Biology and Management of Olive Ridley Turtles (*Lepidochelys olivacea*) in Central America

A Dissertation

Submitted to the Faculty

of

Drexel University

by

Carlos Mario Orrego V.

in partial fulfillment of the

requirements for the degree

of

Doctor of Philosophy

December 2014

Acknowledgements

I started this journey in 1997 when I left Colombia after losing my brothers and father. I decided to be a new migratory species looking for new opportunities following another migratory species, the olive ridley sea turtle. The olive ridley sea turtle gave me the inspiration and three countries in the Americas gave me the opportunity. So I am very grateful to the United States, Costa Rica and Colombia, for supporting me in this migratory idea.

First, I would like to thank to Dr. James Spotila for the years of expert career guidance. He has been a great mentor, friend and professor. I also thank the rest of my committee, Dr. Roldan Valverde, Dr. Pamela Plotkin, Dr. Susan Kilham, Dr. Harold Avery, and Dr. Kenneth Locovara.

I thank Susan Cole and Brenda Jones for their patience in helping me at Drexel.

I thank my colleagues and friends within the BEES Department at Drexel: Steven Pearson, Karen Sullam, Eugenia Zandona, Matt Grey, Bibi Santidrián Tomillo, Gabriela Blanco, Lucio Ibiricu, Aliki Panagopoulou, Yuxiang Fei, Noga Neeman, Shaya Honarvar, Julia Rojoli, Abby Dominy, Jack Suss, Lori Lester, and Laurie Cotroneo.

I thank Dr. Barbara Hoekje from the English Language Center (ELC) at Drexel for her support and friendship.

This research was funded by the Betz Chair of Environmental Science at Drexel University, The Leatherback Trust and Idea Wild, USA.

Approvals were provided by MINAEM in Costa Rica, MARENA in Nicaragua, and Drexel University IACUC, Philadelphia, USA.

I would like to thank to Carlos Manuel Rodriguez, Rod Mast and Carlos Drews for sent the reference letter that I needed to apply for my PhD.

I would like to thank to my local team at Ostional. Without them it would have been impossible to collect all the amazing data to finish this challenge: Gredy Bran G, a good field coordinator and friend, Marcela Rodríguez, Ana Yance Baltodano D, MacDonald Gómez, Gilberto, Rafael Ruiz (q.p.d), Miguel Brenes, Yeudi Gómez, and Rolando Parra.

I would like to thank my local team at La Flor and Chacocente, Nicaragua, without whom it would have been impossible to collect all the amazing data to finish this challenge, especially Miguel Angel Campos Rodriguez, the best field coordinator and friend that accepted the challenge to leave his country and move to Nicaragua; Wendy, Danelia, Janet, Oscar, Adriana, Carlos, Anniett, and Wilbert.

I thank Flora and Fauna International (FFI) in Nicaragua, especially Jose Urteaga and Perla Torres for their support and logistics.

I thank Rosa Zegarra for typing field data from Nicaragua and Juan Valverde for typing field data from Costa Rica.

I thank Dr. Fernando Casanoves and Mayra Alejandra Ospina of the Biostatistical Department, CATIE, in Costa Rica for their logistical support and help to order the database.

I would like to thank all the Ostional stakeholders: the Ostional Development Association (ADIO), Ostional community, University of Costa Rica (UCR), Costa Rican Institute of Aquaculture and Fisheries (INCOPESCA), Participatory Management Commission at Ostional (CIMACO), Ministry of Environment and Energy (MINAE), National Conservation System (SINAC), and Tempisque Conservation Area (ACT).

I would like to thank the Ostional Guides Association (AGLO) for their ecotourism information and their contribution every day to create order with the visitors to protect the Ostional sea turtle habitat.

I would like to thank the ADIO Local Guides for their contribution every day to create order with the visitors to protect the Ostional sea turtle habitat.

I thank hundreds of national and international volunteers around the world who spent night after night with us, helping to collect information.

I thank the Ministry of Natural Resources from Nicaragua (MARENA), and the Chacocente and La Flor National park rangers

I would like thank my supervisors in Costa Rica for signing my last student license in 2014 to come to Drexel to finish this journey, Nelson Marin M., Rafael Gutierrez, and Julio Jurado. I also thank in general the Ministry of Environment, Energy and Seas (Ministerio del Ambiente, Energia y Mares- MINAEM) Protected Areas National System (Sistema Nacional Area de Conservacion-SINAC)

I thank all Area Conservation Tempisque (ACT) and Ostional's park rangers and my coworkers because they also were my family and my friends over the time on this journey in Costa Rica: Laura Brenes, Yamileth Baltodano, Pablo Baltodano, Fabricio Alvarez, and Carlos Hernandez. I also thank Emel Rodríguez, Mauricio Méndez, Nelson Marín, Norma Rodríguez, Ana Rosa Gutiérrez, Martha Díaz, Seidy Fonseca, Lorena Solano. Yeimy Cedeño, Roberto Zúñiga, Roger Gutiérrez, Marvin Díaz, Keneth Díaz and Rafael Fonseca.

I would like to thank Dale Brelsford, Anna Juliano Meade, T. K. Meade and Diane Harrell: my New Jersey family for the rest of my life… I love you all so much. Thank you for your help in this journey…

I thank my friends Julian Garcia and Domenica Alarcon for their time, support, edits, and for pushing me to come to Drexel and finish this challenge.

I would like to thank Michael McCoy, professor, friend, and colleague, for taking his time to help me to improve my statistical analysis skills.

I thank Dr. Carlos Drews for his time, advice, and feedback to improve my chapters and push to the top.

I would like to thank Dr. Claudia Ceballos F for pushing me to finish this journey and for being always in my life challenges.

Finally, I would like to thank my family, especially my mother, who taught that perseverance and patience is the best path to be successful in any project in my life. I am learning… To my sister, Monica, thank you. I am very proud of you and love you so much. The rest of my family, who are not in this earthly life, my brothers Jaime and Albeiro and my father Ramiro, for all them I give thanks, for their support and love that they have provided me. Wherever you are, please, you all have to know that I love and miss you all so much. I would like to thank my beautiful niece Valerie and my handsome nephews Andres Felipe and Juan David because I am very proud of you all and my brother-in-law, Juan Tabares, who is with us forever in our life journey.

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Abstract

The biology and management of Olive Rildley (*Lepidochelys olivacea*) sea turtle in Centro America

Carlos Mario Orrego V.

James R. Spotila, Ph.D.

The purpose of this dissertation was to understand the applied biology of the olive ridley turtle nesting arribada at Playa Ostional, Costa Rica, and Playa La Flor and Playa Chacocente in Nicaragua. Harvest of eggs fromthese beaches was not sustainable. Hatchling production at Ostional and La Flor was insufficient to maintain the current populations of adults and production of hatchlings at Chacocente was marginal. To help ensure the stability of the regional olive ridley population it will be necessary to produce as many hatchlings as possible from the beaches and to reduce at sea mortality of the turtles for the foreseeable future.

Hatching success and the production of hatchlings were controlled by the same spatial, temporal, human and environmental factors on all three beaches so those controls appear to be general in nature, at least in the Central American Pacific coast. Density of eggs did not have a significant effect on hatching success or hatchling production. Plots open to harvest, dogs and poaching did not have higher hatching success or higher hatchling production. Thus, removal of eggs by humans and their animals is not an effective means to increase the number of hatchlings produced from these beaches. The best way to increase hatchling production is stop poaching, reduce dog predation, and find ways to increase hatching success. It is not practical to eliminate the harvest at Ostional because the harvest provides important income for the members of ADIO.

However, the legal harvest can be restricted to the dry season when eggs typically die from heat and lack of water. In the wet season harvest can be restricted to eggs that are on the surface of the sand due to digging by turtles and eggs that are in danger of being washed away by the estuaries and tides. Ecotourism now produces more income at Ostional than the legal egg harvest. A combination of a well-managed harvest of doomed eggs and ecotourism would provide a conservation plan that would eventually provide new income for local residents and increase hatchling production. A participatory management program is needed on the other beaches as well.

CHAPTER 1: INTRODUCTION

There are seven extant species of sea turtles and all but one of them, the Kemp's ridley (*Lepidochelys kempii*), inhabit the Pacific Ocean. Two of those species, the Kemp's ridley and the olive ridley (*Lepidochelys olivacea*), often arrive to lay their eggs on beaches in a large group called"arribada" or "flota" in Spanish. They also display behavioral nesting polymorphism (Bernardo and Plotkin, 2007), which is characterized by three different types of strategies, namely, within a population most females nest in arribadas, a number of females nest solitarily, and some have a mixed strategy in which they nest in arribadas as well as sometimes nesting solitarily. Arribadas became known to science when Hildebrand (1963) discovered a film by Andres Herrera of an arribada of Kemp's ridley turtles in Rancho Nuevo, Mexico in 1947. In that film approximately 40,000 turtles were estimated to have come on shore to nest in one day. Typically an arribada consists of hundreds to thousands of female sea turtles nesting at the same time on a beach during a period of several days. Generally, female ridleys lay two clutches of eggs per reproductive year, remaining near shore for approximately one month between nesting (Plotkin, et al., 1994). The mean clutch size of females differs from beach to beach. For Mexican populations of olive ridleys the average clutch size was 105 eggs, whereas for Costa Rican populations it was 107 for Playa Ostional, and 100 for Playa Nancite (Marquez, 1990 and Cornelius, et al., 1991).

There are only a few nesting beaches in the world where olive ridleys still nest in arribadas (Cornelius, et al., 1991). Major arribada nesting beaches are in Costa Rica (Playa Ostional and Playa Nancite), Mexico (La Escobilla), and India (Gahirmatha).

Minor arribada nesting beaches are in Nicaragua (Playa Chacocente and Playa La Flor), Panama (Isla Canas), Mexico (Ixtapilla) and India (Playa Barunei River) (Spotila, 2004). During the incubation process the embryo grows inside the egg until hatching some 45-55 days later and this process includes the exchanges of heat, water, O_2, and CO_2 with other eggs in the same clutch and in the surrounding area (Ackerman, 1997). In sea turtles and other reptiles, the main factor that determines the sex is temperature. (Merchant, 2000). According to Wyneken, et al. (2007), sex determination occurs in the second third of the incubation period. This is known as the thermo sensitive period (TSP). (Merchant, 2000; Mrosovsky, et al., 2002) The pivotal temperature for the olive ridley is 30-31°C. Individuals from nests in shady, vegetated areas may take 70 days or more to hatch (Hughes and Richard, 1974).

The olive ridley turtle, the second-smallest sea turtle species (Miller, 1997), has a wide distribution in both tropical and subtropical regions throughout the world's oceans. Although they are the most abundant sea turtles in coastal and oceanic waters (Pritchard, 1997; Limpus, 1995; Eguchi, et al., 2007), like other sea turtles olive ridleys have been affected by a variety of anthropogenic activities such as direct harvesting of eggs and turtles, nesting habitat destruction and fishery bycatch (Cheng and Chen, 1997; Pritchard, 1997, Pandav, et al., 1998; Cornelius, et al., 2007; Dapp, et al., 2013). In the eastern Pacific, during the 1960s and 1970s commercial exploitation of olive ridleys resulted in annual harvests of 75,000 to 350,000 turtles in Mexico (Peñaflores, et al., 2000 cited by Cornelius, et al., 2007) and tens of thousands of olive ridleys each year from Ecuadorian waters (Green and Ortiz-Crespo, 1995 cited in Frazier, et al., 2007). More recently, olive ridleys have been subjected to incidental capture resulting from various fishing activities. Despite their seeming abundance and wide distribution, many populations have been greatly depleted by human activities including exploitation, habitat destruction, and fishery-related mortality (Limpus, 1995; Pritchard, 1997; Pandav, et al., 1998). As a consequence of these impacts, nesting abundance on many of the primary nesting beaches has declined (Valverde, et al., 1998; Shanker, et al., 2003).

Due to these threats the Convention on International Trade in Endangered Species of Flora and Fauna (CITES) lists the olive ridley on Appendix I (prohibited from international trade) and the International Union for the Conservation of Nature (IUCN) Red List Assessment currently lists the olive ridley as "Vulnerable" and Current Population Trend: Declining (Abreu- Grobois and Plotkin, 2008). Other relevant international instruments that list the olive ridley as endangered and therefore require its conservation by member states include the Convention on Migratory Species (CMS) and the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC).

Knowledge of sea turtle population status is essential to devise appropriate conservation measures. However, there is little known about population dynamics of the populations of olive ridley turtles that nest in the Eastern Tropical Pacific. There is a lack of published information regarding demographic parameters such as age to sexual maturity, frequency of nesting and inter-nesting interval, foraging and mating area, hatching success and sex ratios and long-term population trends (Cornelius and Robinson, 1985; Cornelius, 1986; Plotkin, et al., 1995; Plotkin, et al., 1996; Plotkin, et al., 1997; Bernardo and Plotkin, 2007).

Anthropogenic causes of olive ridley turtle declines

Olive ridleys were once heavily exploited, and were estimated to be at one point the most commercially important sea turtle in the world (Bernardo and Plotkin, 2007), more so than the green turtle (*Chelonia mydas*). The general context of olive ridley use was economical, political, social, and cultural, and was based on published and unpublished research (Campbell, 2007). The arribada behavior of the olive ridley facilitated illegal (poaching) and in some cases legal collection of eggs or hunting of turtles, and commercialization of eggs on several beaches included exportation to local, national, and international markets (Cornelius, et al., 2007). Collecting and/or slaughtering sea turtles is easier than for other land animals. Hunting of sea turtles and harvesting for subsistence is an old activity that still continues (Frazier, 1980; Frazier, et al., 2007; Moserri-Marlio, 1998; Bird, et al., 2001; David, 2007; Campbell, 2007). In Central America, there are coastal communities that have a tradition of harvesting sea turtles from the ocean (Cornelius, 1986). At the same time there are some countries that permit legal commerce of eggs at specific beaches during certain times. Unfortunately, regulations in many places are ignored and as a result of this, at several beaches it will be impossible to totally eliminate poaching of eggs. The direct capture of adult turtles in fisheries at sea, mainly where they concentrate for their physiological activities such as feeding, mating, or nesting, generally has had a greater impact on population survival than the killing of females on land (Cornelius, et al., 2007).

