Green Sea Turtle (*Chelonia mydas*): A historical review with relevance to population size in Sarawak

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Abstract—Green sea turtles (*Chelonia mydas*) are using selected Sarawak sandy beaches for nesting. Its small-scale conservation efforts have started since the 1950s. However, the success of the effort is still debatable. Moreover, public participation in the conservation effort is still at an infancy stage. This study involved analysing nesting data of green turtles of Sarawak Turtle Islands (STIs) in terms of numbers of turtle landing, eggs collected, eggs incubated, and eggs hatched for Sarawak's green turtle population from 1949 to 2016 with addition of estimation of the egg-laying females and their remigration interval. There was a sharp decline in terms of number of turtle landings from 1949 to the 1970s. The exact cause of this pattern could only be confirmed from old articles of historical value due to limited information on the events happening during those 30 years period. From 1980 to 2016, the annual nesting trend of turtles on STIs shows irregular fluctuation pattern and remigration interval of every 3 to 4 years with internesting frequency of 3. Turtle eggs were harvested annually, with a 36-year average of 223,558 eggs per year. Detailed analysis for data 1980 to 2016 shows that the lowest percentage of eggs incubated was in 1981 (20.4 %) and starting from the year 1991, egg incubation at STIs reached between 90 to 100 percent. There is an upward trend of egg hatching rate for the past 36 years, especially from the 1990s to 2000s, with the latest seven years average of 60%. The results imply that conservation of green turtle in Sarawak have been successful at different levels. However, there is still a need for relevant state agencies to modify and step-up efforts related to conservation of green turtles in Sarawak especially in terms of male:female ratio of hatchlings from STI's hatcheries.

Keywords— green turtle, nesting, eggs, population size, Sarawak.

I. INTRODUCTION

Green turtles are listed as Endangered by the IUCN Red List and are protected from human exploitation in most countries under CITES [1]. Green turtles are widely distributed with the largest Southeast Asian nesting populations being from Sarawak Turtle Islands and Turtle Islands Heritage Protected Area (TIHPA) [2]. In Sarawak, all species of marine turtle (Cheloniidae and Dermochelyidae) are listed as Totally Protected Animal and are fully protected legislatively under the Wild Life Protection Ordinance 1998. Those found in possession of a sea turtle part or derivatives may face imprisonment of two years and a fine of RM25.000 [3].

Comprehensive knowledge on the nesting behaviour and the ecology of marine turtles is important to ensure that the current conservation status and efforts are working. Information on the age, size, growth rate and relative reproductive output of individuals is fundamental in understanding the demography of a population [4]. Assessment of population size should be as accurate as possible, including whether a population is stable, increasing, or declining; they are the foundation on which all management decisions should be based on [5].

Monitoring beach nesting is the easiest and the least expensive means to assess green turtle population and abundance [6]. However, surveys carried out less than 10 years are inadequate because green turtles are long-lived, and the females have been observed to skip several nesting seasons due to nutritional constraints [7].

With respect to behaviour, nesting season of mature females could differ in timing and duration, even among rookeries in the same region. [8], [9] mentioned that this is because some locales could support both nesting and feeding aggregates and non-migratory populations may exist at these sites. Furthermore, global warming phenomenon has negative impact to the sea turtles as the increase in temperature could lower hatching success, leading to a gradual shift towards a feminisation of sea turtle populations [10], affect inter-nesting interval and nesting patterns of sea turtles [11]. Although the trend of female nesters was estimated to remain the same as the past

20 years, there are differences in the trend of turtle nesting as climate change could have easily disturbed the internesting and remigration interval of the nesters. Determining the number of times, a turtle nests during a reproductive season is important, particularly if such data area is averaged and used in calculations to estimate the number of females in the population [12].

Turtle Board of Sarawak Museum Department has recorded the number of turtle landings and the number of eggs collected yearly, since 1927. Unfortunately, the eggs that had been laid since 1927 were harvested. [13] had mentioned that over-harvest of eggs and meat at any nesting beach as one of the most effective ways to destroy a nesting population. Therefore, since 1950s, a rookery management program had been established to help sea turtles' population to strive, but the number of eggs replanted was not enough to ease the effect of decades of over harvesting thus resulting in the serious decline in nesting females [13].

The objectives of this research were to: (1) determine the trend of turtle landings and egg collection at Sarawak Turtle Islands (STIs) for the past 67 years and (2) estimate the reproductive demographic parameters of the nesting population (in terms of re-migration interval and hatching success).

II. MATERIALS AND METHOD

A. Study site and data description

For this study, all data used were secondary data (Table 1). The annual turtle conservation record covering the number of turtle landing, number of eggs collected, eggs incubated, and eggs hatched, that were kept in total per year format for year 1980 to 2016, was obtained from the Turtle Board of Sarawak Museum. The landing data before 1980 were obtained from [13].

The principal rookery for Sarawak's sea turtle stock is located off the coast of Southwest Sarawak on three islands known as Sarawak Turtle Islands (Figure 1). The three islands are Talang Talang Besar, Talang Talang Kecil and Satang Besar. According to [14], the Talang Talang Islands are approximately 2 kilometres apart at 109°46'E., 1°44'N., while Satang Besar Island is located at 110°9'E., 1°47'N., with the former being 9 kilometres off the mouth of Sematan River and the latter is approximately 7.3 kilometres offshore and 18 kilometres away from Santubong (mouth of Sarawak River).

