Sand and Nest Temperatures and Sex Ratio Estimation for Loggerhead Turtle (Caretta caretta) Hatchlings on Göksu Delta

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Abstract: Göksu Delta is one of the important nesting beaches for Caretta caretta (loggerhead turtle) in the Eastern Mediterranean coast of Turkey. In this study, temperatures of nests (n=10) and sand (n=4) were recorded by data loggers and results were examined to determine sex ratio of loggerhead hatchlings. Mean nest temperatures of whole period was 31.1°C that is higher than pivotal temperature of 29°C for Mediterranean loggerhead clutches, mean incubation duration was 51.7 days. The sex ratio of hatchlings of loggerhead turtle on Göksu Delta was estimated at 89.7% female based on temperature of whole period of incubation in nesting season of 2013. Results of estimation show that hatchlings sex ratio is highly female biased at study site.

Keywords: Nest temperature, Caretta caretta, Temperature dependent sex determination, Sex ratio, Göksu Delta.

Introduction

In many cheloniens sex is determined by the temperature of nest during incubation. Low incubation temperature during the middle third of embryonic development produces males, and high temperatures produce females (Yntema, 1976; Yntema and Mrosovsky, 1979; Yntema and Mrosovsky, 1982)

Normal embryonic development occurs between 25°C to 33°C, and the pivotal temperature which gives approximately equal numbers of male and female offspring is around 29-30°C (Yntema and Mrosovsky, 1982; Kaska et al., 1998, Hawkes et al., 2009). The pivotal temperature was found to be 28.9°C by the examination of green turtle (Chelonia mydas) and loggerhead turtle (Caretta caretta) nests on the beaches of Northern Cyprus and Turkey (Kaska et al., 1998). Furthermore, pivotal incubation duration calculated as 59.9 days (Kaska et al., 1998), close to the values for Brazil and the USA (Marcovaldi et al., 1997; Hanson et al., 1998) of 59.3 and 61.7, respectively. The sex ratio for loggerhead turtle was highly biased to female in the Mediterranean (Kaska et al., 1998; Godley et al, 2001; Mrosovsky et al., 2002; Öz et al., 2004; Kaska et al., 2006; Zbinden et al., 2007; Uçar et al., 2012).

Sand and nest temperatures could be reliable for estimating the mean incubation temperature and pivotal temperature are known (Standora and Spotila, 1985; Kaska et al., 1998).
Even if histological examination is the most reliable method to determine the sex of hatchlings (Mrosovsky and Benabib, 1990; Ceriani and Wyneken, 2008), temperature profiles would be useful to have a quick and reliable method of examining the sex of the hatchlings.

To determine nest and sand temperature in a nesting site is the first step of understanding incubation temperature effects on sea turtle population (Booth and Freeman, 2006). In this study, nest and sand temperature profiles were reported from the Göksu Delta where mostly loggerhead turtles nest, also the temperature profiles were used to predict sex ratio of hatchlings in 2013 nesting season.

**Materials and Methods**

Göksu Delta was known a nesting site densely for loggerhead turtle on eastern Mediterranean coastline of Turkey, is located in Silifke-Mersin (36º17' N, 33º39'E) and was 37.8 km in length (Canbolat, 2004). The entire nesting beach was divided in subsections, that started from 760 and ended in 767 (Figure 1). The subsection 767 was not used for nesting (Durmuş et al., 2011). The subsections of 760, 762, 763 and 764 were highly used for nesting (Figure 1). Temperatures of the 10 nests, that selected randomly, were recorded by data-loggers (Gemini Data Loggers-Tinytalk H -30°C/+50°C Part No: TK-0040) during the 2013 nesting season. The loggers were located to the centre of the nest during oviposition. Readings of the loggers were taken at one-hour intervals from the centre of the nests. The data loggers were retrieved from nests after all the hatchlings had emerged.

Sand temperatures of the beaches were investigated whole season by 4 data loggers located at 40 cm depth, from June to September by 2-hours intervals. The mean value of the 12 measurements taken in one day was treated as daily sand temperature. The data loggers for sand temperature were located in highly used subsections 760, 762, 763 and 764, and the loggers were located in dense nesting distance, 17 m for 760 and 762, 20 m for 763 and 764 from sea level (Figure 1).

Sex ratio was determined by estimation from the nest temperature at whole incubation period with basic statistics as observed by Kaska et al. (1998). Regression equations were calculated as Sex ratio (%) female = 16.2 * Whole Period Temperature - 414 from Kaska et al. (1998). All data analyzed by Minitab v. 14.0. The ratio was evaluated as 100% female if the result was higher than 100%.