In the Western Atlantic Ocean both informal and organized harvesting of adults and eggs of all species was common in the Guianas and Brazil. At Eilante Beach in

Suriname there used to be direct consumption of eggs and adult ridleys. According to Reichart and Fretey (1993) about 1500 nesting females were killed annually during the 1930's at Eilante Beach. The harvesting was intense and nearly 100% during 1960's. Although a federal law in 1970 prohibited the collection of eggs, there were conflicts between government and communities resulting in uncontrolled egg harvesting (Reichart and Fretey, 1993; Cornelius, et al., 2007), and the population collapsed. In Brazil the harvest of adults and eggs of all nesting species continues along the Sergipe coast (Marcovaldi and Marcovaldi, 1999; Cornelius, et al., 2007). In the Eastern Atlantic Ocean there are some exceptions; however, nesting olive ridleys are captured along the shoreline and sold in markets (Cornelius, et al., 2007).

In the Eastern Pacific Ocean the harvesting of adults and turtle eggs increased with the arrival of Europeans. Today the harvest is supported by cultural heritage based on legends, stories, and fables that are transmitted from generation to generation (Chacón, et al., 2000; Cornelius, et al., 2007). In addition, cultural consumption of olive ridley eggs and traditional demand is based in part on the use of eggs as a presumed aphrodisiac (Cornelius, et al., 2007 and Arauz Almengor, et al., 1993). Before 1970, coastal communities from Mexico to Panama collected olive ridley eggs on a small scale for subsistence and on a larger scale for local or regional sale. Though past data on egg harvesting are few, it is clear that egg collection reached nearly 100% at many of the regions' nesting beaches and continues at this level in many places (Cornelius, et al., 2007). In Panama, El Salvador, and Guatemala, a clutch of 100 eggs can be bought for $2 to $10 from local egg collectors ("hueveros" in Spanish) (Arauz, 2000). Since the early

1970's large arribadas of 100,000-200,000 nesting females at Ostional, Costa Rica facilitated massive egg harvesting. In 2001, economic benefits for the Ostional community due to egg harvesting totaled over $45,000 (Araya, et al., 2002). In 2007 the Ostional egg-harvesting summary showed that the local cooperative sold 3,993,800 ridley eggs (Morera, 2007). Based on the average of 107 eggs laid by each nesting female at Ostional (Marquez, 1990 and Cornelius, et al., 1991), those eggs were the equivalent of the reproductive output of 37,325 nesting females. In 2007 economic benefits for the Ostional community from egg harvesting generated a total of 139,783,000 colones, an equivalent of $ 251,268 (August 2, 2008 1$ = 556.31 colones). Such income has provided a strong incentive to maintain the egg harvest at Ostional.

Land-based harvesting has been associated with severe declines in several ridley populations around the world. However, the direct cause and effect relationship has not always been clear. In some cases, declines may be due in part to natural phenomena. For instance, the shoreline in Suriname and French Guiana is known for erosion and accumulation of sand as a result of currents (Shultz, 1975; Cornelius, et al., 2007). Another possible cause for the reduction in the nesting population may be the result of females simply dispersing to different beaches depending on accessibility and quality of beach habitat (Shultz, 1971 cited in Cornelius, et al., 2007). In addition, there are few quantitative data on numbers of nesting females, numbers of eggs and adults collected, and number of hatchlings produced.

On some arribada beaches hatching success is often low, so poor that the value of these beaches for sustained recruitment to population has been questioned (Cornelius, 1991; Cornelius, et al., 2007; Honarvar, et al., 2008). The high egg mortality is due largely to very high density of turtles during arribadas, in which the turtles themselves physically disturb from 20% to 40% of deposited clutches. If there are successive arribadas before the end of the incubation period, these result in additional disturbances of in situ nests and further mortality that may occur as result of proliferation of fungi and bacteria, reduced O_2 and increased CO_2 from microbial respiration, and increased sand temperature, limiting embryonic development or increasing embryo mortality (Cornelius, 1991; Cornelius, et al., 2007; Valverde, 1998; Clusella Trullas, et al., 2007; Wallace, et al., 2004; Honarvar, et al., 2008; Brenes, 2013). Arribada beaches may lose quality as optimal nesting beaches to arribadas through time, so that some beaches may only be temporary nesting habitats (Bernardo and Plotkin, 2007), although scientists have not been studying sea turtles long enough to observe such a phenomenon.

Anthropogenic factors affecting the abundance of olive ridleys in some areas are excessive egg collection, harvesting of adult turtles in fisheries, low hatchling success, and incidental capture in other fisheries. These problems can result in a population collapse that will require decades of protection of both the surviving turtles and their eggs to rebuild the population (Cornelius, et al., 1991; Valverde, et al., 1998; Pritchard, 2007). The area from Central Mexico to Panama is the region where there is the greatest overall decline in total number of nesting olive ridleys compared to the rest of their distribution (Cornelius, et al., 2007).

In the early 1980’s, Central American communities and governments recognized that ridleys were declining, with the exception of Ostional Beach, and this reduction was attributed to widespread egg harvesting and the incidental capture of adults by the commercial turtle fishery in Ecuador (Cornelius, 1991; Cornelius, et al., 2007). Although hunting of adult ridleys in Ecuador and Mexico fisheries ended by 1990 (Valverde, et al., 1998), incidental capture in Central American shrimp trawls was still high because few operators used turtle excluder devices that reduce mortality of captured turtles (Arauz, 1995, 2000). Orrego and Morales (2002) undertook a study of natural and anthropogenic causes of mortality on olive ridleys in Costa Rica. They conducted necropsies on 93 dead turtles and found that 73 of 93 (78.5%) died from anthropogenic causes, such as capture and forced immersion by shrimp nets, entanglement in nylon lines and/or hooks, cranial traumas, boat strikes and slaughter to harvest eggs and meat for consumption. The remainder 20 of 93 (21.5%) died from natural causes such as sharks, crocodiles, and coyotes.

There are many cases where intensive harvesting of ridley eggs has resulted in population declines, such as in Suriname, Nicaragua, and possibly Panama. Also, there are many solitary nesting beaches with intensive harvesting in Central America, Myanmar, Malaysia, and elsewhere in the Indian Ocean. Egg harvests contributed to the collapse of the olive ridley arribada populations on the Pacific coast of Mexico and the current downward trend in Orissa, India (Cornelius, et al., 2007). Thus, anthropogenic factors appear to be the primary causes of population declines in the olive ridley turtle.

The situation in Costa Rica

In Costa Rica in 1970 aerial surveys showed that there were two massive arribada beaches, Playa Nancite and Playa Ostional (Richard and Hughes, 1972 and Cornelius, 1986). Each one now has a management category and is administrated by the Ministry of Environment and Energy (MINAE). Turtles on Playa Nancite have been protected from direct consumption of adults and eggs since the formation of Santa Rosa Park in 1971. In 1980 a research study estimated that the total number of turtles nesting on Nancite was in excess of 300,000 (Cornelius, et al., 2007). That number declined to 37,123 turtles in arribadas in the 1990 nesting season and was 44,189 in 1991 (Plotkin, et al., 1997; Honarvar, et al., 2008). The number in 2006 was about 5,000. Thus, Nancite underwent a major population decline over this period (Valverde, et al., 1998). According to Fonseca et al. (2009) there was a downward trend in the abundance of the arribada at Nancite from 1971-2007, but the population was stable.

The first arribada recorded by scientists at Ostional occurred at the end of the 1960’s (Cornelius, et al., 1991). The Ostional National Wildlife Refuge (ONWR) was established in 1983 to conserve and preserve the nesting habitat of sea turtles, and in particular the olive ridley. So in contrast, and paradoxically, to Nancite that is free of human exploitation, Ostional has been inhabited for many years and the human population has increased from about 50 inhabitants in 1980 to almost 600 inhabitants, with at least 120 families depending on egg harvesting as subsistence in 2007 (ADIO, et al., 2007). Exploitation there has taken place since the 1970’s. Monitoring of olive ridley nesting females at Ostional suggests that the olive ridley population is declining (Valverde, et al., 2012).

Arribada nesting behavior at Ostional

Playa Ostional is one of nine known arribada beaches in the world and the second largest (NMFS and USFWS, 1998). Since 1980 the arribada nesting of olive ridleys at Ostional has been monitored by Universidad de Costa Rica (Cornelius and Robinson, 1985). An arribada is recorded as a time when at least 100 turtles are nesting synchronously over one kilometer of beach in one night (Cornelius and Robinson, 1985; Cornelius, et al., 1991; Valverde and Gates, 1999). Two hundred and ninety four arribadas occurred during the period 1971-2006 (ADIO, et al., 2007). Since 1990 there has been a tendency for an increase in frequency of arribadas, particularly in the rainy season and reduced internesting time during the same reproductive year (ADIO, et al., 2007; ADIO, et al., 2012; Cornelius, et al,. 2007). The number of arribadas per year varied from 7-16 with an average of 10.8 ± 2.2 annual events with a duration of between 1-14 days. Generally there was one arribada per month with a duration between re-nesting of 30.9± 14.7. Sometimes in July and August there were two arribadas per month and often there was at least one month during the year with no arribada nesting activity recorded (ADIO, et al., 2007; ADIO, et al., 2012).

For example, during 2007 the arribada size varied greatly between seasons, in the dry season (14,432 ± 7,822) and wet season (164,940 ± 143,287). Arribada nesting frequency was greater in wet season. Unfortunately, the arribadas of August and September were not recorded. However, tracks in different nesting areas of the beach suggested that the numbers were similar to July and November arribadas (Chaves, 2007).

Harvesting eggs at Ostional

To provide benefits to the community of Ostional, the Ministry of Environment and Energy (MINAE) and Fish and Aquaculture Institute of Costa Rica (INCOPESCA) authorized the Ostional Development Association (ADIO) to use olive ridley turtle eggs as a way of subsistence (consumption and selling) by Executive Decree # 28203, published on November 30, 1999. It was based on law Nº 7064 for promotion of farming production (FODEA), published in the Gaceta, an oficial newspaper from the Costa Rica Government on May 8, 1987. The decision to allow harvesting of olive ridley eggs was based on the results of social and biological studies performed by the University of Costa Rica (Cornelius, 1991; Chaves and Morera, 1987, 2003; Orrego, 2008). At Ostional, the large number of olive ridley females arriving at the nesting beach resulted in large numbers of nests being destroyed by subsequent nesting events, so there was a significant loss of eggs during every arribada event. The MINAE decided that this situation justified egg harvesting, because if eggs were not collected they would be destroyed by later nesting females (Cornelius and Robinson, 1985; Cornelius, et al., 2007; Campbell, 2007; NMFS and USFWS, 1998). In addition, studies of hatching success indicated that Nancite had a lower hatching success rate than Ostional (Cornelius, et al., 1991; Arauz-Almengor and Mo, 1994). However, there have been no scientific studies of hatching success at Ostional and it is not known if harvesting in Ostional actually increases hatching success (Cornelius and Robinson, 1985). To date, it is not clear that the harvest improves hatching success or increases the number of hatchlings produced on the beach. In addition, during the dry season eggs may not have an optimum microenvironment for embryonic development because the sand is too dry and the incubation temperature too high (Valverde, 1999; Valverde et al., 2010).

In Ostional legal harvesting is permitted on the main nesting beach during the first 36 h of an arribada, mainly in the wet season because arribadas are larger in the wet season than in the dry season. Egg collection occurs under supervision of a biologist. The work is distributed among all members of ADIO. This includes any woman or man who has been resident in Ostional and who is over the age of 15. After harvest, eggs are stored in a communal building where eggs are packaged in bags of 200. A commercial bag of eggs from Ostional is sold by the ADIO for 11,000 colones (October 22, 2014 1$=541. 45 colones), equivalent to $20.31.

In general, the commercialization of eggs in Ostional is based on the fact that a large number of eggs are destroyed during arribada nesting and that the egg harvest provides an important source of income to the Ostional community (Alvarado, 1990). Moreover hatching success in Ostional is usually below 15%, which is very low when compared with almost 90% for olive ridley eggs at solitary nesting beaches (Reichart, 1993). Although the final cause of this low hatchling success is unknown, it may be a result of the large number of eggs destroyed in an arribada, which produce a high amount of organic matter that may serve as a substrate for microorganism growth, thus leading to a significant decrease in oxygen availability for embryo development (Cornelius and Robinson, 1985; Cornelius, et al., 1991; Cornelius, et al., 2007; Valverde, et al., 1998; Valverde, 1999; Clusella Trullas, et al., 2007, Honavar, et al., 2008., Brenes, 2013). For example, Playa Nancite has a large microbial community that is thought to be sustained by the availability of organic matter (Mo, et al., 1990; Mo, et al., 1995). Moreover, these microorganisms may also negatively impact fertile eggs by causing disease during the incubation period (Phillott and Parmenter, 2001a, b; Clusella, et al., 2007; Honarvar, et al., 2008; Brenes, 2013).

In Ostional the frequency of occurrence and duration of arribadas is increasing. However, the size of the nesting population in Ostional is decreasing (Valverde, et al., 2012). In addition, other variables may play a role in the current status of the Ostional nesting population, including the possible exchange of adult females from Nancite beach to surrounding beaches, such as Ostional (Cornelius and Robinson, 1986).

Demographic parameters for olive ridley population in arribadas are largely based on biased or inadequate methodology and /or weakness in the counting methodology (Valverde, et al., 1998; Valverde and Gates, 1999; Ballestero, et al., 1998; Hope, 2002). The current status and recovery of olive ridley can only be assessed using monitoring of demographic variables, and employing robust and consistent statistical methods for data analysis (Carr, 1980; Meylan, 1982; NRC, 1990). As a result, it is necessary to conduct further studies about the effects of olive ridley egg harvesting during arribadas on hatching success and hatchling production to develop an improved understanding of population status of the turtle and the effect of harvest of eggs on the long term viability of the population (Chacon and Arauz, 2001; Cornelius, et al.; 2007).

Valverde (1999) compiled all recommendations from academic institutions, government and international conservation organizations and scientists for addressing these Ostional problems. Those recommendations offered research based solutions toward biological issues to the maintenance of the olive ridley population, and organizational issues to consolidate the egg harvest program. The biological relationship between hatching rate and extraction needs to be determined since it is unknown whether the harvest of eggs impacts hatching success, though unpublished reports have suggested that hatching success increases due to egg collection (Cornelius and Robinson, 1985; Valverde, 1999). Also it is important to develop tools to evaluate the impact of the egg harvest on the maintenance of the adult population, in particular a methodology that permits establishing the relationship between the size of the egg harvest and the size of the nesting population at a time when the hatchlings would become mature adults. Evaluating hatching success and its relationship to temporal and spatial distribution of clutches will be useful in making management decisions in Ostional. Cornelius, et al. (1991) suggested that to implement a project of rational use of sea turtle eggs it is necessary to develop an efficient inter-institutional coordination between the administrative and operative entities of ONWR. Finally, the role of government in addressing the problems at ONWR needs to be clarified.