Table 1. Type of data, year, and source

Type of data	Year	Source of data
Turtle landings/ nesters	1949 - 1979	[13]
Turtle landings/ nesters	1980 - 2016	Sarawak Turtle Board
Eggs collected, incubated and hatched	1980 - 2016	Sarawak Turtle Board

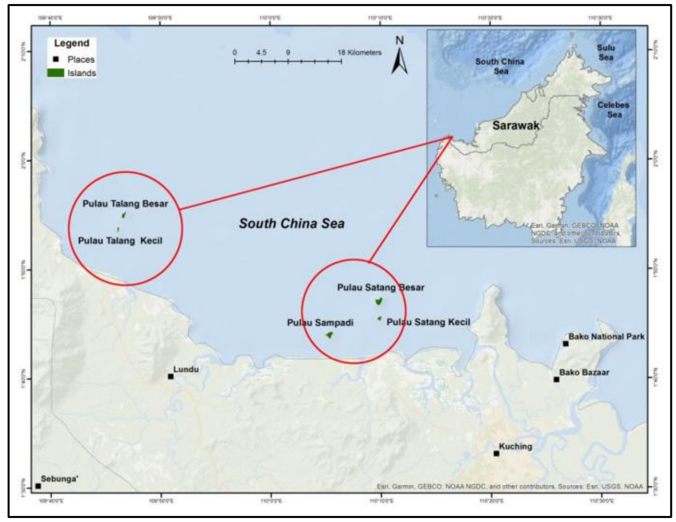

Figure 1. Location of Talang-Satang National Park (Sarawak Turtle Islands) and Sampadi Island (turtle foraging ground).

B. Estimating the size of the stock of mature female turtles

Stock size of mature egg-laying female turtles was estimated with the turtle nesting or turtle landing data. The total number of nesting was assumed to be related to the number of mature females depending on their remigration interval (r) and interesting frequency (i). The formula adapted for the estimation of mature (or egg-laying) female stock was adapted from [15]. The formulas used are as follows:

For r = 1, use: $$\frac{1}{5i}\sum_{j=-1}^{3} nj$$

For r = 2, use: $$\frac{1}{6i}\left[2\sum_{j=-1}^{3} nj + (n0 + n2)\right]$$

For r = 3, use: $$\frac{1}{2i}\left[\sum_{j=-1}^{3} nj + n1\right]$$

For r = 4, use: $$\frac{1}{2i}\left[\sum_{j=-1}^{3} nj + \sum_{j=0}^{2} nj\right]$$

For the equations given, n*j* denotes the total number of nesting turtles in a particular j^{th} breeding season where j=1,2,3,4,5. Since the estimation for the stock's latter number of mature females will be estimated every 10 years and the data used will be the data from the first half of the decade for that time (example: 2010 until 2014), n-1, n0, n1, n2 and n3 indicates total number of nesters in year 2010, 2011, 2012, 2013 and 2014 respectively. From the data obtained, the stock size of mature egg laying females will be estimated from the data of year 2000 to 2004 (data A) and data of year 2010 to 2014 (data B).

Population of *Chelonia mydas* in Sarawak does not reproduce on a yearly basis; instead, they exhibit a 2, 3 or 4 year breeding periodicity with the triennial cycle being the normal cycle [15]. According to [15], the internesting frequency (i) of Sarawak's green turtle is from 2 to 5 times per breeding season with an average egg-laying of 3 clutches per female in a season. Hence making $2 \leq r \leq 3$ and $3 \leq i \leq 5$. The main breeding activities on STIs have been determined to be from May to October each year although nesting takes place all year round.

III. RESULTS

The nesting turtle section is divided into three sections namely (i) nesting turtles annual trend for year 1949 to 1979, (ii) nesting turtles annual trend for year 1980 to 2016, and (iii) estimation of egg-laying females. Other results that will be discussed are the egg collection and incubation on Sarawak Turtle Islands (STIs) and the eggs hatched on STIs from 1980 to 2016.

A. Nesting turtles annual trend for year 1949 to 1979

The nesting for mature nesters from year 1949 to year 1979 shows declining trend (Figure 2). The highest number of nesters was in the year 1950 with 23,576 nesters while the lowest was recorded in year 1966 at 960 nesters. This shows a reduction of 95.9 % (1950 to 1966). With regards to decade data, the average number of nesters for year 1950 to 1959 was 13,462 nesters, for year 1960 to 1969 was 4,527 nesters and for 1970 to 1979 was 2,339 nesters. The decrease in terms of percentage from the 1950s to 1960s was 66.4 % and from the 1960s to 1970s was 48.3 %.

B. Nesting turtles annual trend for year 1980 to 2016

From year 1980 to 2016, the highest number of nesters was in the year 1991 while the year with the lowest number of nesters was in 1987 (Figure 2). In terms of decades, the average number of nesters for year 1980 to 1989 was 2,071 nesters while the average for year 1990 to 1999 was 2,263 and the average for year 2000 to 2009 was 2,337 nesters. The average number of nesters for the past three decades is in equilibrium of approximately more than 2,000 nesters. However, this situation could also be interpreted as a plateau phase achieved after a sharp descend in terms of average nesters from the year 1950s and 1960s. Comparison of the average of the 1950s and 1960s to the year 2000's shows reduction trends, approximately 82.6 % and 48.4 %, respectively.