**Figure 1.** Subsections of the Göksu Delta beach and dense nesting subsections.
Results

The total number of loggerhead nests determined in 2013 nesting season was 199 and 5.26 nests per km. Temporal distribution of nests was given in Figure 2. The majority of nesting activities occurred in June with 102 nests and July with 64 nests, thus all 10 nests sampled here were recorded during June and July. The average clutch size determined as 68.3 eggs per clutch by uncovering for control of 121 nests. Thus, 38% of the eggs were predated and 42.4% of them were hatched successfully. Mean incubation duration of loggerhead nests was calculated as 51.7 days. Mean nest depth was 46.9 cm from the surface to the bottom of the nest.

![Figure 2. Temporal distribution of loggerhead nest numbers in Göksu Delta.](image)

Temperature data of sampled nests is summarized in Table 1. The mean nest temperature ranged from 30.0°C to 32.4°C and the average nest temperature was 31.1°C. As for mean temperatures at monthly period, they were 29.7°C, 30.7°C and 32.1°C from June to August, respectively. The mean nest temperatures were all higher than pivotal temperature of 28.9°C.

![Table 1. Temperature values of sampled nests and sex ratio estimations (% female).](table)

The sex ratio of hatchlings was evaluated by regression equation calculated by Kaska et al. (1998). The sex ratio estimations for hatchlings were summarized in Table 1. According to the whole period temperatures the

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**Table 1. Temperature values of sampled nests and sex ratio estimations (% female).**

<table>
<thead>
<tr>
<th>Nest No</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>Whole period of incubation</th>
<th>Sex ratio (% female)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>mean ± SD</strong></td>
<td><strong>mean ± SD</strong></td>
<td><strong>mean ± SD</strong></td>
<td><strong>mean ± SD</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>29.87±0.29</td>
<td>31.59±1.02</td>
<td>33.38±0.17</td>
<td>31.69±1.27</td>
<td>99.38</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>30.11±0.83</td>
<td>32.11±0.39</td>
<td>30.69±1.16</td>
<td>83.11</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>29.29±0.77</td>
<td>31.09±0.31</td>
<td>29.97±1.09</td>
<td>71.58</td>
</tr>
<tr>
<td>4</td>
<td>29.53±1.30</td>
<td>30.91±0.72</td>
<td>32.03±0.31</td>
<td>30.90±1.15</td>
<td>86.66</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>30.30±0.38</td>
<td>31.01±0.26</td>
<td>30.72±0.47</td>
<td>83.74</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>30.50±0.44</td>
<td>31.57±0.31</td>
<td>31.15±0.64</td>
<td>90.61</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>31.93±1.33</td>
<td>32.91±0.48</td>
<td>32.41±1.12</td>
<td>100.00</td>
</tr>
<tr>
<td>8</td>
<td>-</td>
<td>30.48±0.84</td>
<td>32.15±0.30</td>
<td>30.81±1.17</td>
<td>85.18</td>
</tr>
<tr>
<td>9</td>
<td>29.70±0.80</td>
<td>31.25±0.87</td>
<td>32.70±0.24</td>
<td>31.30±1.21</td>
<td>93.02</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>30.91±0.72</td>
<td>31.88±0.34</td>
<td>31.30±0.85</td>
<td>93.00</td>
</tr>
<tr>
<td>Mean</td>
<td>29.70±0.80</td>
<td>30.73±0.79</td>
<td>32.08±0.31</td>
<td>31.09±1.01</td>
<td>89.73</td>
</tr>
</tbody>
</table>

**Sex ratio (% female)** 67.07  83.76  100.00  89.73
sex ratios of female hatchlings were varied from 71.6% to 100.0% with 89.7% female on average. On the other hand, according to the monthly temperatures the sex ratios of female hatchlings were amongst 67.1% to 100.0% with increasing trend from June to August.

Positioning data loggers in both the sand and the nests were used to compare the temperatures at the same depth. Sand temperatures were increased from June to August and monthly mean temperatures were calculated as 26.8°C, 29.4°C and 31.3°C, respectively (Table 2). The monthly mean sand temperatures were lower than the nest temperatures as 2.9 °C in June, 1.3°C in July, 0.7°C in August and 1.6°C for the whole season.

Table 2. Monthly mean temperature of sand at 40 cm depth (°C).