Objectives of the thesis

The overall purpose of this thesis was to develop an understanding of the applied biology of the nesting arribada at Playa Ostional in Costa Rica and Playa La Flor and Playa Chacocente in Nicaragua to determine if the harvest was of benefit to the turtle population and to assess the effectiveness of the participatory management program at the ONWR. To understand the biology of the arribada and to design the most effective conservation and management strategies for a successful program for sustaining the olive ridley nesting population in the ONWR this research project sought to answer the following questions:

1. How many olive ridley turtles nest on Ostional beach?
2. What are the spatial and temporal differences in nest locations/density on Playa Ostional?
3. What are the effects of natural and anthropogenic factors on clutch survival?
4. Does hatching success vary spatially and/or temporally on Playa Ostional?
5. Does hatchling production vary spatially and /or temporally on Playa Ostional?
6. Is there a relationship between nest density and hatching success?
7. Does egg harvesting increase hatching success and hatchling production?
8. How do the answers to these questions at Ostional compare to answers to the same questions posed at other arribada beaches with smaller arribadas?
9. Do participatory environmental management and community-based conservation provide a successful strategy for management of the Ostional National Wildlife Refuge?

Chapter 1 of the thesis addresses the first seven questions at Playa Ostional for the 2009 and 2010/2011 arribada seasons. Chapter 2 answers question 8 by addressing questions 1-7 for Playa La Flor and Playa Chacocente in Nicaragua and for Playa Ostional for the 2010 arribada season. Chapter 3 reports on the results of a case study of the participatory management program at Ostional. Finally, chapter 4 compares the findings of the previous chapters and makes management recommendations for the future of the Ostional, La Flor, and Chacocente wildlife refuges in Central America.

List of References

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CHAPTER 2: ANTHROPOGENIC, NATURAL, SPATIAL AND TEMPORAL FACTORS AFFECT HATCHING SUCCESS OF OLIVE RIDLEY ARRIBADA CLUTCHES AT OSTIONAL

Abstract

Harvest of olive ridley eggs is common at arribada beaches around the world and is implicated in the decline of many such populations. For example, the olive ridley population at Terengganu, Malaysia declined precipitously from thousands of annual nests to only a few dozen due to long-term overharvest of eggs. The decline in Mexican and Central American olive ridley populations were attributed to egg harvest and capture in fisheries. Up to 100 % of olive ridley eggs were colllected from beaches in the Gulf of Fonseca, Honduras since 1940. Even where egg harvest is legal enforcement of regulations is uneven and in some places totally ignored. For example, at Chococente and La Flor in Nicaragua egg-harvest quotas were based more on demands of the local market than on the conservation needs of the turtles leading to chaotic, illegal egg collection and discusses the socioeconic aspects of egg harvest in Pacific Central America and concludes that communities involved in the use of olive ridley eggs are marginalized economically and that there are little opportunities for income substitution.

The results of this study indicate that hatching success and the production of hatchlings is controlled by spatial, temporal and environmental factors. Density of eggs did not have a significant effect on hatching success or hatching production. There was a strong tendency for plots open to harvest, dogs and poaching to have a higher hatching success, but not a higher hatchling production. Therefore, the egg harvest program at

Ostional did not improve hatchling production, but also did not reduce it. Given the historic decline in hatchling production at Ostional it is now apparent that the beach is no longer producing enough hatchlings to replace the adult population through time. Therefore, we expect that there will be a sharp decline in the population through the lifetime of the current adult population. To help to ensure the stability of the population it is necessary to produce as many hatchlings as possible from the beach and to reduce at sea mortality of the turtles. Spatial and temporal management measures should include systematic and long-term monitoring of arribada parameters and large-scale experiments on the effect of sand cleaning on hatching rates, and hatchling production. It is not practical to eliminate the harvest at Ostional because the harvest provides important income for the members of ADIO. However, the legal harvest can be restricted to the dry season when eggs typically die from heat and lack of water. In the wet season harvest can be restricted to eggs that are on the surface of the sand due to digging by turtles and eggs that are in danger of being washed away by the estuaries and tides. At the same time the members of ADIO can work with volunteers to relocate eggs to clean sand to improve hatching success. The volunteers and tourists can pay to assist them in this activity, thus beginning an ecotourism business. There should be no new development at Ostional nesting beach because it will cause an increase in disturbance to the arribada and an increase in impact from people and dogs. The area of sector 1 from this study should be kept free of anthropogenic effects because it has the highest rate of hatching success and hatchling production. The negative effect of dogs is much greater than the effect of legal harvest. A control program is necessary to educate people about the impact of dogs, remove dogs from the wildlife refuge and, if necessary, to euthanize dogs that cannot otherwise be removed. It may require interinstitutional strategies to eliminate the effect of dogs and poaching on the beach. Strict enforcement of controls against dog predation and poaching such as permanent patrolling from MINAE, ADIO and police over the whole beach is necessary as a start to the dog and poaching control process. Harvest justifies and increases poaching of olive ridley and other sea turtle eggs throughout Costa Rica, so an evaluation of what to do about the harvest has to take into account not only the impact of the harvest on the arribada population at Ostional, but also the impact on conservation of sea turtles in the country as a whole, and finally the impact on the local people who rely on the harvest for a portion of their income. Finally MINAE should coordinate with National Service of Guard Coast to implement an integral strategy to protect the marine coastal area and reduce the at sea mortality of olive ridley in bycatch on longlines, in trawls and in nets.

Introduction

Sea and freshwater turtles are among the most at risk groups of vertebrates for extinction, and one of many threats to turtle populations is high levels of predation of egg clutches (Gibbons, et al., 2000; Spotila, 2011; Welicky, et al., 2012; Riley and Litzgus, 2014). Different animals prey upon turtles nests, including mammals, birds, reptiles, and invertebrates (Ernst and Lovich, 2009; Riley and Litzgus, 2014). Predation is an important cause of egg and hatchling mortality of endangered sea turtles (Leighton, et al., 2010), and recent data suggest that survival of eggs and hatchlings is important for population recovery (Leighton, et al., 2010). Studies of turtle nest predation show that most predation events occur during the first week after egg laying. The high peak of predation after ovoposition occurs because cues alerting predators to the presence of a nest are most prominent at this time (Leighton, et al., 2010; Riley and Litzgus, 2014). These cues include olfactory stimuli (e.g the scent of oviposition fluid) (Spencer, 2002), presence of female turtles (Eckrich and Owens, 1995), and soil disturbance (Riley and Litzgus, 2014). Spatial and temporal nest location also has an important role in egg predation (Leighton, et al., 2010), as well as in hatching success and hatchling production.

Another predator of turtle eggs is the human. In some areas humans collect, legally or illegally, many eggs from turtle nesting beaches (Nietschmann, 1975; Cornelius, et al., 2007; Valverde, et al., 2012). In Costa Rica humans illegally collect (poach) eggs from most unprotected sea turtle nesting beaches (Santidrián Tomillo, et al., 2008; Santidrián Tomillo, et al., 2014; Blanco, et al., 2012), and at Ostional beach in

Guanacaste legally collect large numbers of eggs from olive ridley (*Lepidochelys olivacea*) nests during large scale nesting events called arribadas (described below) (Cornelius, 1982; Cornelius and Robinson, 1985; Campbell, 2007; Valverde, et al., 2012). Based on low hatching success at Playa Nancite, a protected arribada beach in Guanacaste, and the high densities of clutches there (Fonseca, et al., 2009; Honarvar, et al., 2008) unpublished claims have been made by local biologists that such egg removal actually improves hatching success on the beach, although quantitative data are lacking to support those claims.

The olive ridley turtle and Kemp's ridley turtle (*Lepidochelys kempii)* are two sea turtle species that are characterized by three different types of reproductive strategies within a given population, namely, a number of females nest solitarily, some nest gregariously in synchronized emergences, and some utilize a mixed strategy (Bernardo and Plotkin, 2007). These synchronized emergences are called, in Spanish, "arribada" or "flota". An arribada consists of hundreds to thousands of female sea turtles nesting at the same time on a beach during a period of several days. This phenomenon was first documented by Andres Herrera in a film taken at Rancho Nuevo, Mexico in 1947 of a Kemp's ridley sea turtle arribada in which approximately 40,000 turtles came on shore (Hildebrand, 1963). Arribada nesting is the most important form of olive ridley nesting since the vast majority of clutches are deposited during arribadas.

There are only a few nesting beaches in the world where olive ridleys still nest in arribadas (Cornelius, et al., 1991). Major arribada nesting beaches are in Costa Rica (Playa Ostional and Playa Nancite), Mexico (La Escobilla), and India (Gahirmatha).

Minor arribada nesting beaches are in Nicaragua (Playa Chacocente and Playa La Flor), Panama (Isla Caήas and La Marinera), Mexico (Ixtapilla) and India (Playa Barunei River) (Spotila, 2004). Generally, olive ridley females lay two clutches of eggs per reproductive year, remaining near shore for approximately one month between nesting (Plotkin, et al., 1994). The mean clutch size of females differs significantly from beach to beach. For Mexican populations the average clutch size is 105 eggs, and sizes for the two nesting beaches in Costa Rica are 107 for Playa Ostional, and 100 for Playa Nancite (Marquez, 1990 and Cornelius, et al., 1991).

On certain arribada beaches, hatching success is often so poor that the value of these beaches for sustained recruitment to the adult population has been questioned (Cornelius, et al., 1991; Cornelius, et al., 2007; Honarvar, et al., 2008). The high egg mortality is largely due to very high density of nesting during arribadas, when the turtles themseles physically disturb 20% to 40% of deposited clutches. If there are successive arribadas before the end of the incubation period, these result in additional disturbances of in situ nests. Further mortality may occur as a result of proliferation of fungi and bacteria, reduced O_2, increased CO_2 from microbial respiration, and increased sand temperature, that limit embryo development (Cornelius, et al., 1991; Cornelius, et al., 2007; Valverde, et al., 1998; Wallace, et al., 2004; Clusella Trullas and Paladino, 2007; Honarvar, et al., 2008; Brenes, 2013). Arribada beaches may lose quality as optimal nesting beaches over time, such that some beaches may only constitute temporary nesting habitats (Bernardo and Plotkin, 2007)

In Costa Rica, aerial surveys carried out during 1970 showed that there were two massive arribada beaches: Nancite and Ostional (Richard and Hughes, 1972; Cornelius, 1986). Each beach has a different management category and is administrated by the Ministry of Environment and Energy (MINAE). Playa Nancite has been protected from direct consumption since 1972 (Cornelius, et al., 2007). At Playa Nancite, up to 37,000 turtles nested there in arribadas during the 1990 nesting season and 44,000 in 1991 (Plotkin, et al., 1997), but only about 5,000 turtles nested there in 2006 (Honarvar, et al., 2008). Thus, Nancite underwent a major population decline (Valverde, et al., 1998). Fonseca, et al. (2009) did a meta-analysis of published data from 1971-1997 on the number of nesting females per arribada, adding new estimate of arribada size using a strip transect method. Their conclusion confirmed that the Nancite arribada population underwent a significant decline over 36 years and seemed to have arrived to a stable low point.

The first arribada recorded by scientists in Ostional occurred at the end of the 1960’s (Cornelius, et al., 1991). The Ostional National Wildlife Refuge (ONWR) was established in 1983 in order to protect the nesting habitat of sea turtles, and in particular of the olive ridleys. In contrast to Nancite that is free of human exploitation, Ostional turtle eggs have been subject to direct consumption for subsistence since at least 1970. Ostional has been inhabited for many years and the human population has increased from about 50 in 1980 to almost 600 inhabitants in 2012, with at least 120 families depending on egg harvesting for their subsistence (ADIO, et al., 2007, 2012). Recent monitoring of olive ridley nesting females at Ostional suggests that the olive ridley population is decreasing (Valverde, et al., 2012).

Playa Ostional has 7 km of available nesting area; however, arribadas primarily occur along 900 m of the beach in an area called the Main Nesting Beach (MNB) (Chaves and Morena, 2003; Chaves, 2007; personal observation 2000-2014). Olive ridleys are space limited when it comes to their nesting location because they concentrate in this small area. This could be due to optimal sensory conditions to nesting between estuaries (Robinson, 1987) and/or it could be because this area is still undeveloped. Thus, nest destruction at Ostional is a density-dependent disturbance that results from a lack of space. Arauz (1995) cited by Honarvar, et al. (2008) suggested that these populations may have reached the "local egg-carrying capacity in the sand", which could also lead to long-term declines. However, the impacts of these disturbances on the population dynamics of olive ridley arribada behavior in Ostional are as yet unknown.

Studies of hatching success indicate that Nancite has a lower hatchling success rate than Ostional (Cornelius, et al., 1991; Arauz-Almengor and Mo, 1994). Additional studies are needed to determine whether harvesting in Ostional increases hatching success (Cornelius and Robinson, 1985).

Objectives

The purpose of this study was to improve our understanding of anthropogenic, natural, spatial and temporal factors that affected hatching success of olive ridley arribada clutches at Ostional, as a contribution to the design of a more effective conservation and management plan for olive ridleys in the ONWR. Specifically, this research sought to answer the following questions:

1) How many olive ridley turtles nested on Ostional beach from 2009 to 2010/2011?
2) What are the spatial and temporal differences in nest locations/density on Playa Ostional?
3) What are the effects of natural and anthropogenic factors on clutch survival?
4) Does hatching success vary spatially and/or temporally on Playa Ostional?
5) Does hatchling production vary spatially and /or temporally on Playa Ostional?
6) Is there a relationship between nest density and hatching success?
7) Does egg harvesting increase hatching success and hatchling production?

Methods

Ostional National Wildlife Refuge

Ostional National Wildlife Refuge (ONWR) was established in 1983. It is limited to a small area in the Guanacaste Province of Costa Rica (from 85 43’50” W. 10 01’00’ N to 85 40’40” W. 09 54’30”N), corresponding to the marine-terrestrial zone (MTZ) of Ostional, Nosara, Peladas and Guiones beaches. The total area of Ostional Refuge was 13,390 km^2 with 12,875 km^2 in the ocean and 515 km^2 on land. The land portion consisted of a thin area 200 m wide and 19 km long and associated wetlands (Figure 2. 1). The ONWR was in the life zone of the basal humid rain forest transitioning to dry forest. The dry season lasted from December to April and the rest of the year was the wet season. The annual mean precipitation was 2,100 mm and the annual mean temperature was 27.5 °C (22 to 33 °C) (Barrantes, et al., 1985).