C. Estimation of egg-laying females and their re-migration interval

In this study, the estimation of the stock of mature female nesters was carried out using data from 2000 to 2004 (A) and data from 2010 to 2014 (B). The estimated number of mature female nesters as a function of remigration intervals (r) and internesting frequency (i) is as shown in Table 2 (data A) and Table 3 (data B).

1.Using data from 2000 to 2004 (data A)

Table 2. Estimation data of mature female nesters for decade of 2000

Internesting frequency (i)	**Remigration interval (r)**			
	1-year	**2-year**	**3-year**	**4-year**
2	1121	2225	3399	4469
3	747	1484	2266	2980
4	561	1113	1700	2235
5	448	890	1360	1788

2. Using data from 2010 to 2014 (data B)

Table 3. Estimation data of mature female nesters for decade of 2010

Internesting frequency (i)	**Remigration interval (r)**			
	1-year	**2-year**	**3-year**	**4-year**
2	1527	3102	4537	6210
3	1018	2068	3025	4140
4	763	1551	2269	3105
5	611	1241	1815	2484

Table 2 shows the estimated number obtained from using existing data of turtle landing from year 2000 to 2004 while Table 3 shows the data obtained from using the existing data from year 2010 to 2014. As the data were estimated from the same large group of turtles that is the stock of mature female turtles in Sarawak, if r is taken as 3, then the 2003, 2006 and 2009 turtle landings correspond to the same group of turtles which is 1 out of 3 equal parts of the total mature female group.

The stock of mature female nesters in the decade of year 2000 is estimated to be between 1,484 and 2,266 individuals. The value 1,484 is from r =2, i = 3 while the value 2,266 is from r =3 and i = 3. However, the average number of nesters for the 2000 decade was 2,337 which was slightly different from the estimated value. There are two possibilities for this situation; (1) the turtle's remigration interval was every 3 or 4 years with internesting frequency of 3 or (2) the turtles do practice remigration of every 2 or 3 years but have a lower internesting frequency of 2.

Therefore, from Figure 2, an average number of nesters from 2010 to 2016 was calculated and compared to data set B (Table 3). The average of 7 years of landing data was 3,088 which when compared to Table 3 corresponds to the remigration interval of every 3 to 4 years with internesting frequency of 3 ($3 \leq r \leq 4$, i = 3).

D. Egg collection and incubation on Sarawak Turtle Islands (STIs)

Egg collection from year 1980 to 2016 (Figure 3) shows that the eggs were harvested annually with a 36-year average of 223,558 eggs per year. The highest number of eggs collected was in year 1991 at 384,579 eggs while the second highest collection was in 2013 at 314,552 eggs. The lowest number of egg collection was at 107,873 in the year 1987. Note that the eggs were collected from all three islands of STIs. The number of eggs incubated shows a rapid increment, in which there is an overlap between the number of eggs collected and the number of eggs incubated from year 1991 onwards.

The lowest percentage of eggs incubated was in year 1981 at 20.4 % (Figure 4). Year 1991 was the first time that egg incubation at STIs reached 90 percent (92.2 %) thus causing the overlap between the egg collected and egg incubated (Figure 3). Moreover, 100 % incubation of eggs collected from STIs was recorded for year 2000, 2002, 2005 and 2009 (Figure 4). The percentage of eggs incubated on all islands for 2010 onwards was at least 99 % with an exception for year 2011 at 98.6 % (Figure 4).

