A STUDY OF GUT FUNCTION IN YOUNG LOGGERHEAD SEA TURTLES, CARETTA CARETTA L. AT VARIOUS TEMPERATURES

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ABSTRACT

The effects of temperature within the range 20°C to 30°C, on rate of passage of material through the gut were studied in juvenile captive loggerhead turtles (*Caretta caretta*). Total gut clearance time (TGCT) decreased with increasing temperature ($Q_{10} = 1.6$). The difference in value of TGCT was greater between 20°C and 25°C, where it fell by 33 hours, than between 25°C and 30°C, where it decreased by 6 hours. At 25°C and 30°C the satiation ration amounted to 3.73 per cent body weight; at 20°C the value was only 0.92 per cent. It was calculated that appetite would return to satiation level at a faster rate at 20°C than at 25°C or 30°C.

Food was retained in the oesophagus of juvenile loggerhead turtles for up to one hour after feeding.

INTRODUCTION

Little is known of the behaviour and feeding activity of young marine turtles after entering the sea. It is thought that their passive migration is influenced by currents and oceanic gyre systems, (Witham 1980). Hatchlings have been found associated with sargassum rafts where they presumably feed on the associated fauna of the raft community (Carr and Meylan 1980). Juvenile loggerheads, like the hawksbill Eretmochelys *imbricata*, are thought to be omnivorous. Sargassum was found to be the most prevalent item in the stomachs of loggerhead hatchlings washed onto the Florida coast by Hurricane David in 1979, (Carr and Meylan 1980). This contrasts with the known carnivorous nature of adult Caretta. The rates of digestion in young green turtles were studied by Hadjichristophorou and Grove (1983) and Davenport and Oxford (1983). Davenport and Oxford also found that young C. mydas probably possesses a cellulose degrading gut microflora, although this was already known for adults of the species, (Bjorndal 1979).

In this study we compared the gut action of young *Caretta caretta* with that of green turtles of similar age, and studied the effect of temperature on the rate of digestion in captive loggerheads fed a high protein artificial diet.

MATERIALS AND METHODS

COLLECTION AND MAINTENANCE

Six juvenile loggerhead turtles were obtained from the Department of Fisheries, Cyprus. The turtles were kept in a recirculating sea water system under constant illumination. During maintenance the temperature of the water was kept at 25°C ± 1 and the salinity held at 33-34 °/00. The turtles were fed every 24 hours on an artificial diet of Omega trout pellets (OTF) at a ration of 1.5 per cent body weight per day. The artificial diet (OTF) was used throughout these experiments. Three temperatures were chosen; 20°C, 25°C and 30°C. For each set of experiments the temperature in the recirculating system was altered and the animals allowed to acclimatize for a 4 to 5 day period. No studies of physiological acclimation appear to have been carried out on sea turtles, so the chosen acclimatization period was selected rather arbitrarily. However, sudden seawater temperature changes of similar magnitude are very common in the Mediterranean which is generally rather shallow and subject to brief storms alternating with periods of strong sunlight.

CHROMIC OXIDE MEALS

Labelled pellets were prepared by grinding OTF into a fine powder and adding chromic oxide (2 per cent by weight). The resultant green mixture was made into a paste by adding water, extruded through a hypodermic syringe, dried and cut into pellets.

Prior to chromic oxide meals the turtles were starved for 27 hours, then fed a 1.5 per cent body weight ration of the labelled pellets. The 3 hour extra deprivation beyond the normal feeding interval ensured that total consumption occurred. Normal feeding procedure was maintained before and after feeding the labelled meal.

To determine the time of production of labelled faeces accurately, the turtles were taken out of the recirculating system 1 to 2 days after consuming the chromic oxide meal and placed in holding tanks containing sea water kept at the experimental temperature. A system of slats mounted 2cm above the bottom of the tanks ensured that any faeces produced were not broken up or consumed by the turtles. The experimental process was repeated ten times at each temperature, and average values for the following parameter calculated:

Total Gut Clearance Time (TGCT): the time taken for food to pass completely through the digestive system estimated as the time elapsed between feeding and the appearance of the last green faeces. The relationship TGCT = $a'W^{b'}.e^{c'T}$, (where W is the weight of the animals, T is the temperature in degrees Celsuis and a', b' and c' are constants) was calculated separately for each turtle by multilinear regression since individual turtles differ in their rate of digestion. These separately calculated values were then averaged.