Arribada nesting behavior only occurred in the Ostional and Nosara areas inside ONWR within 7 km that were marked every 50 m between two points, post 1 in the north "Punta India " and post 140 at south, the Nosara River Mouth. The other beaches provided conservation, recreation (surfing, swimming, etc.) and ecosystem services to local residents and visitors.

Ostional was a very dynamic beach that changed in the size of the berm or sand dune, in its slope and in presence of flora (Chaves, 2007). There were several estuaries and mouths of streams and rivers (Cornelius and Robinson, 1985). The flora along the beach included almond trees (*Terminalia catappa*), majagua (*Hibiscus tiliaceus*), columnar cactus (*Stenocereus aragonii*) and beach vine (*Ipomoea pes caprea*). Vegetation was dominated by the spiny *Bromelia pingui* that was used by people for building fences. In the wet season the mouths of the estuaries created dunes more than 2 m high in different sectors of the beaches and sometimes the estuaries opened with connection to the sea.

Study Area

Ostional hosted one of the largest arribadas in the world. The beach had an available nesting area of approximately 19,000-52,000 m^2, which changed due to erosion, run off and tidal influence. Ostional was divided into 7 zones of nesting from Punta India (North) to the Nosara River (South): Rayo1 (approximately 850 m, posts 1-17), Rayo 2 (approximately 550 m, posts 18-29), Rayo 3 (approximately 500 m, posts 30-40), Rayo 4 (approximately 900 m, posts 41-59), Main Nesting Beach (MNB, approximately 900 m, post 60-78), Nosara 1 (approximately 2300 m, posts 79-125), and Nosara 2 (approximately 700 m, posts 126-140). The MNB had the greatest nesting activity. It was free of human development and was located between two estuaries. That was where most activity took place: arribadas, harvesting, hatching, tourism visitation, research, and management. However, the trend from 1992 to 2012 was that there was a shift to other parts of the nesting beach where the frequency of arribadas increased (Cornelius, et al., 1991; Ballestero, et al., 1998; Chaves, 2007). The village of Ostional was located along Rayo 4 sectors 45 to 59 (ADIO, et al., 2007). There were two estuaries that during the wet season often broke through the beach into the ocean as result of heavy rains, and destroyed many turtle clutches**.** Based on previous studies I established three sectors on the beach for my study with a total of 2,800 m : Sector 1 (included Rayo 2 and 3, posts 20-40 approximately 1000m) , Sector 2 (included Rayo 4 approximately 950 m posts 41-60) and Sector 3 (included MNB approximately 850m, posts 61-78) (Figure 2.2). The MNB accommodated most of the turtles and I set up the other sectors due to the relatively lower abundance of nesting in them, with sector 1 having typically the lowest nesting.

Arribada nesting activity

I used the concept of Valverde, et al. (1998) to declare an arribada as the presence of 100 or more nesting olive ridley females on the beach at any time during a nesting session. I only counted turtles that displayed egg-laying activity, so a turtle was equivalent to one clutch. From April 2009 through March 2011 I estimated the arribada size using the strip transects in time method (Gates, et al., 1996; Valverde and Gates, 1999).

Experimental Plots

I defined three beach zones from vegetation to the sea: zone 1- high beach (vegetation), zone 2- mid beach (open sand), and zone 3- tidal (below the high tide line) (Figure 2.3). From April 2009 to March 2011, during each arribada, I placed 6 plots (2 x 2 m) in each zone making 18 plots in each Sector. Three plots in each zone were "open plots" and three were "closed plots" (Figures 2.4 and 2.5). Open plots were unprotected and exposed to predators and egg collecting. Closed plots were fenced to keep out predators and humans. I marked each "open plot" in the nesting area by using four small posts, one in each corner of the plot (Figure 2.4). The "closed plots" were surrounded with a wire fence of 3 cm x 3 cm mesh, 8 m long x 1.5 m high. (Figure 2.5). I marked study nests inside of each plot with a numbered 30-cm-long plastic flagging tape within the nest chamber before the turtle finished nesting (one color for each arribada).

Plot monitoring

I started monitoring plots on day 2 of the incubation process and continued until the end of incubation for each arribada (day 55). I inspected each plot four times/ day (06:00, 12:00, 18:00 and 00:00 h) and recorded: plot number; sector; zone; sand temperatures at 35 cm in depth for each plot (Valverde, et.al., 2010); presence of new nests and false nests (when a sea turtle came to the beach but did not nest); predation and/or loss of eggs by insect larvae or vertebrates such as dogs (*Canis familiaris*) and raccoons (*Procyon lotor*); erosion; harvest; encroachment of an open estuary; poaching activities; nesting turtles; and other general observations relevant to the incubation dynamics. The presence of a flagging tape on the surface of the sand during or after an arribada was an indication that the nest was destroyed by other nesting females. If the flagging tape was found at any other time, checked the area for tracks to see if the clutch was destroyed by predation, poaching, and /or erosion from tidal action or an open estuary. Legal harvest data from open plots came from ADIO during each arribada.

Excavations and hatching rate

I excavated all plots 55 d after oviposition. I dug to 70 cm deep in each plot that remained until the end of incubation, removed all egg shells and hatchlings, and took a sand sample from the center of each plot at 35 cm to analyze for organic matter (Valverde et al., 2010). Excavation data for each plot included number of: a) empty shells (the criterion used was > 50% shell - 1 egg) , b) dead and live hatchlings, c) emerged hatchlings, d) eggs with or without apparent embryo development, and e) neonates that were predated by worms, beetle larvae, and larvae of flies. Eggs were classified into embryonic development stages according to Ackerman (1997) and Chacón, et al. (2007): Stage 0 (no apparent embryonic development), stage I (embryo filled 1- 25% of amniotic cavity), stage II (26-50%), stage III (51-75%), stage IV (76-100%), and stage V (empty eggs shells from hatched turtles). However, to facilitate my control on the plot production, I included an additional stage that put together all neonates depredated on by worms, beetle or fly larvae and defined this as Stage V. Thus the former Stage V (empty eggs shells, from hatched turtles) became my Stage VI. I calculated hatching rate for each surviving plot (escaped from natural or anthropogenic cause of egg loss) as follows:

Hatching rate (%) = Number of Empty Egg Shells) x 100 / (Total Number of Eggs)

Hatchling production

I estimated hatchling production, for each arribada, from April 2009 to March 2011 for each plot by zone and sector of the beach during excavations. I calculated percent hatchling emergence based on observations from marked plots. I estimated proportion of clutches destroyed by predation, erosion, open estuaries, subsequent nesting females, poaching activity, harvest, and other causes. I estimated number of successful clutches (clutches with at least one hatchling emerged). Percent emergence was calculated according to the formula:

$$E = N \times 100 / H$$

where E is the percent emergence, N is the number of emerged hatchlings, and H the number of eggs per clutch.

I estimated the total of nesting area for each sector by arribada (changed due to erosion and accretion of sand), calculated the hatchling production for each sector based on the production per m^2 and extrapolated those data into the total nesting area available for each arribada at Ostional. The beach had a nesting area of approximately 19,000-52,000 m^2, which changed over time from erosion, run off and tidal influence.

Natural or anthropogenic causes of eggs loss

I estimated the proportion of clutches destroyed by natural causes (sand erosion-high tide, opened estuaries, raccoon predation and nesting turtles) and by anthropogenic causes (harvest, poaching or dog predation).

Morphometric measurements

For each arribada I selected at least 30 turtles to take morphometric measurements such as curved carapace length (CCL) and curved carapace width (CCW), total eggs/turtle, and time spent laying eggs.

Statistical analysis

I tested for homogeneity of variance with Cochran's C test. I used parametric, two and three way ANOVA to estimate differences between means. I used parametric, three-way ANOVA to estimate differences in mean hatching success by beach zone, plot type (open or enclosed), blocking on individual plots. I used two-way ANOVA to estimate differences in mean number of eggs lost by nesting activity between beach zone and sectors.

I used General Linear Models (GLM) to test for differences in mean: a) hatching success between beach zones and sectors; b) number of total of eggs laid between zones and sectors; c) number of hatchlings (Stage VI) produced between zones and sectors; d) number of hatchlings (Stage VI) produced between zones and types of plots (open or enclosed); e) number of hatchlings (Stage VI) produced between sectors and types of plots (open or enclosed). A posteriori comparison between means were carried out with

Least Significant, Tukey or Scheffe tests. Statistical procedures followed Sokal and Rohlf (1995). Statistical analysis was completed with Statgraphics Centurion XV 15.1.02 sofware by (Statpoint Tecnologies, Inc.).

Results

General Information

There were 10 arribadas at Ostional during the study period, five in 2009, an El Niño year, with a total of 231,896 nesting females, (Table 2.1) and five in 2010/11, a La Niña year, with a total of 489,940 nesting females (Table 2.2). These data were published in Valverde, et al. (2012).

From April 2009 to March 2011, I placed 414 plots among the three sectors of the beach during ten arribadas. There were 180 plots in 2009 between posts 40-78 (Sector 2 and 3), because the arribadas did not occur in sector 1. In 2010/11there were 234 plots, between posts 20-78 (Sectors 1, 2, and 3). In the fifth arribada turtles only nested in sector 3, the main nesting beach. I monitored a total of 5,211 study clutches in the 414 plots. There were 2,344 clutches during 2009 (45.0%) and 2,867 clutches during 2010/2011 (2867 = 55.0%). There was an average of 95 eggs per clutch (n = 978; range = 2 – 193; SD = 2,1363), so there were 222,680 eggs laid in 2009 and 272,365 eggs laid in 2010/11 in the experimental plots. There were 209 (50.5%) open plots and 205 (49.5%) closed plots with their incubation dynamics.

I used a General Linear Model to investigate the effect of zone and sector on the number of eggs laid. The ANOVA indicated that the model was statistically significant (df = 3, 395; F = 3.49; p = 0.0159). A second ANOVA indicated that the main effect was sector (df = 1, 395; F = 8.50; p = 0.0038) and that the interaction of zone and sector was also significant (df = 1, 395; F = 5.89; p = 0.0157). There was a trend for zone to also have an effect and it was marginally significant (df = 1, 395; F = 3.78; p = 0.0527). The largest number of eggs was laid in zone 1 of sector 3 and the smallest number of eggs was laid in zone 1 of sector 1 (Figures 2.6, 2.7).

Natural and anthropogenic clutch loss

Of the 5,211 marked clutches, 2,141 (41.1 %) were lost to natural and human causes, 912 in 2009, and 1229 in 2010/2011. A total of 1,404 study clutches were lost due to natural causes (65.6% of losses), 668 in 2009 and 736 in 2010 (Table 2.3). Most of them were lost due to erosion and opening of estuaries and nesting activity. Erosion from opening of estuaries and high tides destroyed 51.8 % of clutches lost due to natural causes. In 2009, 60.7 % of clutches lost to erosion were in sector 3 and 75.0 % of clutches lost were from zone 3. In 2010/2011, 34.5% of clutches lost to erosion were in sector 1 and 31.0 % were in sector 3. Most clutches lost were in zone 3 (79.3 %) near the water. Erosion had the greatest effect in sector 3 followed by sector 2. Nesting activity had the greatest effect in sector 3 and zone 2 (Table 2.4).

Nesting females dug up 47.5% of clutches lost to natural causes. In 2009, 91.4% of clutches dug up were in sector 3 and 8.6% were in sector 2. In 2010 most of the clutches dug up were again in sector 3 (50.6%), 27.2% were in sector 1 and 22.2 % were in sector 2. Raccoons (*Procyon lotor*) dug up 0.7 % of clutches lost to natural causes. In 2009 all raccoon predation was in sector 2 and 50% of clutches lost to raccoons were in zone 3 near water. In 2010, 100% of clutches taken by raccoons were in sector 3 and zone 1. No clutches were destroyed by coati (*Coati mundi*), coyotes (*Canis latrians*), or other wild mammals. Crabs and avian predators also had an important role in removing eggs at Ostional once a nest was opened. Black vultures (*Coragys atratus*), turkey vultures (*Cathartes aura*), crested caracara (*Caracara cheriway*), frigatebirds (*Frigata magnificenses*), and chickens came to nests after they were dug up by dogs, raccoons, and people, or exposed by natural causes such as erosion due to open estuaries and tides, and nesting activity. Wood storks (*Mycteria americana*) and Black Vultures (*Coragyps atratus*) also foraged on emerging turtle hatchlings.

A Two Way ANOVA indicated that there was a statistically significant effect of sector (df = 2; 395; F=12; P = 0.0000) and zone (df = 2; 387; F = 4; P = 0.0282) on the excavation of clutches by nesting turtles (Figures 2.8, 2.9). Number of clutches excavated was lowest in sector 2 and zone 3.

Anthropogenic causes destroyed 737 study clutches (34.4 % of total losses), 243 in 2009 and 494 in 2010/2011 (Table 2.5). Dogs had the greatest impact, followed by legal harvest and poaching. Dogs destroyed 126 clutches in 2009 and 303 in 2010/2011 (58.2% of anthropogenic losses, but 8.2% of total clutches). Illegal harvest (poaching) by humans removed 75 clutches in 2009 and 40 in 2010/2011 (15.6 % of anthropogenic losses, but 2.2 % of total clutches). Legal harvest from open plots removed 42 clutches in 2009 and 151 clutches in 2010/2011 (26.2 % of anthropogenic losses, but 3.7% of total clutches). Dogs had the greatest impact in sectors 3 and 2 and were active in all zones. Poaching was greatest in sector 2 and in zones 1 and 2. Harvesting took place in all sectors. In 2009 it was greatest in zone 2 but in 2010/2011 it was evenly distributed in all zones (Table 2.6).

Embryonic Development

Of the 3070 clutches (58.9%) that survived natural and anthropogenic disturbance (1432 in 2009, and 1638 in 2010/11), there were 136,037 eggs (46.6%) in 2009 and 155,607 eggs (53.4%) in 2010/2011. Of those eggs 91.2 % showed no development; 1.2 % were stage I; 0.9% were stage II; 1.8% were stage III; 0.3% were stage IV; 1.2% were stage V; and 3.4% hatched (Table 2.7). Hatching success was 1.8% in 2009 and 4.9% in 2010-2011.

The spatial distribution of plots with successful clutches varied by zone and sector In 2009, 56 plots had successful clutches, 30 plots (53.6%) in sector 2, and 26 plots (46.4%) in sector 3; those plots were distributed by zone; 16 (28.6%) in zone 1, 22 (39.3%) in zone 2, and 18 (32.1%) in zone 3. In 2010/2011, 72 plots had successful clutches, 18 plots (25.0%) in sector 1, 20 plots (27.8%) in sector 2, and 34 plots (47.2%) in sector 3; those plots were distribuited by zone, 16 (22.2 %) in zone 1, 24 (33.3%) in zone 2, and 32 (44.4%) in zone 3 (Table 2.8).

