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The stomach contents of post-hatchling green and loggerhead sea turtles in the southwest Pacific: an insight into habitat association

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Abstract Dietary information obtained from stomach contents can provide a wealth of information on an animal's ecology. Where animals are cryptic, such as the post-hatchling life history stage of a sea turtle, the ecological insight that dietary analyses can provide, may be otherwise unobtainable. Investigations into post-hatchling turtle stomach contents have found planktonic organisms, dominated by pelagic molluscs and crustaceans, hydrozoans, *Sargassum* and fish eggs. The nature of these dietary organisms provides evidence for the widely accepted hypothesis that, with the exception of the flatback turtle (*Natator depressus*), the post-hatchling stage of a sea turtle's life history is pelagic and oceanic. As the majority of studies that have investigated the stomach contents of post-hatchling sea turtles have been conducted on loggerhead turtles (*Caretta caretta*) in the northern Atlantic and Pacific Oceans, insight derived from dietary investigations into post-hatchling ecology is biased. This study investigates the diet of post-hatchling green turtles (*Chelonia mydas*) and loggerhead turtles in the southwest Pacific Ocean. Stomach contents were obtained from 55 green and loggerhead post-hatchling turtles that had stranded or been consumed by *Coryphaena hippurus*. Our findings demonstrate that loggerhead and green post-hatchlings in the southwest Pacific share similar feeding ecology and feed on a variety of neustonic items that are indicative of an oceanic and pelagic existence. The dietary items consumed by both species investigated belong to similar taxonomic groups as those found in previous studies with species level distinctions occurring owing to the different geographical location.

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Introduction

The post-hatchling stage of a sea turtle's life history encompasses the period of life after a hatchling leaves its natal beach and swims offshore, seldom to be seen again until it returns to coastal waters some years later as a larger juvenile. The obscure nature of post-hatchling sea turtles in their natural environment has made it difficult to obtain ecological information on this life-history stage via direct in situ observations. Consequently, our understanding of post-hatchling ecology has primarily been obtained through studies of behaviour and diet.

Dietary investigations have been particularly informative in contributing to current knowledge on post-hatchling sea turtles and have provided insight into habitat use (Witherington 1998; Tomas et al. 2001), foraging strategies (Tomas et al. 2001), energetics (Mann et al. 2000) and diet contaminants (McCauley and Bjorndal 1999). Previous studies have found that post-hatchling sea turtle stomachs contain a range of organisms that are dominated by pelagic molluscs and crustaceans (e.g. Cirripedia and Amphipoda), hydrozoans, *Sargassum* sp. and fish eggs, with a notable lack of benthic organisms. Synthetic items such as plastics, balloons and tar balls, are also ingested frequently (Witherington 1994, 1998; Richardson and McGillivary 2001). The pelagic and oceanic nature of the components of the post-hatchlings' stomachs provide evidence for the widely accepted hypothesis that, with the exception of the flatback turtle (*Natator depressus*), the post-hatchling stage of a sea turtle's life history is pelagic and oceanic (Bolten 2003).

In some studies the dietary items consumed by post-hatchlings provide quite specific information on the turtle's habitat association. For example, items such as *Sargassum* floats and leaf parts, and snails (*Litiopa melanostoma*) associated with *Sargassum*, are found within the stomachs of post-hatchling loggerhead turtles (*Caretta caretta*) stranded along the Florida coastline (Carr and Meylan 1980; Plotkin 1999). These items provide evidence of an association of these turtles with the *Sargassum* rafts that occur along the convergence zones within the Atlantic Ocean. Off the coast of Baja California post-hatchling loggerhead turtles inhabiting regions of up-welling have a diet that is dominated by the pelagic red crab (*Pleuroncodes planipes*) that is characteristic of this region (Nichols et al. 2000).