BARIUM SULPHATE MEALS

To study the progress of food along the gut, the turtles were fed a 1.5 per cent body weight ration of a barium sulphate labelled meal at a concentration of one part $BaSO_4$ to four parts OTF by weight. The labelled pellets were prepared in the same fashion as those containing chromic oxide. Before feeding, the turtles were starved for 27 hours and the normal feeding procedure was maintained before and after the meal. X-radiography was performed just after feeding and at various time intervals subsequently.

SATIATION MEALS

The turtles were deprived of food for the length of time corresponding to the calculated 'gastric emptying time 'GET (the time interval between appearance and disappearance of chromic oxide labelled faeces); stomach fullness is considered to be one of the main controls of appetite. They were then fed a satiation ration. To do this, 50g of pellets was weighed out and the pellets offered to each turtle until they had refused five pellets in five minutes. The amount eaten was calculated by deduction of the weight of the uneaten food from the original 50g.

The relationship:

satiation amount (g) = a"W^b".e^c"T, (where W is the weight of the animals, T is the temperature in degrees Celsuis and a", b" and c" are constants), was calculated for all the animals.

RATE OF APPETITE RETURN

After the satiation meal described above, each turtle (studied in pairs) was given a second satiation meal at intervals of 6, 12, 18, 24, 30 and 36 hours after the start of the first satiation meal. To express the return of appetite the Von Bertalanffy equation was fitted to the data for each temperature. The Von Bertalanffy equation assumes that data rise towards some theoretical maximum and the closer their value gets to the maximum the slower the rate of change. The equation is as follows:

$Wt = W(1 - exp(-K(t - t_0)))$

Where Wt is the % body weight meal ingested after time t,

and W is the theoretical maximum % body weight meal.

K is a constant at each temperature.

An algorithm capable of finding an unconstrained minimum of a sum of squares (through the NAG subroutine E04FDF) was used to fit the Von Bertalanffy equation to the data. By this method estimates of W, K and t_0 were obtained for each temperature.

RESULTS

TOTAL GUT CLEARANCE TIME

Initially it was hoped that gastric emptying time (GET) could be measured. The method of labelling food with chromic oxide to estimate GET assumes that after the food has left the stomach its rate of passage through the rest of the gut occurs at a constant rate. It also assumes that the food enters the stomach immediately after eating. The time of feeding affected faecal deposition; turtles defaecated most material just after feeding. This finding suggests that passage of food through the latter part of the gut does not occur at a constant rate so GET cannot be measured accurately.

At 20°C the turtles has to be fed several times each day to ensure the complete ingestion of the 1.5 per cent body weight meal. Therefore, given the observed association of feeding and defaecation, it is not surprising that TGCT values at this temperature tend to be rather variable.

Fig. 1 shows the presence of food in the oesophagus for at least one hour after a meal. Food retention indicates that the oesophagus acts as a temporary food store or crop. This was observed in animals at 10 months (weighing approximately 500g) and 20 months (weighing approximately 2500g) of age. Whether this novel finding also applies to adult loggerheads is unknown.



Fig. 1 I hour after feeding; food in the eesophagus.

The data (Table I) for TGCT and body weight were found to be normally distributed in each case, and ANOVA showed that for each quantity the populations from 20°C, 25°C and 30°C differ significantly because of the growth of the animals (P<0.001). TGCT was found to decrease with increasing temperature. The increase from 20°C to 25°C had a greater effect on TGCT than the increase from 25°C to 30°C. From 20°C to 25°C the value for TGCT fell by approximately 33 hours and from 25°C to 30°C it fell by a further 6 hours.

The calculated equation for TGCT was found to be: TGCT = $420W^{-0.0025}$.e^{-0.049T hours}

In this equation weight (W) had no effect on TGCT (W^{-0.0025}). The effect of temperature (T) on TGCT was pronounced. ($Q_{10} = 1.6$)).