Hatching Success

Of the 3070 surviving clutches (58.9%) (1432 in 2009, and 1638 in 2010), there were 136,037 eggs (46.65%) in 2009 and 155,607 eggs (53.3%) in 2010/2011. Of those eggs, 3.4% hatched. Hatching success was 1.8% in 2009 and 4.9% in 2010-2011. Hatching success was greater for zone 3 ($\bar{x}$ = 0.05 %) than for zone 2 ($\bar{x}$ = 0.02 %) and zone 1 ($\bar{x}$ = 0.01 %) (One Way ANOVA with Tukey multiple range test) (F =10.01; df = 2, 393; P = 0.0001) (Figure 2.10).

A three way ANOVA estimated the effects of zone and plot (open and closed) on mean hatching rate. There was a significant difference in hatching rate due to zone but not due to whether a plot was open or closed (df = 2, 395; F = 9.28, p = 0.0001). There was a strong trend for open plots to have higher hatching success than closed plots and the effect was marginally significant (df= 1, 395; F = 3.81, p = 0.0516) (Figure 2.11). When the variability in the statistical model was decomposed to show the effect of experimental plot the increased hatching success of open plots was clearer (Figure 2.11).

A Two Way ANOVA for hatching success indicated that there was a statistically significant effect of arribada and year on hatching success (F = 5.48; df = 4; 386; P = 0.0003) (Figure 2.12). Hatching success increased with the second and third arribada in 2010/2011 during the rainy season and hatching success in the third arribada was higher in 2010/2011 than in 2009. There was a trend for hatching success to be higher in the fourth and fifth arribadas in 2009 than in 2010/2011 but the confidence limits were high for most arribadas. A Two Way ANOVA indicated that hatching success was higher in the wet season than in the dry season in 2010/2011 (F = 7.23; df = 1, 392; p = 0.0075) (Figure 2.13). There was no statistical difference in 2009 between wet and dry season and no statistical difference in hatching success between the two wet seasons.

I used a General Linear Model (ANOVA) to investigate the interaction between zone and sector as it affected hatching success. The first ANOVA indicated that there was a statistically significant effect of zone and sector on hatching success (F = 9; df =

3;392; P = 0.0001) (Figure 2.14). A second ANOVA indicated that zone had the greatest effect (df = 1, 395; F = 15.2; p = 0.001), sector was also significant (df = 1, 395; F = 4.31; p = 0.0385) and the interaction of zone and sector was also significant (df = 1, 395; F = 7.23 and p = 0.0075). Hatching success was highest in zone 3 in sector 1 and lowest in zone 1 of sector 1. The effect of zone was the same in the other sectors, but was less extreme. The r^2 indicated that the model only expained 6.49% of the variability in hatching success. Therefore, there was considerasble variability due to other factors on the beach.

Hatchling production

Hatchling production in my experimental plots was 10,024 neonates, 2413 in 2009, and 7611 in 2010. The available nesting area calculated from the strip transect in time method was 268,325 m^2 in 2009 and 160,321 m^2 in 2010/2011. Taking into account hatchling production each year from each of my experimental plots in each zone and sector, I extrapolated to hatchling production for the entire Ostional nesting beach. Estimated hatchling production in 2009 was 349,983, and estimated hatchling production in 2010/2011 was 435,787. In another estimate of hatchling production I calculated the number of hatchlings produced by taking the number of clutches produced from the turtles counted in the transects, computed the total number of eggs laid based on a clutch size of 95, subtracted the number of eggs lost based on experimental measures of natural and anthropogenic clutch losses, and multiplied the number of remaining eggs by the hatching success from my study. In that estimate there were 241,890 hatchlings produced in 2009 and 1,302,262 hatchlings produced in 2010/2011. Based on these two estimates between 785,770 and 1,544,153 hatchlings were produced during 10 arribadas in the two years of the study compared to 2,410,402 hatchlings in 1984 from two arribadas (Table 2.9).

Hatchling production showed the same trend as hatching success (Figure 13) for the arribadas during the two years of the study. A Two Way ANOVA indicated that there was a statistically significant effect of arribada on hatchling production (df = 4,386; F = 3.13; P = 0.0149). The effect of year was marginally significant (df = 1,395; F = 3.69; P = 0.055) and the interaction of year and arribada was highly significant (df = 4, 386; F = 6.05; P = 0.0001). Hatching production increased with the second and third arribada in 2010 during the rainy season and was higher in the 2010/2011 rainy season than in the 2009 rainy season (Figure 2.15).

I used a General Linear Model (ANOVA) to investigate the interaction between zone and sector as it affected hatchling production. The first ANOVA indicated that there was a statistically significant effect of zone and sector on hatching production (df = 3, 395; F = 6; P = 0.0009) (Figures 2.16, 2.17). A second ANOVA indicated that there was a statistically significant effect of zone (df = 1, 395; F = 11.60; P = 0.0007), sector (df = 1, 395; F = 4.83; P = 0.0286) and the interaction of zone and sector ((df = 1, 395; F = 6.45; P = 0.0115). Hatchling production was highest in zone 3 of sector 1 and lowest in zone 1 of sector 1.

There was no statistically significant difference in numbers of hatchlings produced in open vs closed plots (One Way ANOVA on log transformed data, df = 1, 127, F = 0.48, p = 0.4902). There was also no statistically significant effect of number of eggs per plot on hatchling production. Thus, disturbance by turtles digging other nests and exposing plots to harvest, poaching and dogs did not affect hatchling production. In addition, density of eggs also did not affect hatchling production.

Discussion

Population status

More olive ridley turtles nested at Ostional beach in 2010/2011, a La Niña year (489,940) than in 2009, an El Niño year (231,896). Between 2006 and 2010 arribadas ranged in size between 3,564 and 476,550 nesting females (Valverde, et al., 2012). Contrary to previous studies (Cornelius, et al., 2007; Eguchi, et al., 2007), my data and those of Valverde, et al. (2012) indicate that there were large intra and interannual fluctuations in size of arribadas and no particular recent trend could be determined. Variation in arribada size appears to be related to climatic variation.

It is difficult to assess the historic trend in the olive ridley populations nesting at Ostional because there are few data published in the scientific literature and previous estimates in unpublished reports suffer from methodological problems (Valverde, et al., 2012). Universidad de Costa Rica has monitored arribada nesting at Ostional since 1980 (Cornelius and Robinson, 1985). Two hundred and ninety four arribadas occurred during the period 1971-2006 (Chaves, 2007; ADIO, et al., 2007). Between 1986 and 2006 there was a tendency for an increase in frequency of arribadas, particularly in the winter season and a reduction in internesting time during the same reproductive year (Chaves 2007; ADIO, et al., 2007; Cornelius, et al,. 2007). The number of arribadas per year varied from 7-16 with average of 10.8 ± 2.2 annual events with a duration between 1-14 days.

Generally there was one arribada per month with duration between re-nesting of 30.9±14.7 days. Unpublished reports of arribada estimates (Chaves-Cordero, 2002; Chaves-Cordero, et al., 2006) were not peer reviewed and had important methodological problems, such as counting turtles that were not laying eggs and maintaining set quadrates on the beach when the arribada moved to another section. Thus, some counts were overestimates and some were underestimates. The best indication is that between 1988 and 1997 the mean estimated nesting population was 588,501 and fluctuated between 232,318 and 1,147,969 turtles (Ballestero, et al., 1998). In this study population size fluctuated between 231,896 and 489,940. Thus, my results agree with those of Valverde, et al. (2012) that the nesting population at Ostional has decreased in abundance since that time. The decrease may be due to the low hatchling production on the beach (see below) and the effect of fishing pressure on the population. The Costa Rican longline fishery caught 699,600 olive ridleys, including 92,300 adult females from 1999 to 2010 (Dapp, et al., 2013).

The strip transect in time method (Valverde and Gates, 1999) of counting turtles during an arribada used in this study only counts turtles that are laying eggs and is the most statistically robust way to assess the population (Valverde, et al., 2012). In order to determine the trajectory of the population through time it will be necessary to continue counting turtles with this method for at least one turtle generation (13 years) (Avens and Snover, 2013) and then project the population into the future.

Eggs and hatchlings

During 2009 and 2010/2011 olive ridley turtles laid fewer eggs per clutch (95) at Ostional than they had in the past (107.4) (Cornelius, et al., 1991) and fewer eggs per clutch than for Mexican populations (105) and for Playa Nancite (100) (Marquez, 1990 and Cornelius, et al., 1991). However, recent data from Playa Nancite gave a clutch size of 95 (Honarvar, et al., 2008). It is not clear why this reduction has occurred. The number of eggs laid on Ostional beach varied by sector and zone. The greatest number of eggs was laid in Zone 1, near the vegetation, of Sector 3, the Main Nesting Beach, where most nesting took place. Hatching success, however, was highest in zone 3 of sector 1 and lowest in zone 1 of sector 1. Hatching success was highest in zone 3 followed by zones 2 and 1 of all sectors. Hatchling production mirrored hatching success. Hatchling production was highest in zone 3 of sector 1 and was highest in zone 3 as compared to zones 2 and 1 of all sectors. The high density of clutches in zone 1 of sector 3 was probably responsible for the low hatching success (see below). The large number of eggs laid in zone 1 of sector 3 meant that that area produced more hatchlings than zone 1 of sectors 1 and 2. The high productivity of zone 3 and sector 1was probably due to the fresh sand present there from frequent erosion and accretion of sand from high tides and openings of the estuaries and the limited number of clutches laid in sector 1. Cornelius, et al. (1991) also found greater hatchling production near the water and associated it with a positive effect of the wave wash.

Open experimental plots had a higher hatching success than closed plots, but the difference was only marginally significant ($p = 0.0516$). That suggests that removal of eggs by natural and anthropogenic forces, reducing density, may improve incubation conditions. However, there was no statistically significant difference in numbers of hatchlings produced in the two types of plots. There was also no statistically significant effect of number of eggs per plot on hatchling production. Thus, disturbance by turtles digging other nests and exposing plots to harvest, poaching and dogs did not affect hatchling production. In addition, density of eggs also did not affect hatchling production. Factors such as zone and sector appeared to play a more important role in controlling hatching success and hatchling production than whether a plot was open to harvest and other anthropogenic effects. More plots would be needed to determine whether removal of eggs by natural and anthropogenic factors would improve hatching success. The high variation in hatching success in plots due to other factors overwhelmed the effect of harvest since removal of clutches did not increase or decrease hatchling production. These results do not support the unpublished claims of local biologists that the egg harvest, by reducing egg density, would increase hatchling production. Arauz-Almengor and Mo (1994) also found that the egg harvest did not increase hatchling production as compared to areas with no harvest. Honarvar, et al. (2008) reported that olive ridley hatching success was higher (71.6 %) in low density (2 nests m^{-2}) and moderate density (5 nests m^{-2}) experimental plots on Playa Nancite than in high density (9 nests m^{-2}) plots (29.5%). However, hatchling production was similar in high (192 m^{-2}) and moderate (189 m^{-2}) density plots, but higher than in low (100 m^{-2}) density plots. In addition these densities were much lower than densities in plots at Ostional.

There was variation in hatching success for the different arribadas and that was probably due to the number of clutches deposited in an arribada, the amount of harvest and environmental factors. During small arribadas during the dry season almost all eggs were harvested (Valverde, et al. 2012) and at other times in the dry season high temperatures and drought killed all the eggs (Valverde, et al., 2010). Hatching success was highest in the wet season as opposed to the dry season in 2010/2011. Thus, environmental factors and sand quality played the key roles in controlling the number of hatchlings produced on Ostional beach.

Natural clutch loss

Natural causes removed 26.9% of experimental clutches. That was lower than the estrimate for Nancite (36.7 %) but higher than the estimate for Ostional (20 %) by Cornelius, et al. (1991). Erosion from estuaries and high tides removed 51.8% of clutches and nesting by other turtles destroyed 47.5% of the clutches lost to natural causes. Most clutches lost to erosion were in zone 3 of sector 3. Cornelius, et al. (1991) reported a similar loss due to erosion at Ostional. Losses from erosion are also high for leatherback turtle clutches at Tortuguero, on the Caribbean coast of Costa Rica (Leslie, et al., 1996) and at Sandy Point on St Croix in the US Virgin Islands (Boulon, et al. 1996). Both are high energy beaches where sand is often removed and redeposited during the nesting season. Nesting by other turtles at Ostional destroyed 47.5% of clutches lost due to natural causes. Not surprisingly most of the loss was in sector 3 where most of the clutches were laid, but was also high in sector 1. The effect of excavation by turtles was much lower in zone 3 than in zones 1 and 2. Losses from natural predators was minimal.

Racoons only removed 10 clutches in two years and other wild mammals had no effect. Birds and crabs removed eggs once nests were opened by people and dogs, or were exposed by erosion. Burger and Gochfeld (2014) also observed that wood storks and black vultures depredated eggs of disturbed nests and emerging hatchlings at Ostional.

Natural predators usually have a great effect on turtle clutches and in freshwater turtles can remove up to 84 % of eggs (Burke, et al., 1998). On many nesting beaches natural predators have a large impact on sea turtle nesting success (Heithaus, 2013). In northeastern Australia more than 90 % of nests were depredated by foxes before control measures were introduced (Limpus and Limpus, 2003). At Hobe Sound on the Atlantic coast of Florida racoons and armadillos (*Dasypus novemcinctus*) destroy up to 95% of sea turtle nests (Engeman, et al., 2006). In Turkey, foxes and golden jackals depredate up to 75 % of green turtle (*Chelonia mydas*) nests (Brown and MacDonald, 1995). At Nancite beach in Costa Rica natural predators including coatis, vultures, coyotes, and others destroy many olive ridley nests (Cornelius, 1986; Cornelius, et al., 1991; personal observation).