Only a handful of locations have been identified where post-hatchling sea turtles can be found in their natural environment and these sites are predominately occupied by post-hatchling loggerhead turtles. As a result, the majority of dietary information on post-hatchlings has been derived from loggerhead turtles in the northern Atlantic and northern Pacific oceans (reviewed by Bjorndal 1997). These post-hatchlings were caught in high-sea driftnets in the central northern Pacific Ocean (Parker et al. 2005), in the waters around the Azores (Bolten and Balazs 1982; van Nierop and den Hartog 1984) and in the Atlantic Ocean's Gulf Stream (Richardson and McGillivary 2001). Several dietary studies have also examined post-hatchling loggerhead turtles captured in the neritic habitat, including waters near nesting beaches in the south-eastern USA and South Africa (Hughes 1974) and from stranded individuals found along the coast of Texas (Plotkin 1999), and Florida (Carr and Meylan 1980). In comparison to post-hatchling loggerhead turtles, only scarce documentation on dietary studies is available for green (*Chelonia mydas*) (Hughes 1974; Frick 1976), hawksbill (*Eretmochelys imbricata*) (Meylan 1984; Limpus and Limpus 2007), Kemp's ridley (*Lepidochelys kempi*) (Shaver 1991), leatherback (*Dermochelys coriacea*) (Brongersma 1970) and flatback (Zangerl et al. 1988) post-hatchlings, whilst there appears to be no documentation on the diet of post-hatchling olive ridley turtles (*Lepidochelys olivacea*).

As the majority of ecological information derived from the stomach contents of post-hatchlings has originated from loggerhead turtles in the northern Atlantic and northern Pacific oceans, our capacity to make broad generalisations on post-hatchling ecology is limited. To refine our understanding of post-hatchling feeding ecology and gain a greater insight into the ecology of post-hatchling turtles, further dietary studies are required. In this study, we investigate the stomach contents of green and loggerhead post-hatchling turtles in the southwest Pacific Ocean region. The stomach contents described provide qualitative information on species in this region and are used to make inferences on their ecology.

Materials and methods

The stomach contents of 55 post-hatchling sea turtles were collected for qualitative dietary analysis. These samples were excised from 31 green turtles and 7 loggerhead turtles that had stranded on beaches between northeast New South Wales (−32.817, 151.9), and southeast Queensland (−26.5, 153.0) (Fig. 1). The mean curved carapace length (CCL) of the stranded post-hatchling green turtles was 7.7 cm (SD = 1.46, range = 5.5–11.3) and of the post-hatchling loggerhead turtles was 6.4 cm (SD = 1.99, range = 4.6–10.6). The remaining 17 post-hatchlings were green turtles retrieved from the stomachs of *Coryphaena hippurus* (also known as dolphin fish or mahi mahi) captured in long-line fisheries operating around sea mounts offshore from Queensland and New South Wales (Fig. 1) and ranged in size from 5.9 to 9.4 cm CCL (mean 7.3, SD 1.18). As all of the turtles examined were well under the minimum size for their respective species that have been observed foraging in neritic habitats (i.e. <66 cm CCL loggerhead turtles and <38 cm CCL green turtles, Limpus and Limpus 2003; Limpus et al. 2005), they were considered to be post-hatchlings.

Necropsies were performed to remove the stomach and intestinal tract from the deceased turtles, and the mouth cavity and oesophagus were examined to check for any food items that had been ingested prior to death. The digestive tract was divided into anterior (stomach) and posterior (large and small intestine) portions and gross observations of the contents were made under a dissecting microscope. The contents were sorted and items were identified to the lowest possible taxon level. Stomach contents were divided into three groups that were determined by the post-hatchlings from which they were derived, (1) green turtles excised from fish stomachs, (2) stranded green turtles and (3) stranded loggerhead turtles. The frequency of occurrence of dietary components was then calculated for each group by dividing the number of stomachs in which the prey item occurred by the total number of stomachs examined in that group. While the frequency of occurrence identifies the items that are consumed by the greatest number of turtles, it does not convey the importance of particular food items for any one turtle. Volume and biomass were not estimated in this study as different types of items are digested at different rates, which result in biased information on the actual biomasses ingested. For example, non-digestible, hard-bodied items will persist in the digestive tract longer than soft-bodied items, which are rapidly digested; resulting in hard-bodied items being over-represented.