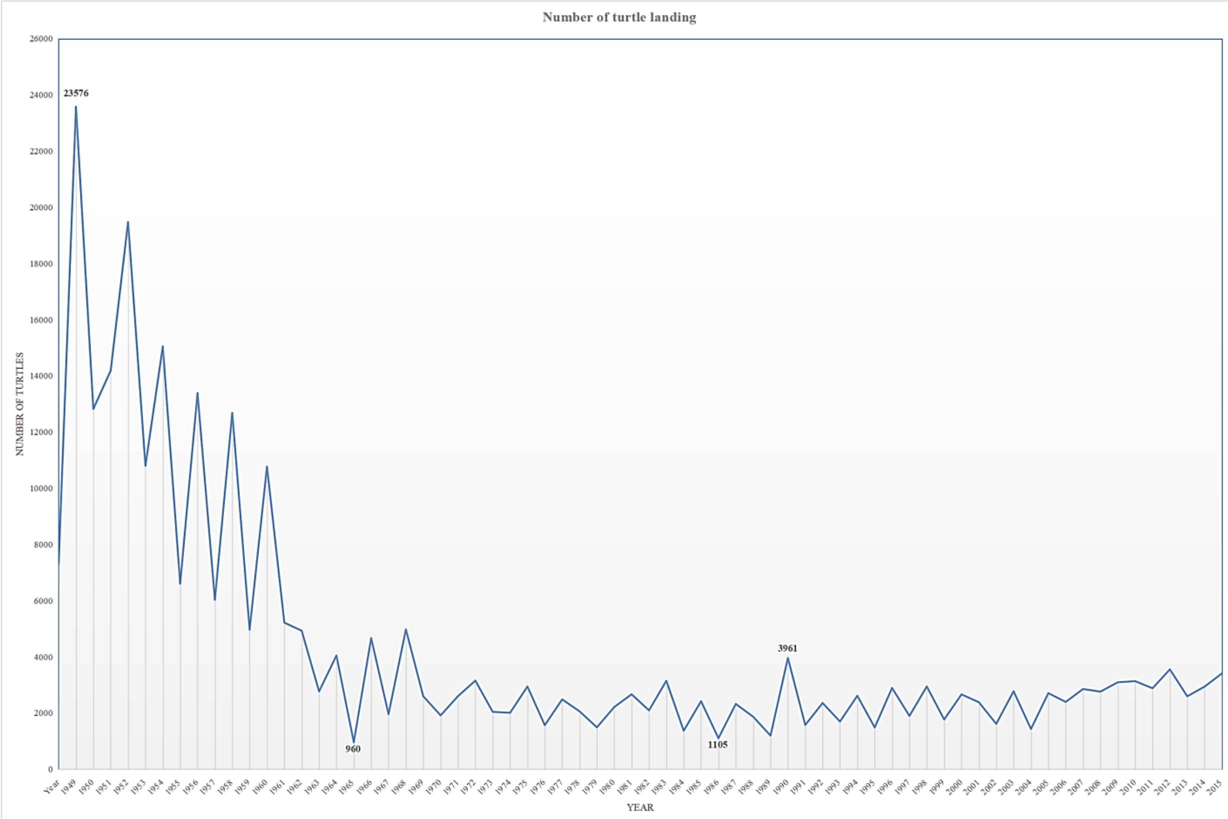

Figure 2. Turtle nesting trend from year 1949 to 2016

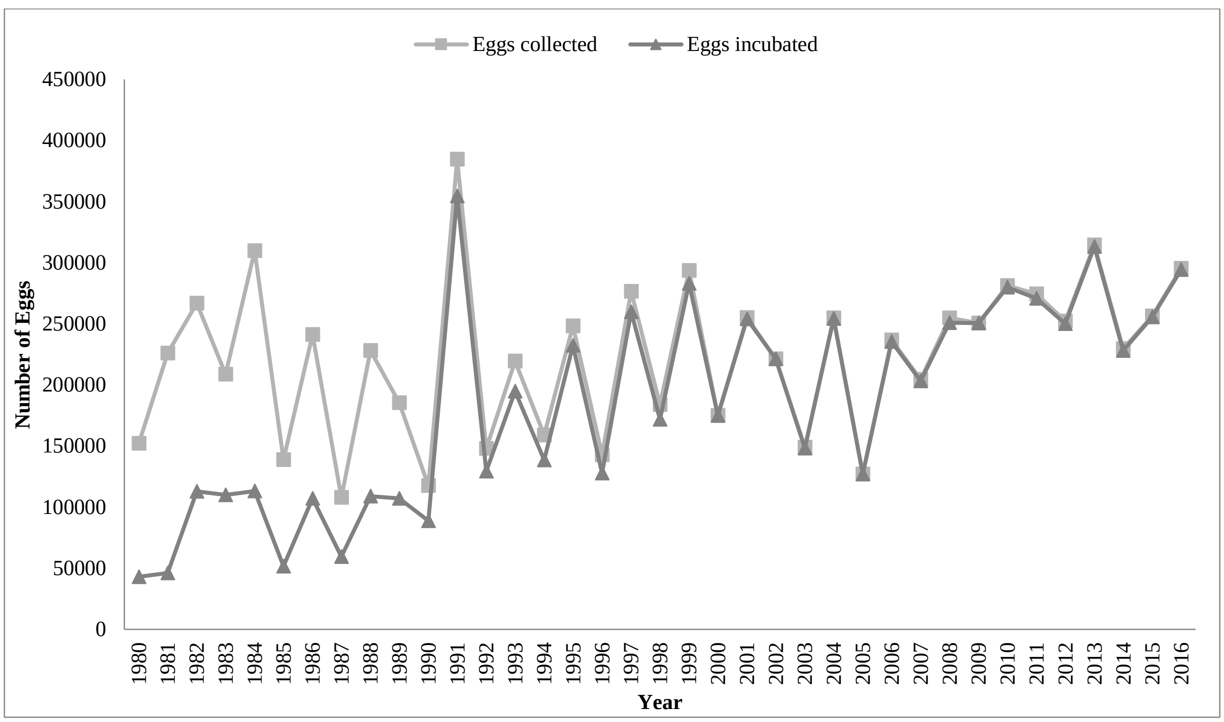

Figure 3. Total number of eggs collected and incubated trend from year 1980 to 2016