<table>
<thead>
<tr>
<th>Loggers</th>
<th>June (°C) mean ± SD</th>
<th>July (°C) mean ± SD</th>
<th>August (°C) mean ± SD</th>
<th>September (°C) mean ± SD</th>
<th>Mean (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 1</td>
<td>27.19±1.13</td>
<td>29.70±0.70</td>
<td>31.42±0.21</td>
<td>30.60±0.72</td>
<td>29.69</td>
</tr>
<tr>
<td>S 2</td>
<td>26.18±0.72</td>
<td>28.99±0.90</td>
<td>31.24±0.57</td>
<td>30.51±0.76</td>
<td>29.17</td>
</tr>
<tr>
<td>S 3</td>
<td>26.69±0.93</td>
<td>29.34±0.81</td>
<td>31.33±0.39</td>
<td>30.55±0.75</td>
<td>29.43</td>
</tr>
<tr>
<td>S 4</td>
<td>26.94±1.03</td>
<td>29.52±0.74</td>
<td>31.38±0.30</td>
<td>30.58±0.73</td>
<td>29.56</td>
</tr>
<tr>
<td>Mean (monthly)</td>
<td>26.75</td>
<td>29.39</td>
<td>31.34</td>
<td>30.56</td>
<td>29.46</td>
</tr>
</tbody>
</table>

Discussion

Even histological examination of the gonad is the most reliable method to determine the sex of sea turtle hatchlings that lack sexual dimorphic characteristics for now, though there are encouraging efforts on new techniques (Mrosovsky and Benabib, 1990; Mrosovsky and Godfrey, 1995; Ceriani and Wyneken, 2008; Lopez-Correa et al., 2010) as estimation by nest temperatures.

Our result of sand and temperature of loggerhead nests difference for the whole period of nesting is 1.6°C on average. Thus, results have been reported, as nest temperature is higher than the surrounding sand temperature and increases after the first half of incubation period, to 2-4°C above sand temperature at hatching for green turtle (Booth and Freeman, 2006). Hence, there may be temperature difference between nesting sites, and sand and nest temperature difference could be variable because of nest site selection. The sand covering a nest acts as a barrier in different ways through diffusing heat, thus different sands produce varied nest environment (Milton et al., 1997).

Nest temperatures are all ranged in normal embryonic development that occurs between 25°C to 33°C (Billett et al., 1992). However, in this study, there is just one exception in August temperature of nest 1 with 33.4°C and none for mean temperatures of whole incubation period. This thermal increase is thought to be related with metabolic heating, because metabolic heat significantly increases on last third of incubation duration (Godfrey et al., 1997; Sandoval et al., 2011).

The relationship of nest temperature with incubation period is clear with negative correlation. 1°C lowering of nest temperature will be reflected in a 4-5 days increase in incubation time (Mrosovsky and Yntema, 1980). The mean nest temperature of all nests is 31.1°C which is 2°C higher than pivotal temperature of 29°C determined for Mediterranean (Kaska et al., 1998). The mean incubation duration of nests in this study is 51.7 days which is shorter than pivotal incubation duration of 59.9 days for Mediterranean (Kaska et al., 1998). Thus, 2°C increase in mean nest temperature results 8-10 days decrease in mean incubation durations. Our
result shows that 1°C increase in main incubation temperature translated to 4.1 day decrease in mean incubation period.

The reported sex ratio of sea turtles for Turkey is generally focused on loggerhead turtles and there is limited information for green turtle, besides sex ratio is biased to female (Kaska et al., 1998; Öz et al., 2004; Kaska et al., 2006, Uçar et al., 2012, Kılıç and Candan, 2014). Reported sex ratio for loggerhead turtles is generally female dominated not only in the Mediterranean but also in Brazil and USA (Marcovaldi et al., 1997; Hanson et al., 1998). Results of this study directly match up with the literature due to indirect estimation of nest temperature. In this study, sex ratio estimation of loggerhead turtle hatchlings on Göksu Delta is 89.7% female due to the whole period temperature.

Mean incubation temperature and mean middle third temperature are both adequate for estimating sex ratios of loggerhead turtles, but sex ratio varies at the different parts of nest because of temperature gradients in the surrounding sand (Kaska et al., 1998). Determining the sex ratio of sea turtle hatchlings in a wide range is rather difficult to manage. Hence temperature records of the nests and sand could be useful to determine the sex ratio in a wide range.

Acknowledgements

This research was undertaken as a part of “Habitat and Species Conservation and Monitoring Project of Göksu Delta Specially Protected Area” (Project No. 156.01) and the project was supported by General Management of Natural Properties of Ministry of Environment and Urbanization.

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