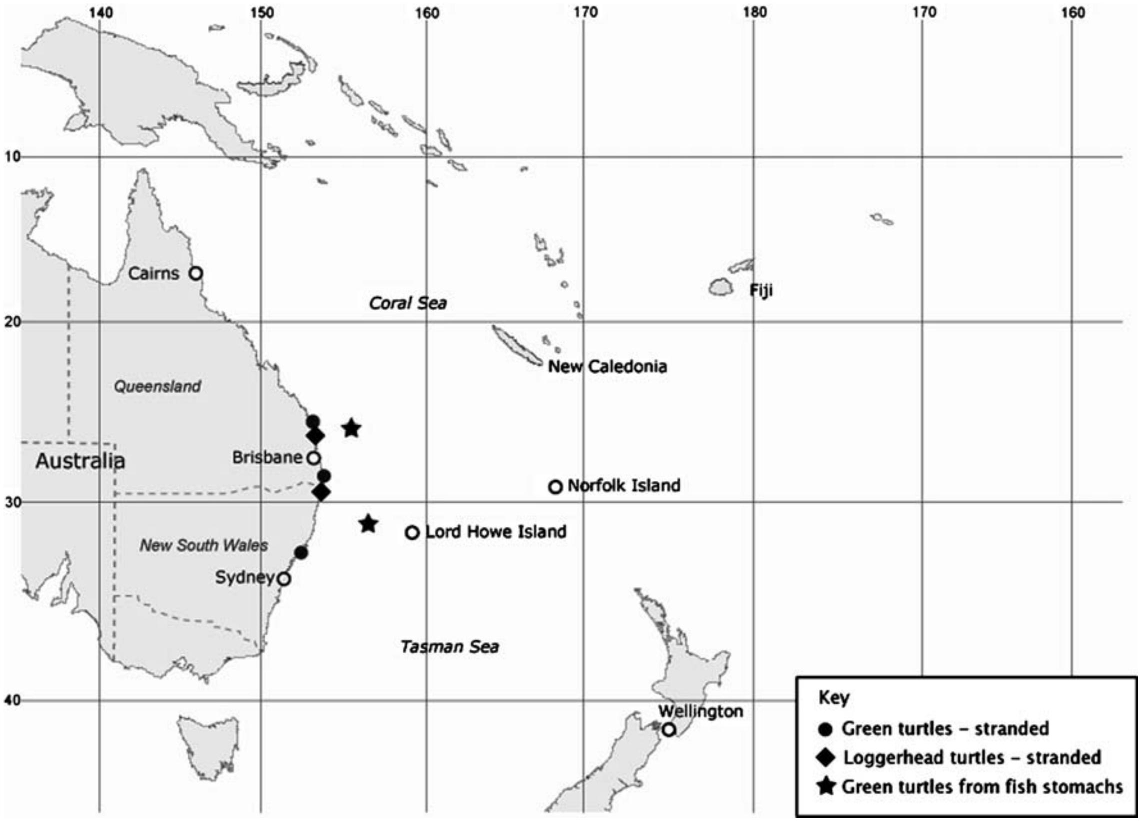

Fig. 1 The distribution of post-hatchling green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) sea turtles collected for dietary analysis. The post-hatchling turtles collected had either stranded on beaches or had been consumed by dolphin fish (*Coryphaena hippurus*)

A multi-response permutation procedure (MRPP), was applied to determine whether dietary items differed significantly between (1) stranded green and loggerhead post-hatchling turtles, and (2) green post-hatchling turtles that were stranded and those that were found within the stomachs of fish. For the MRPP analysis, prey items were categorised into 11 broad taxonomic groups (Table 1). For each post-hatchling, the presence or absence of items belonging to each prey group was recorded with these values representing the observation in the MRPP analysis.