	Temperature °C						
	20°C	25°C	30°C	L.S.D. (T5%)*			
ТӨСТ	155.8	122.0	95.3	7.358			
Body Wt	1409.9	560.5	965.2	144.88			

* Least significant difference

TABLE 1: Mean total gut clearance times (n = 10) and body weights at 20° C, 25° C and 30° C.

SATIATION AMOUNT

From the observed values (Tables 2, 3 and 4) there was no difference between satiation amount at 25°C and 30°C. The mean value at these temperatures was 3.73 per cent body weight, but at 20°C there was a marked drop in satiation ration (mean = 0.92 per cent body weight). Significant linear relationships of log transformed body weight on log transformed satiation amount were found by regression (Fig. 2) for 20°C (P<0.05, $R^2 = 0.35$) and at 30°C (P<0.001, $R^2 = 0.70$). At 25°C satiation amount did not vary with body wt.

This showed that body weight had a more pronounced effect on satiation amount at 20°C and 30°C than at 25°C where there was little relationship between the terms.



Fig. 2 In Satiation weight plotted against In body weight.

□; In Satiation weight at 30°C.

▲; In Satiation weight at 25°C.

 Δ ; In Satiation weight at 20°C.

The calculated equation for satiation amount was found to be:

Satiation amount (g) = $0.696W^{0.0567}$.e^{0.131T}

In this equation temperature increase was found to have a small effect ($Q_{10} = 0.27$) on satiation amount.

RETURN OF APPETITE

There are two main factors which are thought to control appetite; stomach fullness and the previous feeding pattern experienced (amount and frequency of feeding). After the first satiation meal the stomach was assumed to be full although the previous maintenance ration would have affected this value. The time of feeding will also affect the ration consumed; turtles fed at night took less than those fed during the day and ate most when fed close to their regular feeding time (9.00-

Turtle Number	Body Weight (gms)	Satiation Meal (1) 73 (hrs)* (gms)	Satiation Meał as % B.W.	Deprivation Time (hrs)	Satiation Meal (2) (gms)	Satiation Meal as % B.Wt	Satiation Meal (2) as a percentage of Sat Meal (1)		
3	1183	7.2	0.6	6	4.4	0.4	61.1		
4	1821	112.0	0.6	6	8.4	0.5	7.5		
5	1512	16.6	1.1	12	9.9	0.6	59.6		
2	1482	11.7	0.8	12	7.5	0.5	64.1		
5	1535	20.1	1.3	18	29.1	1.9	144.7		
4	1867	17.3	0.9	18	25.4	1.4	146.8		
3	1242	9.0	0.7	24	16.9	1.34	187.7		
2	1527	18.1	1.2	24	33.8	2.2	186.7		
3	1558	14.6	0.9	30	20.6	1.3	141.1		
5	1592	15.9	1.0	30	27.0	1.7	169.8		
4	1946	17.0	0.9	36	31.4	1.6	184.7		
2	1324	12.8	1.0	36	24.5	1.8	191.4		

* = 'Gastric Emptying Time' (see text).

Turtle Number	Body Weight (gms)	Satiation Meal (1) 42 (hrs)* (gms)	Satiation Meal as % B.W.	Deprivation Time (hrs)	Satiation Meal (2) (gms)	Satiation Meal as % B.Wt	Satiation Meal (2) as a percentage of Sat Meal (1)
]	688	31.2	4.5	6	9.5	1.4	30.6
2	637	30.1	4.7	6	7.5	1.2	25.0
4	832	28.6	3.4	12	15.3	1.8	54.6
5	736	31.3	4.2	12	16.1	2.2	51.9
1	736	29.5	4.0	18	21.9	3.0	75.5
4	908	34.3	3.8	18	16.5	1.8	48.5
2	654	28.3	3.3	24	18.7	2.9	66.8
5	774	28.2	3.6	24	20.0	2.6	71.4
1	936	32.6	3.3	30	24.8	2.6	78.1
3	766	28.3	3.7	30	25.1	3.3	89.3
2	832	27.5	3.3	36	28.2	3.4	100.0
5	995	29.4	3.0	36	35.1	3.5	120.7

* = 'Gastric Emptying Time' (see text).

TABLE 3: Satiation and Appetite return at 25°C.

