major contributor to growth and tissue production with an average of 97% of feasible source contribution to tissue accounted for by seagrass leaves and roots combined. This suggests that even though other diet items are consumed, they are either not digested or nutrients derived from these food sources are only a minor component of

nutrients assimilated into the muscle matrix. However, it should be noted here that the model was based on the assumptions that the discrimination value for all potential food types was the same (0.17 ‰ for $\delta^{13}\text{C}$ and 2.8‰ for $\delta^{15}\text{N}$) and that these values would accurately reflect discrimination in a wild adult turtle when they were derived for juveniles turtles held in captivity (Seminoff *et al.* 2006a). It is possible that other diet items may also be assimilated, but due to the large volume of seagrass consumed, seagrass appears to be the dominant source of nutrients assimilated for muscle production in this turtle.

Although sponges and ascidians were not included in the mixing model, we do not anticipate that they contributed significantly to green turtle nutrition because they were visually observed to be intact throughout the length of the alimentary tract. While particle size of the digestive material clearly decreased through the alimentary tract (Table 3), a trend reflected in the obvious breakdown of ingested plant material, the breakdown of fauna (ascidian and sponge) was not obvious. It is possible that as hind gut fermenters (Bjorndal *et al.* 1991) they are not capable of digesting these items that may pass through the alimentary tract without the turtle obtaining any nutritional value.

The break down and assimilation of seagrass and mangrove leaves appear to occur at different locations through the alimentary tract. The lower C and N content of mangrove leaves in the small intestine compared with fresh leaves collected from the field indicates the release of nutrients from mangrove leaves in the crop, stomach and small intestine of the green turtle. The decline of N in mangrove leaves along the small intestine provides further support for this hypothesis. In contrast, there was no significant difference in C and N of seagrass leaves in the small intestine compared with fresh field material, and there was no obvious decline along the small intestine indicating little digestion of seagrass material in the crop, stomach and small intestine of the green turtle (Figures 2 & 3). The high N content and $\delta^{15}\text{N}$ signal of ingested material in the stomach may indicate a release of enzymes from the turtle that could aid nutrient release from the mangrove leaves. Although seagrass is the main diet of the turtle and contributes most to tissue production, mangrove leaves and propagules provide an opportunistic food source from which nutrients are released faster than the most common food source, seagrass.

The C content of ingested material in the large intestine is lower than both seagrass and mangroves leaves in the small intestine, indicating that C release from both of these food sources occurs here. This is consistent with hind gut fermentation (Bjorndal *et al.* 1991). The higher %N in the large intestine compared with the material in the small intestine, and the increase along the hind gut may reflect the increased load of fermentative bacteria relative to ingested plant material (Yamamuro *et al.* 2004). The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in the large intestine may also reflect the presence of these bacteria. Few studies have utilised stable isotopic analysis to assess digestion and assimilation of food in marine vertebrates (Guelinckx *et al.* 2008). Here we provide preliminary evidence to suggest that nutrient content and stable isotope analysis of material in the digestive tract may provide additional tools in understanding the physiological and biochemical mechanisms involved with digestion and assimilation of nutritional sources in sea turtles. Stable isotope data give an indication of the type and location of different digestive processes whereas nutrient content of the material gives an indication of the

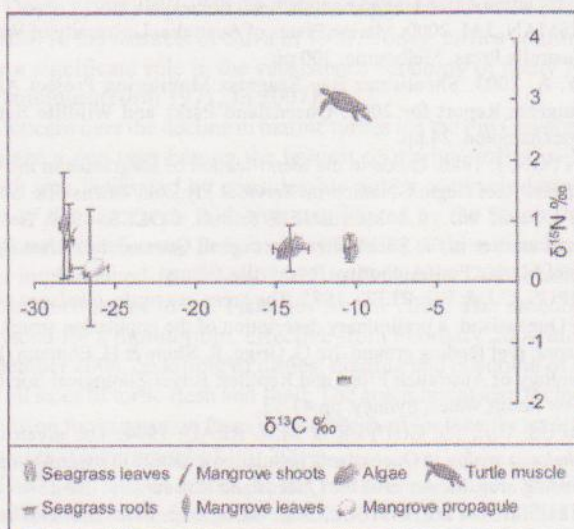


Figure 3. Stable carbon and nitrogen isotopic signatures for potential food sources for green turtles in Shoalwater Bay presented as the mean \pm standard deviation, compared with the carbon and nitrogen stable isotopic signature of muscle tissue from one adult green turtle.

timing and location of nutrient release, and potentially assimilation from different food sources. This approach has also demonstrated that there may be differential breakdown and assimilation of nutrients from different food sources in green turtle digestive tracts.