Results

The majority of material found within the post-hatchlings' digestive tracts was highly digested and for the most part was unidentifiable. Items that could be identified were primarily found in the anterior portion of the stomach, with the exception of synthetic material, pumice and shell fragments, which occurred throughout the digestive tract. The identifiable components of the stomach contents included a range of organisms that were categorised into 13 broad taxonomic groups (Table 2). These groupings were the same as the 11 used for MRPP analysis, with the exception that pelagic gastropods and hydrozoans were further divided into two groups each for descriptive purposes. The MRPP indicated that the consumed items did not differ significantly between the stranded loggerhead and the stranded green post-hatchlings ($P = 0.59$). Similarly, there was not a significant difference in the dietary items consumed by

Table 1 The 11 groups (A–K) of prey items used in the multi-response permutation procedure (MRPP) statistical analysis

Group	Grouping	Group items included
A	Synthetic debris	Nylon, plastics (hard and sheet),
B	Natural debris	Feathers, wood, pumice
C	Class Hydrozoa	All hydrozoans
D	Class Insecta	Orders Coleoptera, Diptera, Hemiptera
E	Class Malacostraca	Orders Amphipoda, Euphausiacea, Isopoda
F	Class Maxillopod	Order Calanoida
G	Class Cirripedia	Order Thoracica
H	Class Gastropoda pelagic	Order Thecosomata
I	Class Gastropoda non-pelagic	Order Pterioda
J	Sand	
K	Plant material	All items of plant origin

Table 2 Prey species encountered in the stomachs of post-hatchling green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles, and the percentage frequency (%F) of occurrence, with the number of stomachs the item occurred within (*n*)

Diet component	Habitat	Loggerhead-ST (total *n* = 7) % F (n)	Green-ST (total *n* = 34) % F (*n*)	Green-PF (total *n* = 13) % F (*n*)
Synthetic flotsam				
Plastics	Pelagic, OW, CW	57 (4)	74 (25)	46 (6)
Styrofoam				
Nylon cord/string				
Natural flotsam				
Feather	Pelagic, OW, CW	14 (1)	26 (9)	31 (4)
Wood				
Pumice				
Phylum Cnidaria				
Unidentified	Epipelagic, OW, CW	43 (3)	50 (16)	62 (7)
Porpita sp.		0 (0)	3 (1)	3 (1)
Phylum Arthopoda	Terrestrial, airborne			
Cl. Insecta		0 (0)	3 (1)	15 (2)
Phylum Arthopoda, sub ph. Crustacea				
Cl. Malacostraca	Various, marine	29 (2)	56 (19)	69 (9)
Cl. Maxillopod		0 (0)	3 (1)	0 (0)
Cl. Cirripedia		0 (0)	12 (4)	38 (5)
Phylum Mollusca				
Cl. Gastropoda	Pelagic, OW, CW			
Tonnidae		14 (1)	26 (9)	0 (0)
Cavoliniidae		0 (0)	24 (8)	0 (0)
Pterioda[a]		0 (0)	3 (1)	0 (0)
Plant	Various, OW, CW	14 (1)	12 (4)	15 (2)
Sand	Benthic, OW, CW	29 (2)	12 (4)	0 (0)

[a] Adult stage Pterioda occupies a benthic habitat

OW Oceanic waters, *CW* coastal waters, *ST* stranded, *PF* fish prey

green post-hatchling turtles from the stomachs of predatory fish and green post-hatchling turtles that had been stranded ($P = 0.24$).

Synthetic flotsam occurred most frequently in the stomachs of the stranded post-hatchlings (both species) and was the third most frequently occurring item in the stomachs of post-hatchling green turtles that had been preyed upon by *C. hippurus* (Table 2). This synthetic flotsam was dominated by hard plastic pieces but also included plastic film, Styrofoam and nylon cord. The occurrence of synthetic items varied between animals from single pieces to volumes that nearly filled the stomach. Natural flotsam (e.g. pumice, wood and feathers) also occurred in the stomach contents of the three groups of post-hatchlings, ranging from 14% in stranded loggerhead turtles to 31% in the green turtles predated by fish (Table 2).

