Turtles Tagged in Developmental Habitat in Bermuda Nest in Mexico and Costa Rica

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Very few green turtles (*Chelonia mydas*) in the Atlantic Ocean have been followed from an immature-dominated developmental habitat to a nesting beach. We know of one example, a green turtle tagged in developmental habitat on the east coast of Florida that later nested at Tortuguero Beach, Costa Rica, in 2002 (Troëng *et al.* 2003). We can now report on three similar cases involving turtles tagged in developmental habitat that were encountered later on the nesting beach. These records provide information bearing on the ecological geography of the Bermuda green turtle foraging aggregation. They also provide some rare empirical data that may help ground truth theoretical estimates of age at first reproduction, a critical demographic parameter (Bjorndal *et al.* 2013).

Three immature green turtles tagged by the Bermuda Turtle Project in benthic developmental habitat on the Bermuda Platform were later observed as adults on nesting beaches, one in Mexico and two in Costa Rica. These are the first three cases in which green turtles (all immature), tagged as part of the long-term (since 1968) tagging project in Bermuda (Meylan *et al.* 2011), have been documented on nesting beaches.

Case 1, BP3969. On 18 November 1992, an immature green turtle was captured on a seagrass flat, Cowground Flat, on the Bermuda Platform (32.31712°N, 64.87015°W). It was tagged with BP3969 (plastic Dalton Rototag) and MM438 (large Stockbrands titanium tag). At the time of tagging, the turtle was 59.8 cm in minimum straight carapace length (SCL_{min}; measurement notation follows Bolten 1999) and weighed 32.3 kg. This turtle was one of seven green turtles captured together with an entrapment net that encompassed approximately 3 ha. The turtle has not been seen again in Bermuda.

Nearly 13.5 years later, between 21 June and 2 September 2006, BP3969 was observed nesting eight times in the Yucatan Peninsula, Mexico, by researchers of the Comité de Protección de Tortugas Marinas en Quintana Roo. When first observed, it was carrying a single titanium tag, MM438. Seven nests were observed on X'cacel Beach (20.33298°N, 87.34880°W) and one at Xel-Há Beach, 0.5 km south of X'cacel. One of three observed non-nesting emergences by this turtle was approximately 1 km to the north, at Chemuyil Beach. X'cacel is a state sanctuary for sea turtles. BP3969 was recorded nesting in subsequent seasons on X'cacel and Xel-Há, five times in 2008 and four times in 2010. The turtle was not observed during the nesting seasons of 2011 or 2012.

The average curved carapace length (CCL_{n-t}) of BP3969 recorded during the 8 nesting emergences in 2006 was 98.5 cm (SD=1.29, range=95.5-99.1). To compare the measurements taken at the nesting beach with those taken in developmental habitat, two conversions of the carapace length were necessary. Using the relationship $SCL_{n-t} = 0.9407(CCL_{n-t}) - 0.0426$ (A. Foley, unpublished data from Florida Sea Turtle Stranding and Salvage Network database; $r^2 = 0.994$, N =2,897) and $SCL_{min} = 0.9883(SCL_{n-t}) - 0.0460$ (Meylan *et al.* 2011; $r^2 = 0.9885$, N=164), we estimate the SCL_{min} at the time of nesting in 2006 was 91.5 cm. The shortest distance by water between the original capture site in Bermuda and X'cacel Beach in Mexico is approximately 2,667 km (least-cost path analysis performed within ArcGIS 10.1, Esri, Redlands, CA)(Fig. 1).

There is an extensive record for BP3969 once she appeared on the nesting beach in Mexico. The turtle was observed 25 times (17 nests, 8 non-nesting emergences) in 2006, 2008, and 2010. She nested (and her nests were evaluated) eight times in 2006, which was likely her first year of reproduction. The average clutch size in 2006 was 99 (SD ±20.3, range 71-133, N=8) with an average hatching success of 95.1% (SD ±3.81, range 87.2-99.0, N=8).

Case 2, BP3754. On 16 February 1993, an immature green turtle was captured at the Crescent West seagrass bed on the Bermuda Platform (32.39173°N, 64.81448°W). It was tagged with BP3754 (plastic Dalton Rototag) and MM457 (Stockbrands titanium). At the time of tagging it was 69.9 cm in SCL_{min} and weighed 54.5 kg. The turtle was one of eight green turtles captured together in the entrapment net; it has not been seen again in Bermuda.

On 30 July 2010, 17.4 years later, beach monitors observed BP3754 returning to the sea after she had nested at Mile 4 in Tortuguero National Park, Costa Rica (10.5240°N, 83.4927°W). The turtle was seen only once. It was carrying a single titanium tag, MM457. Carapace length at the time of nesting was 98.3 cm CCL_{min}; the calculated SCL_{min} is 91.8 cm using a single linear regression equation, $SCL_{min} = 0.9240(CCL_{min}) + 1.0205$ (Meylan *et al.* 2011; $r^2 = 0.9975$, $p < 0.001$, N=164). The shortest distance by water between the original capture site in Bermuda and the nesting beach at Tortuguero, Costa Rica, is 3,149 km (Fig. 1).