Anthropogenic clutch loss

Anthropogenic effects accounted for the loss of 34.4 % of experimental clutches at Ostional. Dogs had the greatest impact (58.2 %), followed by legal human harvest (26.2 %) and poaching (15.6 %). Dogs had the greatest impact in sectors 2 and 3. Sector 2 in front of the village and sector 3 received the greatest number of clutches. Poaching was highest in sector 2. On undisturbed beaches sea turtles transfer significant amounts of energy and nutrients to the terrestrial ecosystem by laying their eggs in the beach

(Bouchard and Bjorndal, 2000; Hannan, et al., 2007; Vander Zanden et al., 2012). Nutrients and energy are transferred into natural predators that in turn cycle it into the ecosystem. At Nancite predators come to the beach before an arribada waiting for the turtles to arrive and there is no anthropogenic clutch loss (Cornelius, 1986; personal observation). The abundance of eggs removed from the beach is an important supplement to the energy and nutrient balance of the populations affected, just as salmon return nutrients and energy to terrestrial ecosystems (Bouchard and Bjorndal, 2000). At Ostional that transfer has been short circuited and diverted to the human dominated ecosystem. Therefore, the natural ecosystem has suffered a loss of resources and that has undoubtedly affected populations of mammals, birds and other animals.

Hernandez (2011) assessed the ecological importance of olive ridleys in terms of energy transfer introduced into the nesting habitat. He quantified the energy and essential nutrients from fresh eggs and hatchlings found dead. Each clutch contributed 744.0 g of organic matter, 90.5 g of protein, 56.4 g of lipids, 13.2 g of carbohydrate, and 15,904.3 kilojoules of energy. Of the total energy put into the beach, 8.1% returned to sea as hatchlings and fresh eggs transported by erosion. Fly larvae and beetles consumed 20.3 %. Detritivores and decomposers used 57.9 % and the egg harvest program removed 11.1%. The remaining 2.6% was released as metabolic heat and gases Although over 75% of the energy budget provided by the mass nesting of olive ridleys at Ostional was transferred to predators and decomposers, little of it was transferred to natural mammalian predators. He did not consider dogs in his analysis.

The ONWR human population was about 600 people and they had a legal egg harvest program for subsistence since 1987 (Spotila, 2011; Valverde, et al., 2012). The harvest only took 193 out of 5,211 experimental clutches (3.7%). However, when dogs and poaching were added, the number increased to 737 (14.1 %). Natural causes eliminated 1,404 clutches (26.9 %) so they had a much larger effect. Once those 1,404 clutches were removed from the count, then harvest removed 5.1 % of the remaining clutches from all experimental plots, but 19.6% of clutches from open plots. All anthropogenic causes removed 19.4% of the remaining clutches from both open and closed plots. Anthropogenic impact was about 39% of unprotected clutches in open plots. Harvest estimates for open plots were similar to those of Ballestero, et al. (1998) and Valverde, et al. (2012) who calculated a mean harvest of 21.2% based on information from ADIO. An analysis of information from ADIO during my study showed a harvest in 2009 of 8.7% , and in 2010/11 of 4.7% of the total of eggs deposited for all nesting females. It appears that harvest estimates by ADIO are not as accurate as data from my experimental plots. Therefore, management decisions about the harvest have been made in the past based on incomplete information. Future estimates should be based on more careful data collection from well placed experimental plots distributed throughout the arribada area. Accurately counting turtles with the Valverde and Gates (1999) method will also improve the harvest estimate since that method also gives an accurate count of the number of clutches laid- one per turtle counted.

Poaching removed 2.2% of all experimental clutches or 3.7% of clutches not lost to natural causes. Poaching of sea turtle eggs is high on most unprotected beaches in

Costa Rica (Spotila, 2011), and in most of the world. For example, poaching of green turtle clutches was high on unprotected Playas Nombre de Jesus and Zapotillal 50 km north of Ostional (Blanco, et al., 2012). Poaching removed 90 % of leatherback turtle clutches from Playa Grande 50 km north of Ostional from about 1970 to 1990 and the population of nesting leactherback turtles declined from 1500 in 1989 to 100 in 2001-2005 (Santidrián Tomillo, et al., 2008). The effect of poaching (3 %) on green turtle nests on Playa Cabuyal, a non protected beach north of Playa Grande, was reduced by the presence of scientists who discouraged the taking of eggs (Santidrián Tomillo, et al., 2014). Most poaching at Ostional in 2009 took place in sector 2 because patrolling by guards from MINAE and ADIO concentrated in sector 3 where most clutches were deposited. In 2010/2011 poachers also worked in sector 1 since nesting included that sector. Since sector 1 had more hatching success and more hatchling production than the other sectors it is important that guards from ADIO and MINAE expand their activity into sectors 1 and 2 to reduce the impact of humans in the areas where incubation conditions are favorable for embryonic development.

Dogs destroyed more clutches at Ostional than harvest and poaching combined. As humans live closer to protected areas around the world free roaming dogs create increased problems with dog welfare, public health, and wildlife protection. In many protected areas domestic dogs from adjacent villages prey on endangered wildlife (Izaguirre, et al., 2014). In Costa Rica domestic animals are prohibited from protected areas. However, that law is not enforced at Ostional or in most other protected areas (Spotila, 2011) where dogs detroy many clutches. For example, at Playa Grande in

Parque Marino Nacional Las Baulas, Costa Rica, dog predation on leatherback turtle eggs and hatchlings increased directly with the human population and increasing development (Santidrián Tomillo, et al., 2008). During 2005-2006 only 8% of the nests were disturbed at Playa Grande, but in 2007-2008 and 2008-2009 dogs dug up more than 50% of nests. As of 2014 there was still no effective control program for dogs in that park. At Playa Cabuyal dogs detroyed 12 % of clutches (Santidrián Tomillo, et al., 2014).

At Colola Santuary in the Mexican Pacific there are similar problems with dogs and people as at Ostional (Izaguirre, et al., 2014). Colola is a nesting beach for green, olive ridley, and leatherback turtles. The protected area has 477 inhabitants in a Nahua indigenous community where farming is the main livelihood. Aroung 60% of the population harvests sea turtle eggs for consumption, in a pattern similar to other coastal communities of Mexico. In 60% of observations, dogs were alone on the beach and in 40 % they were with humans, but overall dogs predated 70% of sea turtle nests.

At Ostional depredation by dogs was now much higher than that caused by dogs and pigs in the 1980s (Cornelius, et al., 1991) and was the greatest anthropogenic impact on turtle reproduction. A control program is necessary to educate people about the impact of dogs, remove dogs from the wildlife refuge and to euthanize dogs that cannot otherwise be removed. In the 1950's large packs of dogs were a problem for green turtle nesting at Tortuguero. The only solutiuon available at that time was to euthanize the dogs (Carr, 1967). Similar measures may be necessary at beaches such as Ostional and Playa Grande where humans do not responsibly manage their dogs and will not remove them from the beach.

Embryonic development

Only 10,024 out of 291,644 eggs in study clutches that survived natural and anthropogenic disturbances hatched. Most eggs (91.2 %) showed no visible signs of development and they were distributed in all sectors and zones. This indicated early death or infertility. There was a tendency for more plots in sector 3 to have eggs with no development than in the other sectors. The same was true for zone 2. That did not mean that they were unfertilized (Bell, et al., 2004) because an early embryo is not visible to the naked eye after eggs has been burried for 55 days. Cornelius, et al. (1991) found that 52 % of eggs at Ostional and 75 % of eggs at Nancite showed no development. Ocana (2010) reported similar results from olive ridleys at the arribada nesting beach at Escobilla, Mexico. There were very few eggs at developmental stages I to V (0.3 to 1.8 %) so whatever agents worked to kill eggs did so soon after they were laid.

High organic content, microbial activity, soil moisture, temperature and gas exchange have all been hypothesized as causes of embryonic mortality (Cornelius, et al., 1991; Acuna et., al 1999; Honarvar, et al., 2011; Valverde, et al., 2012). However, few studies have addressed these hypotheses experimentally. Clusella Trullas and Paladino (2007) moved eggs from the beach at Nancite to a hatchery with clean sand and found that hatching success and hatchling production improved. So it appears that sand quality or organic content plays a role in successful embryonic development. Honarvar, et al. (2008) reported that high nest density results in lower O_2 , higher CO_2 and higher temperatures in the nest and reduced hatching success.

Successful nests at Ostional were associated spatially with the estuary because sand in this area was changing frequently during the wet season when the estuary opened. This natural event removed all organic matter, old eggs, new eggs, and shells and provided a healthier microclimate for successful nests (Cornelius et al., 1991; Valverde, et al. 2012).

Hatching rate for clutches at Ostional has been low through time. Cornelius, et al. (1991) estimated a 8.0% hatching rate combined for their study. Valverde, et al. (2010) estimated a 2% hatching rate and Valverde, et al. (2012) estimated an overall hatching rate of 18.4 %. I found a hatching success in 2009 of 1.8%, and in 2010 of 4.9% (based on results on page with an overall hatching rate of 3.4%). So hatching rate at Ostional has decreased since the 1980s and is now similar to the value for Nancite at that time (Cornelius, et al. 1991).

Hatchling production through time

Hatchling production has declined at Ostional since 1984. There were 2,410,402 hatchlings produced in 1984 from two arribadas (Cornelius, et al., 1991). In this study in ten arribadas, there were between 785,176 and 1,544,153 hatchlings produced. That number of hatchlings appears to be insufficient to ensure continuation of the population. If we assume that a female olive ridley produces two clutches of about 100 eggs a year, nests every year and lives an average of 20 years as an adult, then she produces 4,000 eggs that result in two adult turtles, one male and one female. Based on demographic models (Leslie, et al.,1996) it takes about 1000 hatchlings to produce two adult sea turtles. So hatching success needs to be at least 25 % to produce those 1000 hatchlings.

With a population of about 200,000 to 500,000 females that means that Ostional needs to produce between 10,000,000 and 25,000,000 hatchlings a year to maintain the population. Since hatching success is below 10 % we can expect a sharp population decline over the lifetime of the current adult population.

Conservation implications

Harvest of olive ridley eggs is common at arribada beaches around the world and is implicated in the decline of many such populations (Cornelius, et al., 2007). For example, the olive ridley population at Terengganu, Malaysia declined precipitously from thousands of annual nests to only a few dozen due to long-term overharvest of eggs (Limpus, 1995). The decline in Mexican and Central American olive ridley populations were attributed to egg harvest and capture in fisheries (Cornelius, 1982; Cornelius, et al. 2007). Up to 100 % of olive ridley eggs were colllected from beaches in the Gulf of Fonseca, Honduras since 1940 (Lagueux, 1991). Even where egg harvest is legal enforcement of regulations is uneven and in some places totally ignored (Cornelius, et al., 2007). For example, at Chococente and La Flor in Nicaragua egg-harvest quotas were based more on demands of the local market than on the conservation needs of the turtles leading to chaotic, illegal egg collection (Hope, 2002; Smith, 2002). Campbell (2007) discusses the socioeconic aspects of egg harvest in Pacific Central America and concludes that communities involved in the use of olive ridley eggs are marginalized economically and that there are little opportunities for income substitution. She concludes that when the goal of an egg harvest is sustainable use, ensuring that the economics of the program are equitable is of limited use if that program undermines the survival of the turtle population.

The results of this study indicate that hatching success and the production of hatchlings is controlled by spatial, temporal and environmental factors. Density of eggs did not have a significant effect on hatching success or hatching production. There was a strong tendency for plots open to harvest, dogs and poaching to have a higher hatching success, but not a higher hatchling production. Therefore, the egg harvest program at Ostional did not improve hatchling production, but also did not reduce it. Thus, management decisions about the harvest have been made in the past based on incomplete information. The lack of quantitative data from controlled experiments has led to many years of speculative exploitation. Future decisions on whether or not to harvest and how to harvest should be based on more careful data collection from well placed experimental plots distributed throughout the arribada area.

Given the historic decline in hatchling production at Ostional it is now apparent that the beach is no longer producing enough hatchlings to replace the adult population through time. Therefore, we expect that there will be a sharp decline in the population through the lifetime of the current adult population. To help to ensure the stability of the population it is necessary to produce as many hatchlings as possible from the beach and to reduce at sea mortality of the turtles.

Spatial and temporal management measures should include systematic and long-term monitoring of arribada parameters and large-scale experiments on the effect of sand cleaning on hatching rates, and hatchling production. The harvest should shift in intensity towards the dry season when hatching success is very low because of high temperatures and a lack of moisture in the sand (Valverde et al., 2010).

There should be no new development at Ostional nesting beach because it will cause an increase in disturbance to the arribada and an increase in impact from people and dogs. The area of sector 1 from this study should be kept free of anthropogenic effects because it has the highest rate of hatching success and hatchling production.

The negative effect of dogs is much greater than the effect of legal harvest. A control program is necessary to educate people about the impact of dogs, remove dogs from the wildlife refuge and, if necessary, to euthanize dogs that cannot otherwise be removed.

It may require interinstitutional strategies to eliminate the effect of dogs and poaching on the beach. Strict enforcement of controls against dog predation and poaching such as permanent patrolling from MINAE, ADIO and police over the whole beach is necessary as a start to the dog and poaching control process.

Harvest does not increase hatchling production and hatching success. It does, however, change the distribution of matter and energy from the arribada eggs from the natural ecosystem to the human ecosystem- dogs and people. It also justifies and increases poaching of olive ridley and other sea turtle eggs throughout Costa Rica (Arauz-Almengor, et al., 2001; Spotila, 2011; Blanco, et al. 2012; Santidrián Tomillo, et al., 2014). Therefore, an evaluation of what to do about the harvest has to take into account not only the impact of the harvest on the arribada population at Ostional, but also the impact on conservation of sea turtles in the country as a whole, and finally the impact on the local people who rely on the harvest for a portion of their income. If the harvest is halted then effective measures should be implemented to provide alternative sources of income for the people negatively affected by the closure.

Finally MINAE should coordinate with National Service of Guard Coast to protect the marine coastal area and reduce the at sea mortality of olive ridley in bycatch on longlines, in trawls and in nets.

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TABLES

Table 2.1. Arribada size estimated using the strip transects in time method (Gates et al. 1996; Valverde and Gates 1999) at Ostional National Wildlife Refuge in 2009, indicating standard deviation (SD), lower (LCI) and upper (UCI) 95% confidence intervals.

# Arribada	Month/Year	Size	SD	LCI	UCI
1	April/09	27,790	4,605	22,110	33,469
2	July/09	15,726	2,866	9,993	21,459
3	August/09	39,849	3,947	31,956	47,742
4	September/09	110,438	5,819	98,801	122,075
5	December/09	38,093	3,264	31,565	44,621
Total/09: 231,896 nesting females					

Table 2.2. Arribada size estimated using the strip transect in time method (Gates et al. 1996; Valverde and Gates 1999) at Ostional National Wildlife Refuge, 2010/11, indicating standard deviation (SD), lower (LCI) and upper (UCI) 95% confidence intervals.