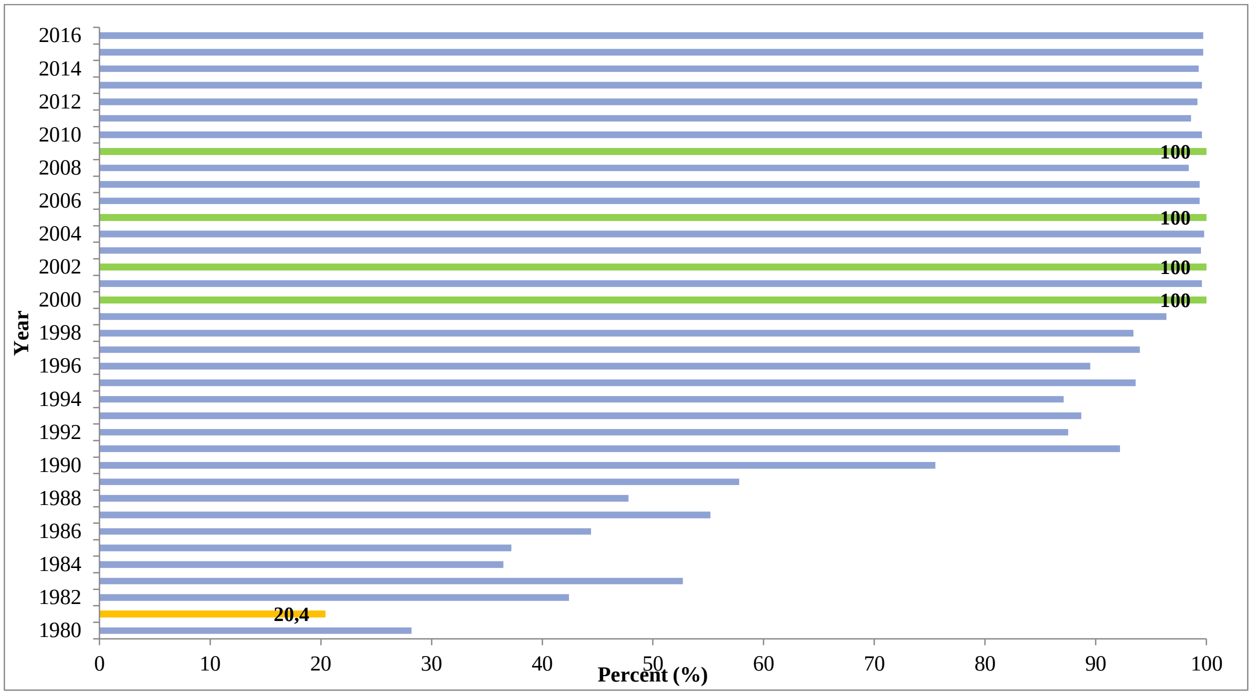

Figure 4. Percentage of eggs incubated from year 1980 to 2016.

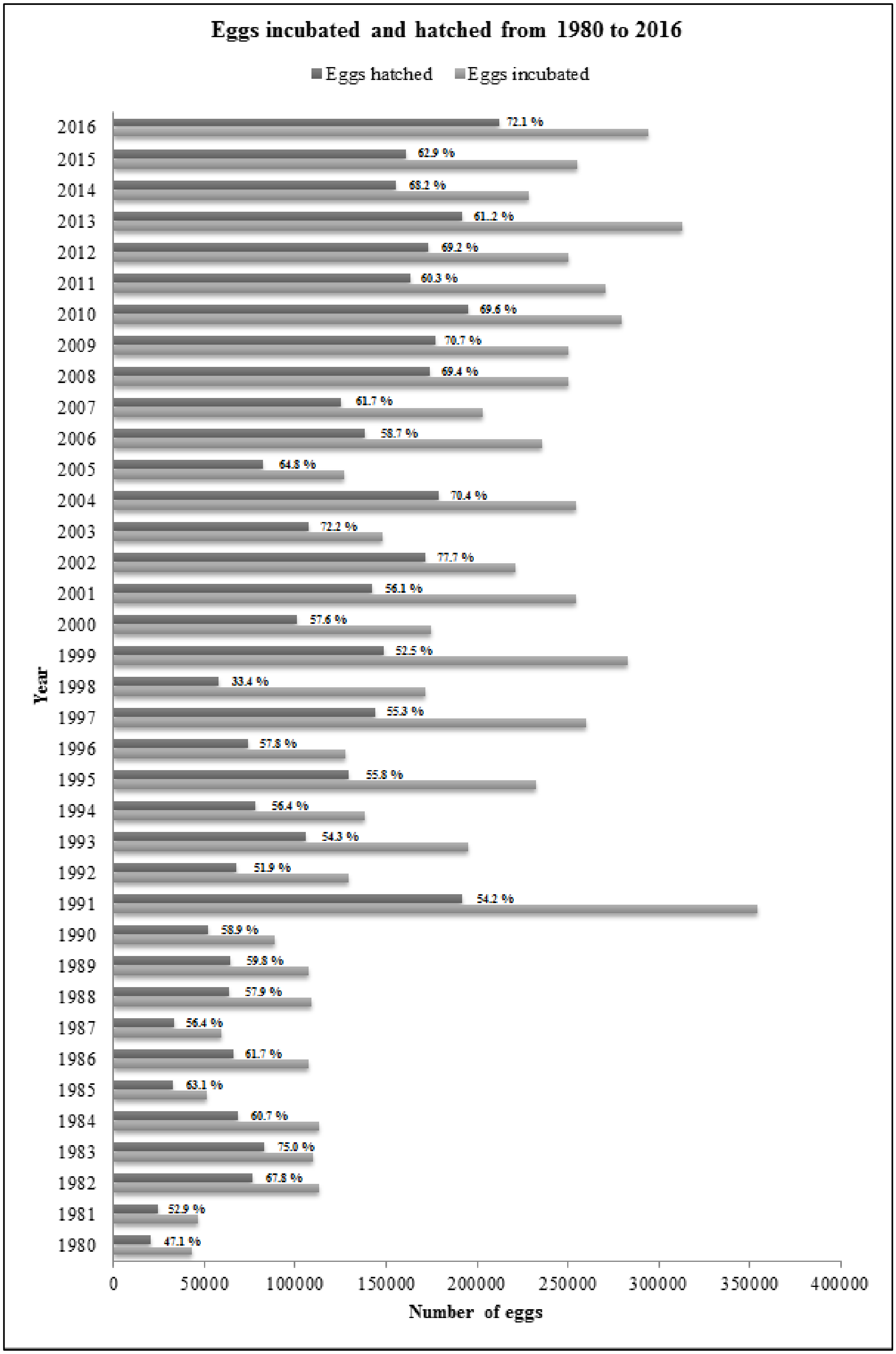

Figure 5. Percentage of egg incubated and hatched from year 1980 to 2016.