Case 3, MB513. On 12 August 1999, an immature green turtle was captured on a seagrass bed at Outside Daniel's Head on the Bermuda Platform (32.32373°N, 64.91963°W). It was tagged with MB513 (plastic Dalton Rototag) and MM709 (Stockbrands titanium). At the time of tagging, it was 54.6 cm in SCL_{min} and weighed 24.2 kg. The turtle was one of 10 green turtles captured together in the entrapment net. This turtle has not been seen again in Bermuda.

On 17 July 2013, 13.9 years later, beach monitors observed MB513 returning to sea after she had nested at Mile 2⅛ in Tortuguero National Park, Costa Rica, (10.55023°N, 83.50566°W). It was carrying a single titanium tag, MM709. The turtle was seen

Figure 1. The shortest distance by water (least-cost paths, ArcGIS 10.1, Esri, Redlands, CA) representing the minimum distance traveled for three green turtles (*Chelonia mydas*) tagged in developmental habitat in Bermuda and observed on the nesting beach in Mexico (BP3969) and Costa Rica (a, BP3754 and b, MB513). This analysis yields minimum distance traveled avoiding land but the turtles likely traveled to other foraging grounds before proceeding to the nesting beach. The overall characteristics of the least-cost path was the same for both turtles travelling to Tortuguero, Costa Rica (a and b), although the distances were slightly different due to differing capture and recapture locations.

only once. Size at the time of nesting was 93.7 cm CCL_{min}; the calculated SCL_{min} is 87.6 cm, calculated as for BP3754. The shortest distance been the capture site in developmental habitat in Bermuda and the nesting site is 3,131 km (Fig. 1).

It is unlikely that any of these turtles traveled directly from Bermuda to its nesting beach. Results of the inwater capture program in Bermuda indicate that green turtles leave Bermuda waters at an average size of 70.6 cm SCL_{min}, while they are still immature (Meylan *et al.* 2011). Tag returns show that they move to foraging habitats (adult foraging range) away from Bermuda to complete maturation, and the extensive seagrass beds off the coast of Nicaragua are the primary destination (Meylan *et al.* 2011: Fig. 1). Evidence from tag returns suggests that Nicaragua also provides the principal foraging grounds of the green turtles that nest at Tortuguero, Costa Rica (Carr *et al.* 1978; Troëng *et al.* 2005). To date, none of 155 tag returns of Bermuda-tagged turtles have been from foraging grounds in Mexican waters.

Turtle BP3969 observed on the beach in Mexico might have been seen during her first nesting season. There is a high level of surveillance of this nesting beach (and thus a high probability of detection). Nightly monitoring has been carried out at X'cacel since 1987, and since 2000 tagging efficiency (percentage of nests assignable to individual females) has been estimated at >90% (TEWG 2009; A. Arenas and J. Zurita, unpublished data). Also, if one assumes that this turtle grew at the average rate recorded in Bermuda and remained in Bermuda until the typical size at departure (Meylan *et al.* 2011), an earlier arrival at the nesting beach seems unlikely. BP3969 increased in SCL_{min} from 59.8 to 91.5 cm over 13.5 yr, for an average rate of 2.35 cm/year, slightly less than the average rate of 2.51 cm/yr (±1.29) observed in Bermuda (Meylan *et al.* 2011). The average growth rate in Bermuda was derived from 71 one-year growth intervals for turtles with a representative size distribution (avg.=45.0 ±11.7 cm SCL_{min}) and whose average carapace length during the measurement interval ranged from 26.2 to 65.0 cm $SCL_{min.}$ If BP3969 were nesting for the second time in 2006, it would have had to reach its initial reproductive size at least two years earlier (one reproductive cycle before), which would have required an even faster growth rate (2.76 cm/yr). We consider this to be improbable because the growth rate of Atlantic green turtles is known to decrease as individuals approach maturity (Bjorndal *et al.* 2000).

Similarly, it is not known whether this was the first nesting season for BP3754 or MB513. Detection probability is less at Tortuguero, with only 5 of 22 miles of beach monitored at night, and thus the possibility of missing an individual turtle is high. BP3754 was larger than BP3969 when captured in Bermuda, and more time had elapsed between observation in developmental habitat in Bermuda and on the nesting beach. BP3754 grew 21.9 cm in 17.4 yrs, or an average of 1.26 cm per year. For MB513, the change in size over 13.9 yr represents an average growth rate of 2.37 cm/yr. The slower growth rate of BP3754 may be a composite of a faster rate in developmental habitat and a slower rate once maturity was reached.