Turtle Number	Body Weight (gms)	Satiation Meal (1) 36 (hrs)* (gms)	Satiation Meal as % B.W.	Deprivation Time (hrs)	Satiation Meal (2) (gms)	Satiation Meal as % B.Wt	 Satiation Meal (2) as a percentage of Sat Meal (1)
1	1276	54.5	4.3	6	26.8	2.1	49.2
2	1134	50.0	4.5	6	16.2	1.4	32.4
3	1012	35.6	3.5	12	11.0	1.1	30.9
4	1444	46.6	3.2	12	17.3	1.2	37.3
5	1285	45.8	3.6	18	30.6	2.4	66.31
6	2250	67.0	3.0	18	44.0	2.0	65.7
1	1409	59.5	4.2	24	40.9	3.3	78.3
3	1097	46.4	4.2	24	40.5	3.7	87.3
2	1225	50.1	4.1	30	49.3	4.0	98.4
5	1359	50.1	3.7	30	48.0	3.5	95.8
4	1579	53.5	3.4	36	54.2	3.4	101.3
6	2327	70.0	3.0	36	74.3	3.2	106.1

* = 'Gastric Emptying Time' (see text).

TABLE 4: Satiation and Appetite return at 30°C.

10.00 hrs). At 20°C the rate at which pellets were taken was so slow in some cases that an accurate determination of feeding cessation was impossible.

The data (Tables 2, 3 and 4) was expressed in the form of the Von Bertalanffy equation for the return of appetite. The calculated equations for each temperature are as follows:

 30° C; Wt = 7.18(1-exp(-0.0177(t+5.42))) 25°C; Wt = 4.34(1-exp(-0.0326(t+5.65)))

 $20^{\circ}C; Wt = 1.86(1 - exp(-0.0894(t - 3.79)))$

The calculated values for the total squares of the absolute and relative errors of the fitted function showed that the reliability of the estimates of W, K and t_0 was greatest at both 20°C and 25°C where more of the curve was expressed by the sample points (Fig. 3). The curves in Fig. 3 were extended beyond the area of the data to illustrate which part of the curve at each

temperature the points expressed. At 30°C the observed values lay in the exponential phase of the curve and consequently the estimate of W is questionable. The greatest theoretical body weight meal size (W) was at 30°C with a value of 7.2 per cent body weight. At 25°C it was 4.3 per cent and the lowest value was at 20°C where it was 1.9 per cent. These values all exceeded the observed values for the first satiation meals, which were as follows: 30°C mean satiation amount = 3.73%; 25°C, 3.73%; 20°C, 0.92%. The greatest differences between first satiation meal size and theoretical maximum were at 20°C and 30°C where the maxima were approximately twice the size of the first satiation meal. The rate of achieving the theoretical maximum was greatest at 20°C, (K = 0.0894). At 25°C and 30°C the values for K were 0.0326 and 0.0177 respectively.



Fig. 3 % body weight eaten (g) after the first satiation meal.

- □; % Satiation weight at 30°C.
- ▲; % Satiation weight at 25°C.
- Δ ; % Satiation weight at 20°C.

DISCUSSION

The results of this study demonstrate that temperature has, over the range between 20°C and 30°C, a considerable effect on the rate of passage of food through the digestive system of young loggerhead turtles. The differences in satiation amount and TGCT were much greater between 20°C and 25°C than between 25°C and 30°C. The results at the two higher temperatures were identical for satiation (3.73 per cent of the body weight), and there was only a 6 hour difference between clearance times. In contrast, between 20°C and 25°C there was a 33 hour difference in clearance time and at 20°C, the satiation ration was only 0.92 per cent of the body weight. Rather surprisingly, appetite returned to satiation level faster at 20°C than at 25°C or 30°C, but this presumably reflects the much lower satiation ration.

These data support available field and growth data. Observations indicate that, in coastal feeding areas, marine turtles largely return to feed or become active when the temperature rises in late spring to around 20°C (Carr *et al.*, 1980). Carr *et al.*, (1980) found that adult *C. caretta* hibernated in the mud of submarine canyons off Cape Canaveral in February when water temperatures averaged 11°C, but by mid March when the water temperature had risen to 19°C the turtles were resting on the bottom. Carr *et al.* (1980) also noted an influx at this time of turtles from other areas.