E. Eggs hatched on STIs from 1980 to 2016

The hatching rate of turtle eggs on STIs is shown in Figure 5. Over the course of 36 years, the year with the highest hatching rate was 2002 at 77.7 % and the year with the lowest hatch rate was 1998 at 33.4 %. The mean hatch rate between years 1980 to 1989 was 60.2 %, between years 1990 to 1999 was 53.1 % while the mean hatch rate for year 2000 to 2009 was 65.9 %. The 7 years mean average from 2010 to 2016 was 66.2 %. The trend of hatching rate for the past 36 years has been increasing especially from the 1990s to 2000s.

IV. DISCUSSION

A. Nesting turtles annual trend for year 1949 to 1979

There was a sharp decline in terms of number of nesters from 1950 to the 1970s. It is hard to point out the exact cause of this pattern due to limited information on the events happening during the 30 years period. The following paragraphs only discuss the possible causes based on published materials and should be read with cautions.

[15] stated that the activity that contributed to the drastic decline in Sarawak's turtle population was the prolonged period of over-harvest of eggs prior to 1965, in which very few or no eggs were kept for incubation; with estimation on the number of eggs harvested annually reaching over 2 million eggs per year [16], [17]. Another possible factor is that the turtles were slaughtered for food in the post-World War II period (1945 to 1948), which was something not practiced in the Borneo waters before the Japanese war [18], [13].

[18] had also mentioned that the Japanese had worsen the situation by having a fighter airstrip built on the opposite Satang Island *i.e* at Sibu Laut area and had used the 'Turtle Rock' located south of Talang-Talang Kecil Island as a bombing practice target. The sound and water pollution had negative impact on the turtle population in the area. Moreover, [15] has also reported that there was a chemical pollution in the marine environment caused by operations of the Sematan Bauxite Company from 1958 to 1965, besides a rapid increase in the ocean traffic due to this industry.

Another possible reason that deterred the mature nesters from laying eggs was the increased number of lightings along the coastlines. [18] mentioned that the Talang-Talang Islands were facing the mine; the lights from the mine's earth loading section was used during the day light and night with the addition of Japanese steamers that anchor offshore and were visible from Talang Besar Island throughout the turtles active breeding months.[19] had emphasized that excessive light incidence can deter turtles from nesting areas.

[20] added that the introduction of trawl and drift net fishing in the 1960s as another contributing factor to the reduction in turtle populations in Sarawak. According to [18], the whole tempo of Sarawak's development was stepped up in the mid-fifties with the increase in disturbance by vessels especially the Chinese motor fishing *kotak* fleet. To make matters worse, turtles that returned to nest at STIs at the time were found to be wounded or evidently escaped from being tied up after catching. [18] stated that this situation had never occurred before 1955 and suspected the mainland inhabitants, Indonesian boats and the Chinese *kotak* fleets as the culprit to this crime.

B. Nesting turtles annual trend for year 1980 to 2016

From 1980 to 2016, the annual nesting trend of turtles on STIs shows irregular fluctuations (Figure 2). It is noted that the nesting turtle stock showed a slight recovery but with dependency to the remigration interval of the turtles. The remigration interval of the turtles depends on the food availability, weather, pollution, location, behaviour of the turtles as well as human disturbance factors. Nesting abundance of sea turtles is affected by the variability in the primary production in sea turtle foraging areas as female turtles depend on specific amount of food for vitellogenesis or formation of yolk in eggs before migrating to nesting beaches [21]. Therefore, lack of food could be directly related to the delayed return, which means that the sea turtles will nest less frequent due to limited food availability [22].

The physiology and overall survival of sea grasses are influenced by the water temperature; therefore, the rising temperature due to climate change phenomenon will surely give negative impact to the sea grass meadows [23]. In Sarawak, seagrass beds were found at Sampadi Island, located at about 5 km from Satang Island, a section of the Talang-Satang National Park [24]. Needle Seagrass (*Halodule pinifolia*) could be found in abundant within the estimated 15 hectare of seagrass bed at Sampadi Island. The seagrass beds comprised of parts that are exposed during low tide and immature green turtles were observed feeding at the deeper parts of the seagrass areas [24]. Other than Sampadi Island, seagrass beds of Kuala Lawas have been confirmed as foraging ground for green turtles in Sarawak [25].

There are many potential impacts of climate change on sea turtle population for example loss of nesting habitats due to sea level rise and the effect of increased sea surface temperature on the nesting patterns of sea turtles [26], [27]. In addition, [28] reported that an increment of 1.5 °C in the sea surface temperature at a foraging ground had resulted in the reduction of almost 500 nests per season in Zakynthos, Greece. [11] also reported a similar trend in Rethymno, Greece; they claimed that the reduction in nesting activity could be due to the deterioration of foraging grounds or could correspond to the strong anthropogenic impact on the beaches, as the downward nesting trend did not affect a nesting beach with limited human presence. [29] had supported statements by [11] by mentioning that the conditions of a beach influenced its suitability for nesting and hatchling emergence.