Organisms from the subphylum Crustacea and the phylum Cnidaria (class Hydrozoa) dominated the organic contents of the examined stomachs (Table 2). Cnidarians were recognised by the remains of *Porpita* sp. disks and various tentacles, and Crustaceans were identified through the remains of exoskeletons, which were often in pieces with no soft parts remaining. Malacostraca was the most dominant class of Crustacea and consisted primarily of amphipods, *Hyperia* sp. (Hyperiidae), Isopods, *Idotea metallica* (Idoteidae) and krill (Euphausiacea). Of the identifiable prey items, organisms from the class Malacostraca occurred regularly in green turtles that had been preyed upon by fish (69%), and in stranded green turtles (56%) (Table 2). Other Crustacea found included copepods (Calanoida) from the class Maxillipoda, and barnacles and cyprid larva belonging to the family Lepadidae (*Lepas* sp.) from the class Cirripedia.

Organisms identified from the class Gastropoda (phylum Mollusca), consisted of tonnoid veliger larvae, and pteropods; *Cavolinia* sp. and *Creseis* sp. These items occurred in 26% of stranded post-hatchling green turtles and 14% of the stranded post-hatchling loggerhead turtles, but were absent in green turtles that had been sourced from *C. hippurus* (Table 2). In one stranded post-hatchling green turtle, a single *Pinctada* sp. (pearl oyster) specimen was found. Other items present in the post-hatchling green and loggerhead turtle stomachs included floating plant matter (seed pods and spores, etc.), insects and sand grains (Table 2). The insects, one each from the orders Diptera, Hemiptera and Coleoptera, occurred in three green turtles. Sand grains were present in the stomachs of six post-hatchlings that had stranded: two from loggerhead turtles and four from green turtles. The sand occurred throughout the digestive tract, but there was no evidence of sand in the mouth or oesophagus in any of the post-hatchlings examined.

Discussion and conclusions

Stomach contents and habitat indications

Our study demonstrates that small post-hatchling green and loggerhead turtles in the southwest Pacific Ocean do not differ significantly from each other in their feeding ecology. The stomach contents examined reveal that both species had ingested a range of items that were dominated by zooplankton, with synthetic and natural flotsam also occurring frequently. This consistency between the diet of early juvenile green and loggerhead turtles has also been revealed through stable isotope investigations in the North Atlantic (Reich et al. 2007).

The types of organisms found within the post-hatchlings' stomachs indicate that the investigated turtles were inhabiting pelagic waters of either the continental shelf or open-ocean. Ingested items that provide evidence of this habitat include: *Porpita* sp., a floating hydroid that typically inhabits pelagic oceanic and continental shelf waters (Wrobel and Mills 1998), the organisms belonging to the family Cavoliniidae (*Creseis* sp. and *Cavolinia* sp.) which are open-ocean pelagic gastropods (Lalli and Gilmer 1989), the planktonic larval stage of the Tonnoid gastropod, which are widely dispersed in ocean currents (Beu 2001), the neustonic isopod *Idotea metallica*, and *Hyperia* sp. a planktonic amphipod (Smith 1977). These ingested items compliment Arthur et al.'s (2008, in press) study that found the stable isotope composition of epidermal tissue of small (<10 cm CCL) green turtles from southwest Pacific was representative of an open-ocean omnivorous diet.

A near absence of benthic organisms in the stomachs of the post-hatchlings investigated further attests to residency within pelagic waters. The only benthic organisms found within the stomach contents were a single juvenile *Pinctada* specimen and sand grains. *Pinctada* sp. have a pelagic larval dispersal stage (Southgate and Lucas 2003), with settlement occurring on hard substrata, typically in coastal waters. However, spatfall (settled larva) have been observed on floating substrate in the open sea (Alagarswami 1977), and therefore it is possible that the juvenile *Pinctada* specimen was consumed by a post-hatchling in the pelagic environment. In light of no further benthic organisms being present, the sand grains were mostly likely ingested as the hatchlings made their initial swim offshore through the surf zone during which time they have been shown to take in water (Bennett et al. 1986; Marshall and Cooper 1988).