Green turtles mature over a range of sizes and ages (Bjorndal *et al.* 2013); thus, the size of these turtles when they were observed on the nesting beach is not informative of their reproductive histories. Putative first-nesters (no tags or tag scars when first seen on the beach) observed at X'cacel range widely in size from 82.8-109.6 cm SCL_{min}, (avg.=97.1 ±4.9 cm SCL_{min}, n=680, data from 2002-

Primary Tag Number	Size (cm) at capture in Bermuda (SCL_{min})	Estimated residency in Bermuda before capture (yr)	Time between capture in Bermuda and first observation on nesting beach (yr)	Estimated age at first observation on the nesting beach allowing 3 yr in epipelagic stage (yr)	Estimated age at first observation on the nesting beach allowing 5 yr in epipelagic stage (yr)	Growth rate for period between observations in developmental habitat and nesting beach (cm/yr)
BP3969	59.8	13.9	13.5	30.4	32.4	2.35
BP3754	69.9	17.9	17.4	38.3	40.3	1.26
MB513	54.6	11.8	13.9	28.7	30.7	2.37

Table 1. Capture and tag return data for three green turtles (*Chelonia mydas*) first captured as immatures in Bermuda and later observed on nesting beaches. Residency in Bermuda before capture was estimated using size at capture minus average size at arrival in Bermuda divided by average growth rate for green turtles in Bermuda (Meylan *et al.* 2011). Estimated age at first observation on the nesting beach is the sum of estimated time spent in the epipelagic stage (Reich *et al.* 2007), estimated time (residency) in Bermuda before capture, and known time to observation on a nesting beach.

2005, measurements converted from CCL_{n-t} as described above, A. Arenas and J. Zurita, unpub. data). The 2.5-percentile value of the size distribution of neophytes, which is sometimes used to define minimum adult size (TEWG 2009), is 87.8 cm SCL_{min} at X'cacel. The size range of putative first-nesters observed at Tortuguero is also wide, 83.6-114.3 (avg.=98.1 ±4.3, n=2926, data from 2009-2012, measurements converted from CCL_{min} as described above, E. Harrison, unpublished data). The 2.5-percentile value of this size distribution is 89.4 cm SCL_{min}, which could be considered the minimum size of adult females at Tortuguero.

These three records provide information about the portion of the life cycle during which individuals shift from developmental habitat to adult foraging range and then on to reproductive sites. Growth data for these stages are rare. Although it is not known whether these turtles were nesting for the first time when they were observed, an estimate of the maximum age at sexual maturity for these turtles can be calculated by adding the estimated time spent in the epipelagic environment (i.e., lost years), the estimated time spent in developmental habitat (presumably all in Bermuda) before capture (and tagging), and the known time that elapsed between capture in Bermuda and observation on the nesting beach (Table 1). Green turtles in the Atlantic are thought to spend on average 3–5 years in the epipelagic or oceanic stage (Reich *et al.* 2007; Goshe *et al.* 2010). Turtles recruit to developmental habitat in Bermuda at approximately 25 cm (Meylan *et al.* 2011). Using the average growth rate observed in Bermuda (see above), we estimated the length of residency in Bermuda before capture. The length of the final time segment, the time between capture in developmental habitat and observation on the nesting beach, is known in all three cases. Given these assumptions about time spent in the lost years, residency time in Bermuda, and growth rate in Bermuda, the estimated age of these three turtles when observed on the nesting beach ranged from 28.7 to 40.3 years (Table 1). These results are similar to the range of estimated time (33-38 yrs) to reach the mean size at maturation suggested by Goshe *et al.* (2010) based on skeletochronology of green turtles of the Florida, Costa Rica and Mexico populations.

These three tag returns provide the first direct evidence of linkages between developmental habitats in Bermuda and nesting beaches in Mexico and Costa Rica. All other foreign tag recoveries of turtles tagged in Bermuda have involved animals captured at sea or stranded on coastlines. The minimum distances represented by these movements (likely a combination of a developmental migration and a reproductive migration for each individual) were large (2,667, 3,149, and 3,131 km). All three of these turtles could be identified because they had retained a large Stockbrands titanium tag; all three had lost their plastic Dalton Rototag. None of these turtles carried PIT tags. We have now marked more than 500 green turtles in Bermuda with these large titanium tags, and all turtles tagged since the early 2000s have also been marked with PIT tags. We anticipate that more tagged turtles will be observed on nesting beaches in the future, allowing further direct association between the Bermuda aggregation and specific nesting beaches, as well as the accumulation of more data relevant to age to sexual maturity.

Traditional flipper tagging remains a valuable tool for research on the biology of marine turtles, especially when long-lasting (e.g., titanium, inconel) external tags are used and complemented by the use of PIT tags. The long-term movement and growth data reported here could not have been obtained using other currently available methods.

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