This is the first study to quantify the diets of green turtles in Shoalwater Bay for all age groups across multiple years. It demonstrates the importance of seagrass habitats to this large foraging population and will aid in the conservation and management of green turtles in Queensland. In addition, this study highlights the value of following foraging behaviour of green turtles through time as individuals may change their behaviour and adapt to the availability of food items. Although opportunistic foraging on mangrove leaves is likely to provide a food source higher in C and with a faster release of nutrients than seagrass, the volume of seagrass consumed by turtles in Shoalwater Bay means that in terms of tissue assimilation, seagrass is the most important source of tissue C and N. Finally, we also explore the value of using multiple approaches to understanding sea turtle feeding ecology and suggest the benefits of using nutrient and stable isotope analysis to explore nutritional physiology in marine turtles.

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Does Fiji's Turtle Moratorium Work?

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Marine turtles are of cultural and spiritual importance to indigenous Fijians. The cultural significance of marine turtles is illustrated in the stories, traditions and contemporary activities of many coastal indigenous communities and is acted out in numerous ceremonies such as the installation of paramount chiefs, funerals, marriages and other traditional occasions (Guinea 1993; Morgan 2007). The meat of green turtles (*Chelonia mydas*) is used preferentially at these traditional occasions (Guinea 1993; Morgan 2007).

Trade in marine turtle products also had significant value within the Fijian economy in the early 1800s (Guinea 1993). During that period, a large turtle fishery operated in Fiji to source both meat and shell trade for Asian markets. Fiji also hosted a smaller industry that used hawksbill turtle (*Eretmochelys imbricata*) scutes to make various artefacts including toilet sets, cigarette cases and jewel boxes (Levy 1949, cited by Guinea 1993). Later, during the 1980s and 1990s, marine turtles were sold at many of the commercial markets of Fiji. Green and hawksbill turtles were the most common, but Doyle (1998) reported the sale of loggerhead turtles (*Caretta caretta*) in the markets of Suva in 1997. Today, turtles continue to play a significant role in the subsistence economy of many Fijian communities (Hirth 1971, Jit 2007).

Concern over the decline in marine turtles led the Fiji Government to place a one year ban on the harvest of marine turtles in 1995, which was facilitated by considerable public outreach during the *Year of the Sea Turtle* initiative coordinated by the South Pacific Regional Environment Programme (SPREP). A three year ban was then implemented from May 1997 to December 2000, followed by an amendment to the Fisheries Act in 2004. The amendment provided for a moratorium, effective from February 2004 until 31 December 2008, on killing of turtles; digging and poaching of eggs; and all sales of turtle flesh and shell. The amendment also included a provision for exemption from the moratorium for take for traditional purposes (Government of Fiji 2004).

The open sale of turtles in the markets no longer occurs but there is anecdotal information that there is still a substantial catch of turtles for subsistence and traditional use and a possible black market for commercial sales (Seeto, J. pers obs. March 2008). This study details the extent of turtle use in the following locations in an attempt to assess the success of the current moratorium: 1. handicraft and municipal markets on the island of Vitilevu; 2. four villages among the Mamanuca Islands.

Market survey at Vitilevu: A market survey for turtle products was carried out, following the recommendations of Tambiah (1999), at 102 different shops in handicraft centres and municipal markets at seven locations around the island of Vitilevu from April 2006 to February 2007. The survey targeted centres and markets frequented by tourists (Figure 1). Any turtle carapaces or derivatives such as combs, spoons, bangles, necklaces and pendants on display at the surveyed shops were recorded. The curved carapace lengths (CCL) of carapaces were measured, and they were photographed and identified to species. Informal interviews were carried out with vendors to ascertain additional information about sale prices and markets, as well as fishery information such as location and date of capture. Vendors were generally cooperative, with all but one allowing inspection of their products.

Village surveys in the Mamanuca islands: Household surveys about turtle use were carried out in four villages in the Mamanuca islands. The Mamanuca's consist of 27 islands southwest of Vitilevu, most of which are popular tourist destinations with hotels and resorts. The villages of Solevu, Tavua, Yanuya and Yaro were surveyed, which are located on the largest islands of Malolo, Tavua and Yanuya (Figure 2).

Acceptable and traditional village protocols were followed with respect to informing village chiefs and elders about the survey and requesting permission. The household surveys involved in-depth, interviews carried out in the Fijian language. Households were

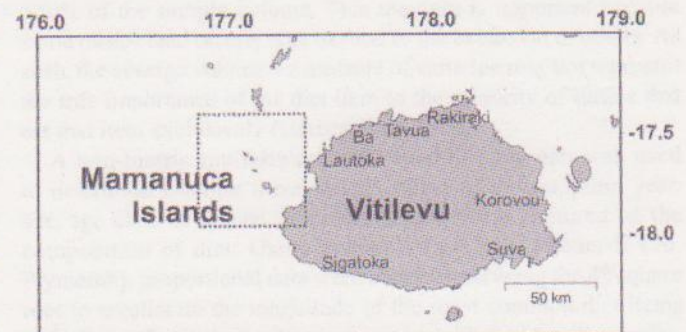


Figure 1. Map of Vitilevu Island, Fiji showing sites of the market survey. Map produced using MAPTOOL (<http://www.seaturtle.org/maptool/>).