Prey items consumed by stranded green post-hatchling turtles and those sourced from *C. hippurus* were similar, thus indicating that in the absence of accessible in situ samples, stranded post-hatchlings provide a valuable source of information of this life stage's feeding ecology. This similarity of dietary items retrieved from live turtles found in situ and from stranded and moribund turtles is also reported in previous studies (see Carr and Meylan 1980; Plotkin 1999 versus Richardson and McGillivary 2001; Witherington 1994).

Ecological insights

The wide range of organisms observed in the stomach contents of post-hatchling turtles (Table 3), reflect an opportunistic feeding strategy. In the oceanic environment post-hatchling turtles are thought to associate with converging border currents and regions of high productivity, such as areas of up-welling (Carr 1987). At these locations a diverse array of food resources will co-occur and an opportunistic approach to feeding allows an animal to take advantage of the resources available. As such, opportunistic feeding behaviour is observed in many oceanic pelagic fish (Bernard et al. 1985; Bertrand et al. 2002) and would benefit sea turtles in the oceanic environment.

The neustonic items consumed by the post-hatchling turtles in this study are characteristic of the planktonic assemblages that occur in association with oceanographic features that concentrate floating organisms (Seki and Polovina 2001). There is a strong similarity in the range and type of prey items found in the present study to that reported by Parker et al. (2005) who investigated pelagic juvenile loggerhead turtles in oceanic waters of the central North Pacific that were associated with the Transition Zone Chlorophyll Front (TZCF).

An association of pelagic loggerhead turtles with oceanic frontal systems has also been reported by recent satellite tracking studies in the northern Pacific Ocean (Polovina et al. 2000, 2003, 2006) which suggest the importance of features that concentrate food resources for pelagic turtles foraging in the oceanic habitat. For post-hatchling loggerhead turtles who undertake transoceanic migrations in the southern Pacific (Boyle 2006), the floating organisms that converge along the fronts associated with the South Pacific gyre will provide valuable food resources. For the southern Pacific green post-hatchlings, who remain in the southwest Pacific Ocean (Boyle 2006), food resources will be found in association with the eddies that develop from East Australian Current and the increased productivity that occurs at seamounts. The capture of multiple *C. hippurus* who had consumed green post-hatchlings in the vicinity of

Table 3 Stomach contents of post-hatchling loggerhead (*Caretta caretta)* turtles in the Atlantic and Pacific oceans showing that post-hatchlings feed on pelagic organisms. % refers to the percentage of post-hatchlings with the specified dietary item in their stomach contents

Atlantic Ocean				Pacific Ocean		
Witherington 1994	Richardson and McGillivary 2001	Witherington 1998	Carr and Meylan 1980	Parker 2005	Peckham and Nichols 2002	This study
Off Florida, at sea ($n = 50$)	Off Florida, at sea ($n = 2$)	Off Florida, at sea ($n = 66$)	Florida, stranded ($n = 5$)	North Pacific at sea ($n = 52$)	Off Baja California (n = 7)	E. Australia*, stranded* (n = 7)
4.0–5.6 cm SCL	4.5–47 cm CL	4.1–7.8 cm SCL	"hatchling"	13.5–74.0 cm CCL	Mean 61.4 cm SCL	4.6–10.6 cm CCL
Cnidaria (40%)	*Sargassum* (100%)	*Sargassum*	*Sargassum*	Gastropods	*Pleuroncodes planipes* – pelagic crab (100%)	Synthetics (57%)
Tar (34%)	Plant material (100%)	Plant material	Gastropods	Cephalopods		Cnidaria (43%)
Synthetics (32%)	Insects (100%)	Cnidaria	Crustaceans	Crustaceans		Crustacea (29%)
Sargassum (26%)	Crustaceans (100%)	Copepods		Cnidaria		Gastropods (33%)
Crustaceans (18%)	Cnidaria (100%)	Insects		Urochordata		Plant material (14%)
Hydrozoans (16%)	Tar (100%)	Plastics & tar (5.1%)		Fish		
Insects (4%)	Fish eggs (50%)	Polycheates		Annelids		
Gastropods (4%)	Plastics/synthetics (50%)	Bryozoan		Algae		
Plant material (8%)						

seamounts provides evidence that these resource-converging features provide a habitat that is occupied by these small pelagic turtles.