# Arribada	Month/Year	Size	SD	LCI	UCI
1	July/10	19,946	2,602	14,742	25,150
2	Sept/10	337,832	11,160	315,513	360,151
3	November/10	75,706	5,200	65,306	86,106
4	January/11	49,470	4,295	40,881	58,060
5	March/11	6,986	1,096	4,794	9,177
Total/10-11: 489,940 nesting females					

Table 2.3. Number of clutches lost during the incubation process to natural causes at Ostional National Wildlife Refuge, 2009 -10-11

Natural causes	2009 n=668	2010-2011 n=736	Total n=1,404
Erosion-open estuary-high tides	472	255	727 (51.8%)
Nesting activity by other turtle	193	474	667 (47.5%)
Raccoon predation	3	7	10 (0.7%)

Table 2.4. Spatial distribution of plots with a total of 1,404 clutches lost to natural causes by zone and sector at Ostional National Wildlife Refuge, 2009 -10-11

Cause	Year	Spatial distribution					
		Sector			Zone*		
		1	2	3	1	2	3
Erosion/open estuaries/tides n=57 plots (727 clutches)	2009 (n=28)	-	11 (39.3%)	17 (60.7%)	2 (7.1%)	5 (17.9%)	21 (75.0%)
	2010/11 (n=29)	10 (34.5%)	10 (34.5%)	9 (31.0%)	1 (3.4%)	5 (17.2%)	23 (79.3%)
Nesting activity n=116 plots (667 clutches)	2009 (n=35)	-	3 (8.6%)	32 (91.4%)	11 (31.4%)	13 (37.1%)	11 (31.4%)
	2010/11 (n=81)	22 (27.2%)	18 (22.2%)	41 (50.6%)	24 (29.6%)	34 (42.0%)	23 (28.4%)
Raccoon predation n=6 plots (10 clutches)	2009 (n=2)	-	2 (100%)	-	1 (50.0%)	-	1 (50.0%)
	2010/11 (n=4)	-	-	4 (100%)	3 (75.0%)	-	1 (25.0%)

*Zone 1: vegetation; Zone 2: open sand; Zone 3: tidal zone

Table 2.5. Number of clutches lost during the incubation process to human causes at Ostional National Wildlife Refuge, 2009 -10-11

Human causes	2009 n=243	2010-2011 n=494	Total n=737
Poaching activity	75	40	115 (15.6%)
Harvest	42	151	193 (26.2%)
Dog predation	126	303	429 (58.2%)

Table 2.6. Spatial distribution of plots with a total of 737 clutches lost to anthropogenic causes by zone and sector at Ostional National Wildlife Refuge, 2009 -10-11

Cause	Year	Spatial distribution					
		Sector			Zone*		
		1	2	3	1	2	3
Poaching activity n=29 plots (115 clutches)	2009 (n=20)	-	12 (60.0%)	8 (40.0%)	5 (25.0%)	9 (45.0%)	6 (30.0%)
	2010/11 (n=9)	2 (22.2%)	7 (77.8%)	-	4 (44.5%)	3 (33.3%)	2 (22.2%)
Harvest n=38 plots (193 clutches)	2009 (n=12)	-	7 (58.3%)	5 (41.7%)	3 (25.0%)	6 (50.0%)	3 (25.0%)
	2010/11 (n=26)	8 (30.8%)	8 (30.8%)	10 (38.5%)	8 (30.8%)	10 (38.5%)	8 (30.8%)
Dog predation n=82 plots (429 clutches)	2009 (n=21)	-	9 (42.8 %)	12 (57.1%)	7 (33.3%)	9 (42,8%)	5 (23.8%)
	2010/11 (n=61)	10 (16.4%)	21 (34.4%)	30 (49.2%)	21 (34.4%)	18 (29.5%)	22 (36.0%)

*Zone 1: vegetation; Zone 2: open sand; Zone 3: tidal zone

Table 2.7. Embryonic development stages of Olive Ridley eggs at Ostional National Wildlife Refuge, 2009 -10/11 upon exhumation, after completing the incubation period.

Embryonic Development Stage	2009 n=136,037	2010-2011 n= 155,607	Total 291,644 eggs
Stage 0 (Non development)	129,237	136,685	265,922 (91.2%)
Stage I	1,263	2,123	3,386 (1.2%)
Stage II	1,407	1,181	2,588 (0.9%)
Stage III	905	4,399	5,304 (1.8%)
Stage IV	258	675	933 (0.3%)
Stage V	554	2,933	3,487 (1.2%)
Stage VI (hatched)	2,413	7,611	10,024 (3.4%)

Table 2.8. The spatial distribution of plots with at least one embryonic development stage represented among the eggs by zone and sector at Ostional National Wildlife Refuge, 2009-10-11

Embryonic Development Stage	Year	Spatial distribution					
		Sector			Zone*		
		1	2	3	1	2	3
Stage 0: No apparent embryonic development n=294 plots (265,922 eggs)	2009 (n=105)	-	47 (44.8%)	58 (55.2%)	40 (38.1%)	44 (41.9%)	21 (20.0%)
	2010/11 (n=189)	60 (31.7%)	54 (28.6%)	75 (39.7%)	56 (29.6%)	74 (39.1%)	59 (31.2%)
Stage I: embryo filled 1-25% of amniotic cavity n=139 plots (3,386 eggs)	2009 (n=45)	-	17 (37.8%)	28 (62.2%)	9 (20.0%)	21 (46.7%)	15 (33.3%)
	2010/11 (n=94)	24 (28.6%)	25 (29,8%)	35 (41.6%)	20 (23.8%)	34 (40.5%)	30 (35.7%)

Table 2.8 (*continued*)

Embryonic Development Stage	Year	Spatial distribution					
		Sector			Zone*		
		1	2	3	1	2	3
Stage II: embryo filled 26-50% of amniotic cavity	2009 (n=45)	-	18 (40.0%)	27 (60.0%)	12 (26.7%)	19 (42.2%)	14 (31.1%)
N=121 plots (2,588 eggs)	2010/11 (n=76)	22 (28.9%)	20 (26.3%)	34 (44.7%)	19 (25.0%)	29 (38.2%)	28 (36.8%)
Stage III: embryo filled 51- 75% of amniotic cavity	2009 (n=29)	-	11 (37.9%)	18 (62.0%)	7 (24.1%)	12 (41.4%)	10 (34.5%)
n=113 plots (5,304 eggs)	2010/11 (n=84)	25 (29.8%)	21 (25.0%)	38 (45.2%)	20 (23.8%)	32 (38.1%)	32 (38.1%)
Stage IV: embryo filled 76-100% of amniotic cavity	2009 (n=9)	-	1 (12.5%)	8 (87.5%)	2 (25.0%)	4 (50.0%)	2 (25.0%)
n=50 plots (933 eggs)	2010/11 (n=41)	13 (31.7%)	11 (26.8%)	17 (41.5%)	13 (31.7%)	12 (29.3%)	16 (39.0%)
Stage V: predated by larvae of fly or beetle	2009 (n=21)	-	10 (47.6%)	11 (52.4%)	4 (19.0%)	11 (52.4%)	6 (28.6%)
n=387 plots (487 eggs)	2010/11 (n=66)	20 (30.3%)	18 (27.3%)	28 (42.4%)	10 (15.1%)	27 (40.9%)	29 (43.9%)
Stage VI: empty eggs shells, from hutched turtles	2009 (n=56)	-	30 (53.6%)	26 (46.4%)	16 (28.6%)	22 (39.3%)	18 (32.1%)
n=128 plots (10,024 eggs)	2010/11 (n=72)	18 (25.0%)	20 (27.8%)	34 (47.2%)	16 (22.2%)	24 (33.3%)	32 (44.4%)

*Zone 1: vegetation; Zone 2: open sand; Zone 3: tidal zone

Table 2.9. Comparison of hatchling production from two arribadas on Ostional beach in 1984 from Cornelius et al. (1991) and 10 arribadas in 2009 and 2010 from this study.

	1984*	2009	2010
Number of arribadas at Ostional	2	5	5
Total number of clutches	207,900	231,896	489,940
Mean clutch size	107.4	95	95
Total eggs	22,238,460	22,030,120	46,544,300
Number of nests that hatched	71,933	-	-
Peecent of clutches that survived incubation	--	61.0%	57.1%
Number of eggs incubated	--	13,438,373	26,576,795
Hatching success (%)	31.12%	1.8%	4.9%
Hatchling production	2,410,402	--	--
Hatchling production by area[1]	--	349,983	435,787
Hatchling production by percentage[2]	--	241,890	1,302,262

*Data from Cornelius et al. (1991). [1]Hatchling production was based on the production in experimental plots extrapolated to the entire beach area. [2]Hatchling production was based on a straight calculation of estimated number of eggs multiplied by hatching success rate for the experimental plots that year

FIGURES

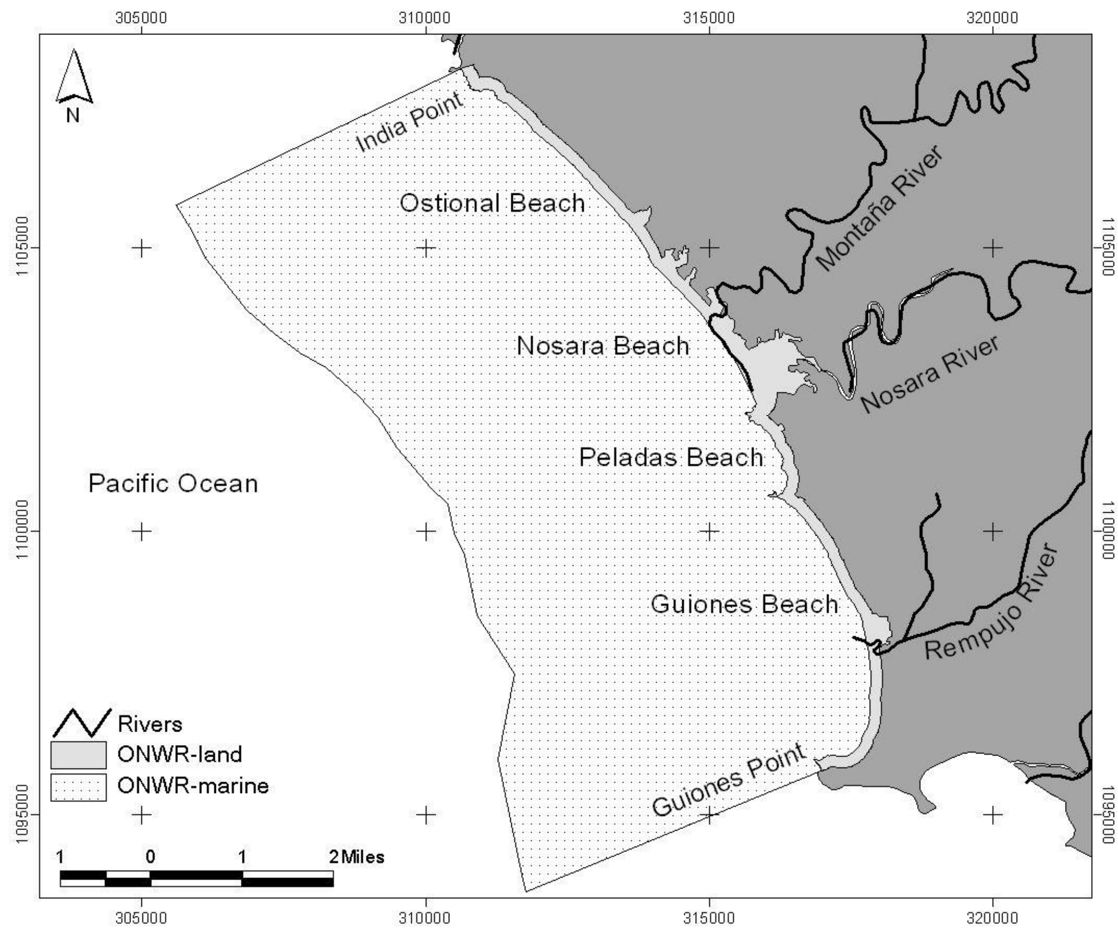

Figure 2.1. Coastal-Marine view of Ostional Wildlife Refuge-ONWR (Ostional, Nosara, Peladas, Guiones).

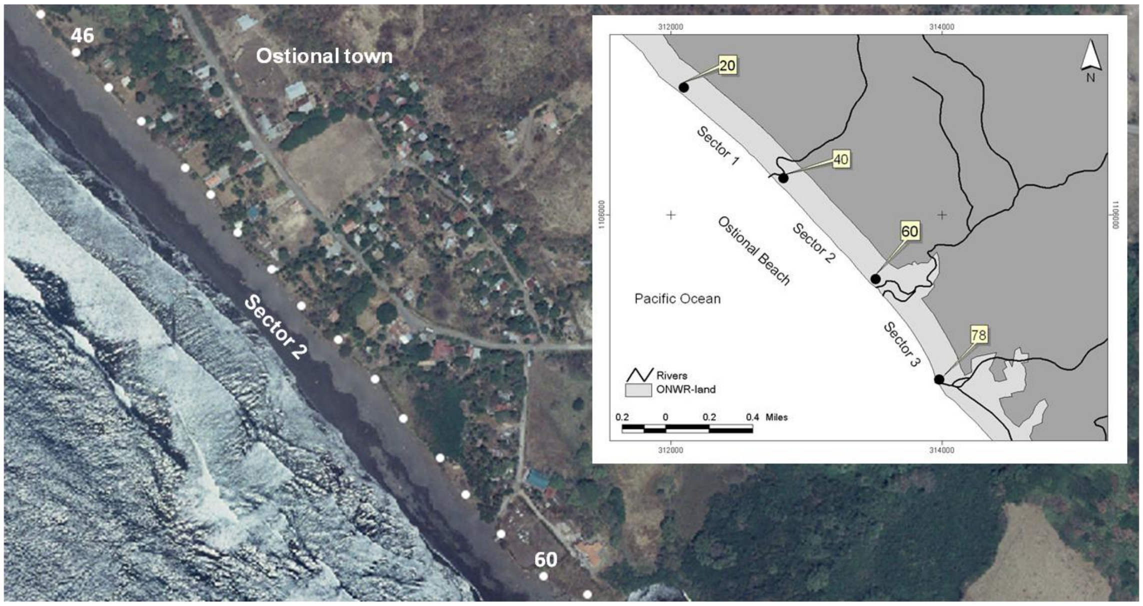

Figure. 2.2. Study Area at Ostional Beach, Ostional National Wildlife Refuge, consisting of three sectors with a total of 2.800 m: sector 1 (approximately 1000m, posts 20-40), sector 2(approximately 950m, posts 41-60) and sector 3 (approximately 850m, posts 61-78). The Ostional villege is located between posts 46-60.