Although climate change concept is generally accepted, there is still on-going debate on the magnitude of its effects. The other factors that could affect the nesting behaviour of the turtles are the characteristics of sand of the landing beach, the coastal vegetation, the offshore approach, and the shoreline composition. [12] mentioned that sand characteristics such as grain size coupled with other conditions such as smooth slopes, sandy beaches and the humidity level could be factors forcing females to change their nesting behaviour. [30] supported this as their research showed that the temporal distribution of nesting turtles in Setiu, Terengganu, Malaysia, could be affected by the northeast monsoon which characterized by strong waves leading to habitat alterations from November until February. [31] had suggested that rainfall affects the frequency of nesting of marine turtles as damper sand encourages nesting.

Natal homing is the dominant paradigm for sea turtle migration, although the geographic specificity of homing varies widely [32]. A matured adult female usually practices natal homing but could switch to social facilitation or chance-encounter, if their birthplace was deemed to be unfit for nesting. [33] had demonstrated that there were two clades in terms of nesting females of sea turtles of the STIs based on D-loop region gene namely the clade of Talang-Talang Island nesters and clade of mixture between the Talang-Talang and Satang Besar Islands. The presence of the first clade shows that natal homing dominates, because the nesting population possess a unique genetic signature in terms of female transmitted mtDNA [32] while the presence of the second clade suggested the social facilitation or chance encounter hypotheses. [34] have stated that climatic fluctuations could have altered the availability of the green turtle habitats, thus promoted straying and wandering female nesters that are thought to be advantageous, adaptable to change and necessary for colony proliferation. The change in nesting habitat of Sarawak's egg laying female stock from Satang Island to Talang-Talang Island could be attributed to the active eco-tourism activity being carried out in Satang Besar Island [13].

However, both islands of Talang-Talang are strictly for turtle conservation activities led by Sarawak Forestry Corporation (SFC) since 1999. Talang-Talang Besar Island is home to a sea turtle egg hatchery and a nesting beach for most green turtles that visit STIs. The six islands namely Talang-Talang Besar, Talang-Talang Kechil, Satang Besar, Satang Kechil, Tukong Ara and Tukong Banun were gazetted as a Marine Protected Area in 1999 for protection of marine turtle critical habitats and ecosystem [24]. Besides that, since 1999, the Sarawak State government had also enforced a total ban on selling of turtle egg to the public besides commencing the reef ball project, which among many of the objectives is to help maintain population of green turtles in Sarawak [25].

C. *Estimation of egg-laying females and their re-migration interval*

The estimation of mature egg-laying female turtles was done to estimate the current mature turtle populations in Sarawak. Based on this estimation, the internesting and remigration interval of the mature turtles could be predicted and the factors that affect the turtles could be identified. Moreover, the number of new females could be estimated as the new females would make up the rest of the number after deduction of the existing stock number from a particular year. A hatchling could take a minimum of 19 years to 30 years before it grows to a mature adult female and once reaching maturity, it could continue laying eggs for 30 or 40 more years [35].

The number of mature females needs to be estimated so that the future stock could be maintained as turtles that mature in the 1970s could possibly not lay eggs anymore in 2020. [36] stated that 40 to 70 years or more is the time duration of when a female first hatches out of her egg and when she stops laying eggs, which means that the current population is composed of individuals that would have hatched from their eggs anytime between 1947 and 1997.

From the quasi-periodicity in estimated nester abundance suggests that female green turtles migrate to nest at STIs every 3 or 4 years, major ocean climate anomaly had been named as an environmental forcing function which could have synchronized multi stock nesting at Southeast Asian green turtle rookeries [37]. If this situation is proven to be true, there might be a downward trend in the near future if new juvenile females are not cultivated from now.

Apart from that, another possible reason for this is females' nest more frequently, which means that the return period between successive nesting seasons is shorter rather than there being more nesters. This could be a plausible reason as there seems to be a fluctuating trend in nester abundance which occur every 2 or 3 years since 1980. The increment in sea surface temperature could have been the causal factor for the shorter remigration interval. This fact was supported by [38] and [39] which have shown that there was an association between sea surface temperature with annual fluctuations in the nesting of green turtles at the Hawaiian and Tortuguero rookery.

[40] pointed out that if clutch frequency varies between years, the increase in nesting does not necessarily reflect an increase in the females. In addition, environmental variables may influence the number of turtles ready to nest each year [37]. If the mean remigration interval has decreased as a result of environmental change, an increase in nesting would occur without an increase in female [22].

D. *Egg collection and incubation on Sarawak Turtle Islands (STIs)*

[13] has described the population of nesting females on STIs as critically endangered due to the long period of egg harvest as prior to 1976; less than 2 % of the eggs laid annually were placed in the hatcheries. She stated that a serious decline in number of nesters should be expected in the next couple of decades as only a small number of eggs was protected between 1963 and 1975; considering the current estimation of survival from egg to adulthood range from 1 female produced per 1000 eggs to 1 female per

10000 eggs. To protect the green turtle population of Sarawak, [13] has recommended implementation of 100 % protection of eggs collected following the suggestion that at the very least 70 % or more eggs need to be protected when the population has a history of over-harvest [41]. There is a positive increase in terms of number of eggs incubated from 1980 to 2016. The number of eggs collected fluctuated over the course of 36 years, similar to the number of turtle landings. The efforts made by the turtle custodians of Sarawak to help the turtle population grow is translated in the increased number of eggs incubated. This effort also shows that the implementation of Wild Life Protection Ordinance 1998 (Laws of Sarawak, Chapter 26) which prohibits exploitation and trade in all marine turtles, their eggs and any derivatives or their body parts [42], is working.