In addition to food resources, such fronts also concentrate an array of synthetic items. Although synthetic material is most likely over-represented in the stomachs of the studied post-hatchlings owing to its non-degradable nature, the high frequency at which it occurred raises health concerns. McCauley and Bjorndal (1999) report that post-hatchling turtles do not compensate for the consumption of non-nutritional items, which results in reduced energy and nitrogen uptake. Even though the effects of synthetic material were not directly assessed in this study, it is interesting to note that synthetic material occurred less frequently in post-hatchlings (46%) that had been consumed by *C. hippurus* compared to those that had become stranded (69%).

Inter-study comparisons

Obtaining post-hatchling sea turtles in the southwest Pacific is unavoidably opportunistic, and consequently the present study was restricted to small turtles (<10 cm CCL) that were no more than a few months old. All the turtles sampled were collected southwards of the Southern Great Barrier Reef and would have travelled away from their natal beach in the direction of the East Australian Current. Despite this somewhat biased sampling, the organisms consumed by the post-hatchling turtles examined in this study belong to similar taxonomic groups as those reported in previous dietary investigations.

However, owing to the varying geographical locations, some notable distinctions occur, such as the absence of *Sargassum* and the organisms that specifically associate with *Sargassum* rafts in the stomachs of post-hatchlings feeding in the southwest Pacific Ocean (Table 3). Studies conducted in the Atlantic Ocean frequently report *Sargassum* and other plant material in the stomach contents of loggerhead post-hatchlings (Table 3). Conversely, studies conducted in the Pacific Ocean do not report the same consistency of plant matter as the Atlantic studies (Table 3). Parker et al.'s (2005) study on post-hatchling loggerhead turtles caught in the central northern Pacific Ocean reported stomach contents that were dominated by animal matter, primarily *Carinaria cithara*, *Janthinia* sp. *Lepas* sp., *Planes cyaneus* and *Pyrosomas*, with a small mention of the brown algae, *Cystoera*. The discrepancy between the studies conducted in Pacific and Atlantic are not surprising given that the large rafts of Sargassum that characterise the North Atlantic do not occur in the South Pacific Ocean.

In addition to geographical location, some of the differences that occur in the stomach contents of post-hatchlings between studies can be attributed to the size classes of the turtles investigated. Larger turtles have a larger gape size than a smaller turtle and will therefore have a greater capacity to manipulate and ingest larger food items. Peckham and Nichols (2002) investigated post-hatchling loggerhead turtles with an average straight carapace length (SCL) of 61.4 cm and found stomach contents that were dominated by the pelagic red crab, *P. planeipes*. In comparison, studies conducted with smaller (<15 cm CCL) turtles (Witherington 1994, 1998; Richardson and McGillivary 2001; present study) found stomach contents that contained a wide variety of small planktonic organisms.

The prey items reported within this study add to the growing body of literature that support Carr's (1986, 1987) early speculations that sea turtles spend their early juvenile stage in the surface waters of oceanic habitats. The results of this study demonstrate the consistency of the diet of early juvenile life stage sea turtles in the southwest Pacific with what has been reported in other regions. Additionally, the items consumed highlight the role of oceanic frontal systems in providing a habitat that offers accessible food resources for the pelagic life stage of a sea turtle. The descriptive dietary information we present is the first for green and loggerhead sea turtles of this size in this region, and as such it provides a valuable contribution to life history information for these species.

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