Hughes (1974) studied growth in hatchling loggerheads. At 14°C and 15°C turtles ate little and lost weight, while those at 17°C and 18°C ate more but grew much more slowly than turtles kept at 24°C. It appears that active feeding starts at approximately 20°C though the preferred temperature of *Caretta* is over 25°C. In this respect loggerhead turtles appear to closely resemble *Chelonia mydas*. Bjorndal (1980) found that water temperature affected digestive efficiency in the green turtle, with efficiencies becoming more variable during the winter months when the temperature approached 20°C. The studies of gut dynamics described here were compromised to a certain extent by the unavoidably small number of turtles available, which meant that their weights had changed somewhat between experiments at different temperatures. Fänge and Grove (1979) considered the problem of using different sized animals in digestion studies. If (as in the present study) meals of constant percent body weight are fed to experimental animals, then the absolute rate of digestion of food will be faster in a larger animal (because the surface area of food bolus exposed to enzyme action is greater), but digestion will be completed sooner in a smaller animal (because the surface area-to-volume ratio of the smaller meal is greater).

It took 122±7 hours for food to pass completely through the gut of *C. caretta* but for *C. mydas* of similar size it took 176±11 hours (Hajichristophorou and Grove, 1983). These shorter evacuation times may be indicative of the more carnivorous habit of *Caretta*. Young loggerheads appeared to be far more voracious feeders than young green turtles. The satiation ration of *Caretta* at 25°C was twice the size of that of *Chelonia* and appetite return was 25 per cent quicker in loggerheads.

During passive migration the young loggerhead turtle presumably relies on an opportunistic feeding strategy. The adaptation of the oesophagus as a temporary food store allows the animal to take advantage of occasional overabundances of prey. The oesophagus possesses soft conical papillae on its luminal surface. These papillae project towards the stomach, but it is not known whether they act solely to prevent food returning to the mouth or whether they also have a glandular function. Oesophageal food storage has not been reported for other sea turtles, and is certainly not characteristic of *Chelonia mydas* in which food always reaches the stomach within 5 minutes (Davenport and Oxford, 1984).

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HABITAT DESTRUCTION AND ITS EFFECT ON A POPULATION OF SMOOTH NEWTS, TRITURUS VULGARIS: AN UNFORTUNATE FIELD EXPERIMENT

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ABSTRACT

Partial clearance of the terrestrial vegetation surrounding a pond in southern England resulted in a significant decrease in the size of the smooth newt (*Triturus vulgaris*) population breeding there, relative to a nearby, intact pond. This finding supports the suggestion of Beebee (1981) that the terrestrial habitat surrounding a pond is an important determinant of that pond's suitability for amphibians.

INTRODUCTION

In a survey of the status of British amphibians in which England, Scotland and Wales were divided into 12 'survey regions', populations of the smooth newt (*Triturus vulgaris* L.) were reported to have suffered declines in three regions. Over 70 per cent of the respondents in this survey blamed these declines on loss of suitable habitat due to human activity (Cooke and Scorgie, 1983).

Loss of ponds is an obvious cause for concern amongst those involved in the conservation of amphibian populations. However, loss of the terrestrial habitat surrounding extant ponds can also have detrimental effects on the amphibians which visit the ponds in order to breed and feed. The importance of such habitat was stressed by Beebee (1981), who surveyed a large number of ponds in southern England and found that those with marginal scrub habitat were more likely to support amphibian populations than were those without (all other requirements being equal).

In 1986, the author was afforded the opportunity to study the effect of terrestrial habitat destruction on smooth newts at a local level. In 1985, as part of an investigation into the reproductive biology of this species, breeding population size was assessed at two, closely-situated ponds. In the autumn of that year, about one half of the marginal terrestrial vegetation was removed from one pond; the other pond was left intact. In 1986, the two ponds were surveyed once more, and the influence of habitat destruction on smooth newt breeding population size was determined.

METHODS

The two study sites are ponds situated on the Conniburrow housing estate in Milton Keynes, Buckinghamshire, southern England. They are approximately 0.25 miles from one another. In 1985, both