E. Eggs hatched on STIs from 1980 to 2016

Despite the commendable effort by the relevant Sarawak agency, which is mirrored through the number of eggs incubated, the result would still be the same if the hatching rate of eggs is low. In this study, average percentage of successful hatching from year 2010 to 2016 was 66.2 %. This is lower compared to the hatching success rate in Setiu, Terengganu, Malaysia [43].

The sand's grain particle size and the pore water content are said to have a direct impact on the gas exchange rate of the nest environment. [44] showed that there is an optimum range of grain size for hatching success, as nests can fail if the sand is too fine or too coarse. [45] had mentioned that inadequate gas exchange could slow the growth and increase embryonic mortality. As the same colony of green turtles were observed to utilize a wide range of sand types (from fine sand to coral pebbles), it was concluded that the grain size is probably less important to a turtle in her choice of a nesting beach [46], [44].

Another major factor that could affect the hatching rate of turtle eggs is the climate change. Turtle eggs hatchability rate and the gender of the turtles depend on the temperature of the nest; within the range of 26 to 32 °C, a change of 1 °C will result in addition or subtraction of 5 days to the incubation period [47]. The pivotal temperature varies among species and between populations [48]; however, the general idea is, the cooler temperature will produce males while warmer temperatures most likely will produce females [49]. Turtle eggs are highly sensitive to temperature change, as eggs that are incubated at temperatures lower than 23 °C for the last third of incubation seldom hatch, while eggs that are held at 33 °C for an extended period will not hatch.

Other than temperature, the eggs are also sensitive to desiccation and excessive moisture; the egg mortality rate is higher in drier condition and during inundation of eggs for extended period of time (hours) [50]. Therefore, if the amount of rainfall were to increase and the temperature of the sand at the nest site decreases, the hatching rate will be lowered. Similarly, [51] reported that the percentage of unhatched eggs was up to 82 % during the wet season (November to April) at STIs.

Another factor that could influence the hatching rate of sea turtle eggs in Sarawak is the fertility of the eggs. [15] shows that the depth of the nest had no significant effect on the hatching rate and incubation period while clutch size did. It was mentioned that the infertile eggs could have a dampening effect on viable fertile eggs as those are not able to generate metabolic heat to create optimum thermal environment for nest incubation. The examination of unhatched eggs done by [15] revealed that infertility was the cause of low hatch rates instead of embryonic mortality. Meanwhile, in Setiu, approximately 73.9 % of eggs incubated had been successfully hatched with only 19.7 % of unhatched eggs showing no embryonic development [43]. In addition, [52] suggested that the high proportion of infertile eggs could be due to fewer males being available to mate with females.

A recent study by [53] had caused renewed concern over this matter. [53] had conducted a mixed stock analysis using molecular markers from samples of green turtles at Mantanani and Layang Layang Island, which both areas are known as foraging ground for the immature turtles. They claimed that more that 80 % of the juvenile turtles originated from the genetic stocks of Sarawak Management Unit (MU), Peninsular Malaysia MU and Sulu Sea MU which includes the TIHPA (Turtle Islands Heritage Protected Area). They found that the estimated mean contribution of males and females from STIs were only 2 and 25 %, respectively, which contradicts with Peninsular Malaysia's contribution of 62 % of males and 30 % of females. Lack of contribution of males from STIs suggests that conservation efforts carried out in STIs need to be stepped up to ensure sustainable population of *Chelonia mydas*.

Besides that, [54] had estimated that hatchery-raised hatchlings for Sarawak rookery was highly female biased (80- 96 % females) in comparison to *in situ* nest. Although [55] claimed that the higher breeding frequency of males may counteract female biased sex ratio, it should be noted that the highly skewed sex ratio will eventually bring impact to the clutch fertility as males become a limited resource especially when considering predictions of future increment in temperature which could lead to female bias hatchling recruitment [56], [57], [58]. Moreover, [59] had suggested that concern should be raised if male: female (M: F) sex ratio of hatchlings across all nesting beach for a particular stock approaches 1M: 4F. It is still not known how much a female bias population can sustain the overall population as green turtles takes 20 to 50 years after hatching to reach sexual maturity thus making female bias condition undetectable until decades later.

V. CONCLUSION

There is a decreasing trend of turtle landing at Sarawak Turtle Islands (STIs) for the past 67 years. Conservation efforts including changes in legislation and enforcement activity have shown positive impacts on the number of eggs collected, incubated, and hatched for 36 years period for STIs (1980-2016). However, the future trend should be observed closely due to the climate change phenomena which may shorten the remigration interval between nesting seasons. Future nesters should be continuously cultivated and the average 60 % of hatching rate of turtle eggs on STIs should be addressed and improved. Moreover, the male:female ratio of hatchlings produced at STI's hatcheries need to be re-investigated and tackled to ensure a well balanced and sustainably fertile population of green sea turtles for Sarawak.

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