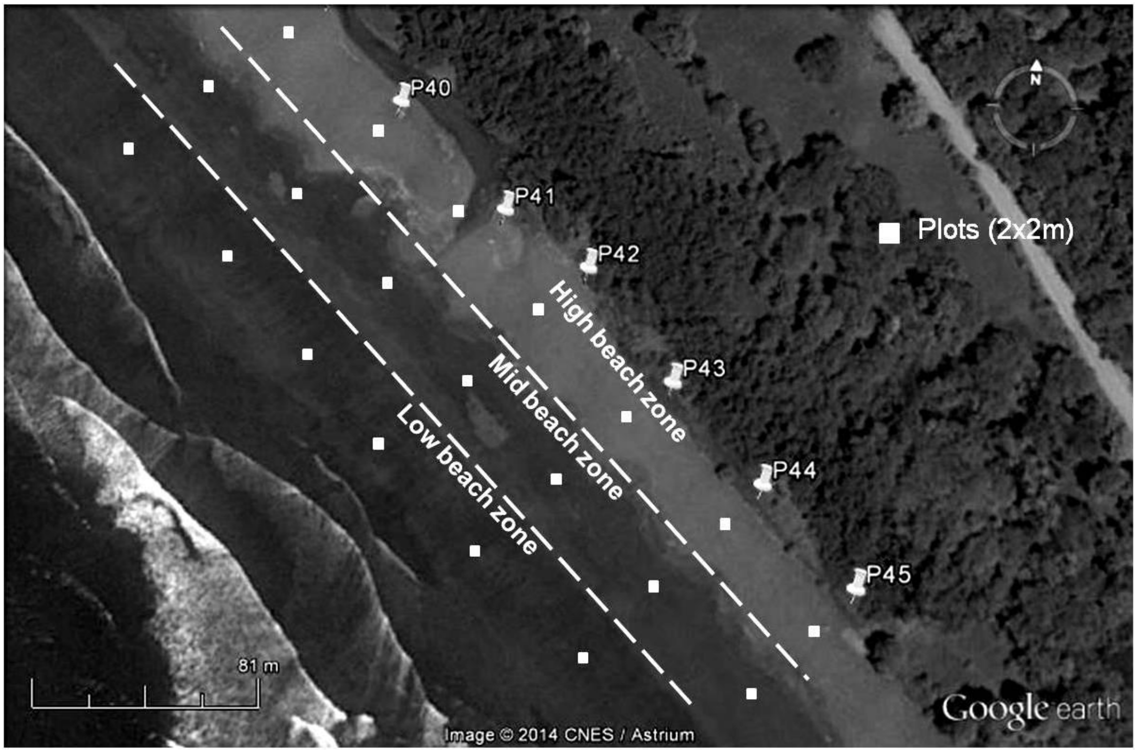

Figure. 2.3 Spatial distributions of plots by sector and zone of the Ostional nesting beach.

Figure 2.4. Example of an “Open Plot” (2 x 2 m) on Ostional beach in North west Costa Rica. This plot is in the low beach zone, below the high tide line. The open beach and vegetation zones are also apparent.

Figure 2.5. Example of a “Closed Plot” (2x2 m) in the low beach zone, below the high tide line of Ostional Northwest Costa Rica.

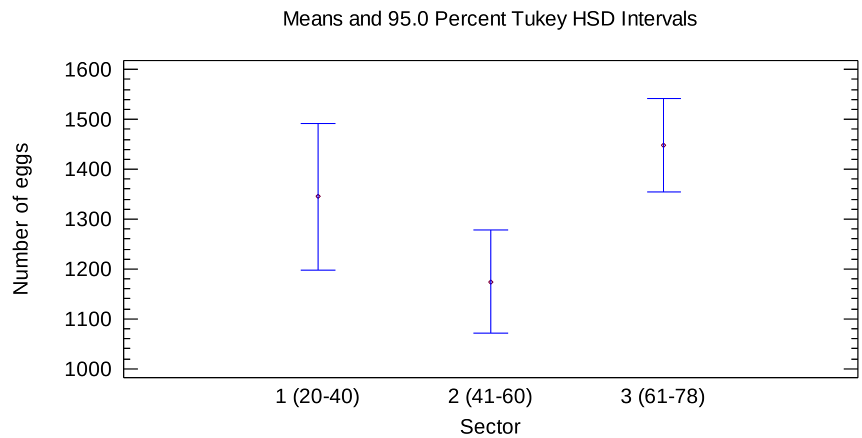

Figure 2.6. Number of eggs laid in each sector by olive ridley turtles during arribadas at Ostional National Wildlife Refuge, Costa Rica, 2009-10-11.

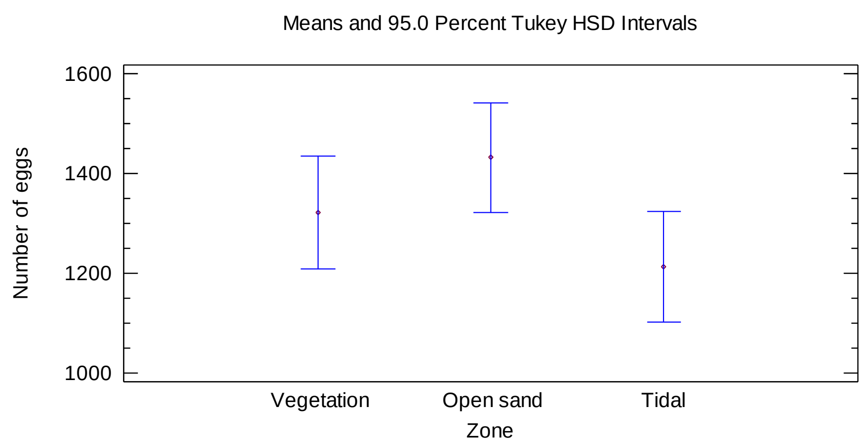

Figure 2.7. Number of eggs laid in each zone by olive ridley turtles during arribadas at Ostional National Wildlife Refuge, Costa Rica, 2009-10-11.

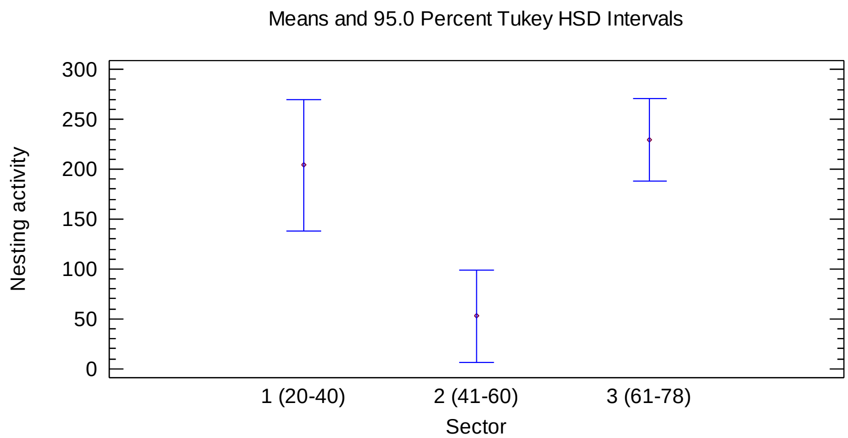

Figure 2.8. Number of clutches losts to nesting activity by sector. Confidence level (95%). Ostional National Wildlife Refuge, Costa Rica, 2009-10-11.

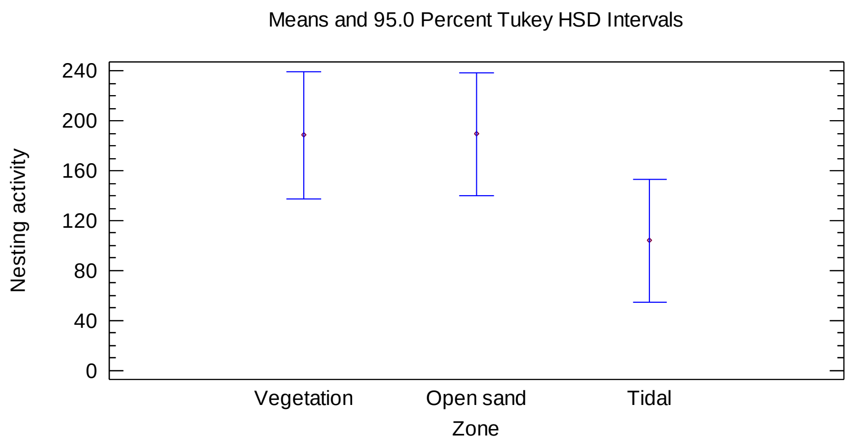

Figure 2.9 . Number of clutches losts to nesting activity by zone. Confidence level (95%). Ostional National Wildlife Refuge, Costa Rica, 2009-10-11.

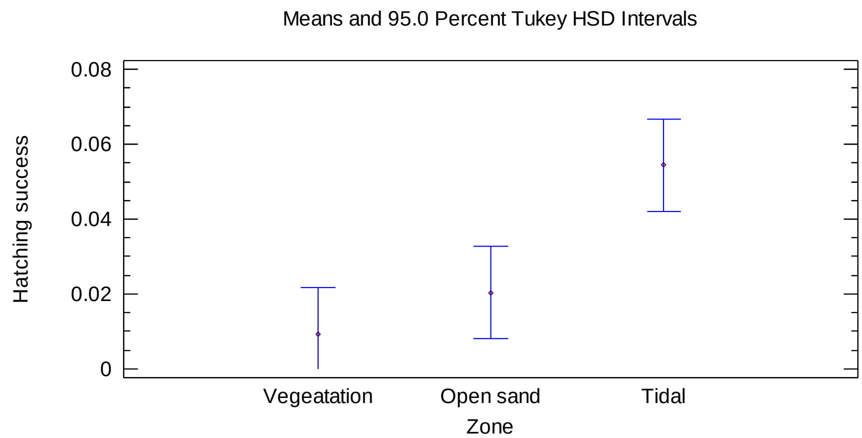

Figure 2.10. Mean hatching success for olive ridley arribada clutches in each beach zone at Ostional National Wildlife Refuge, Costa Rica, 2009-10-11. Vertical error bars show Tukey confidence interval (95%).

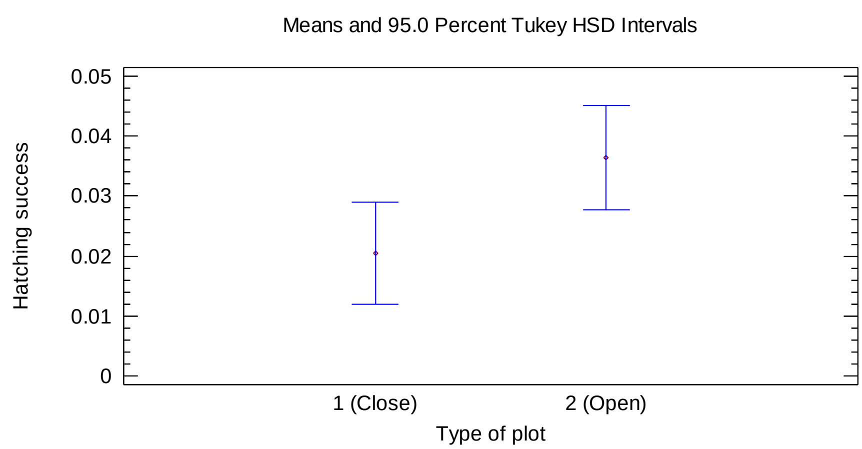

Figure 2.11. Mean hatching success for each type of experimental plot at Ostional National Wildlife Refuge, Costa Rica, 2009-10. Error bars show Tukey Confidence interval (95%).

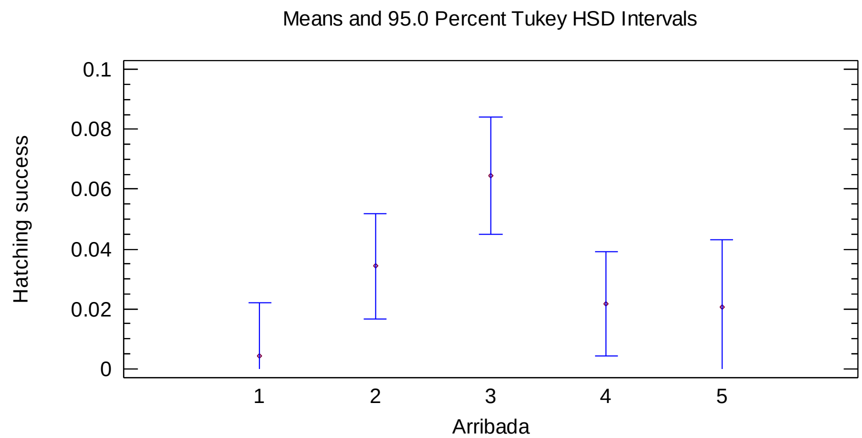

Figure 2. 12. Effects of arribadas on the hatching success of olive ridley clutches at Ostional National Wildlife Refuge, Costa Rica, 2009-10. Error bars show Tukey Confidence interval (95%).

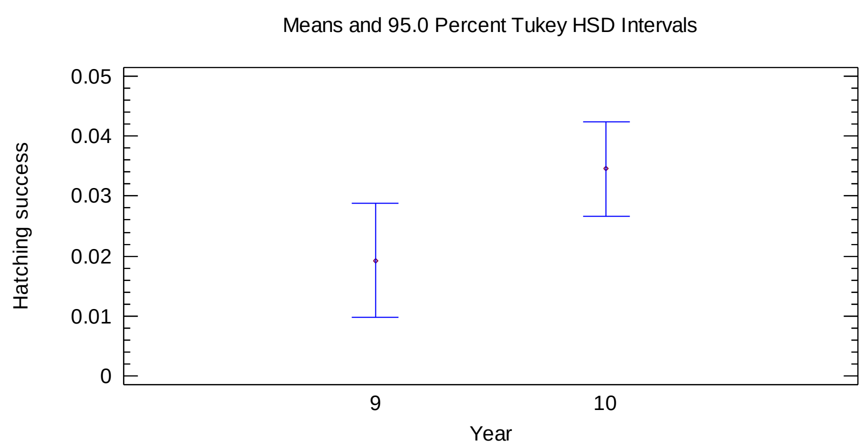

Figure 2.13. Hatching success of olive ridley clutches from year was higher in 2010 or La Niἠa year than 2009 or El Niἠo year at Ostional National Wildlife Refuge, Costa Rica. Error bars show Tukey Confidence interval (95%).

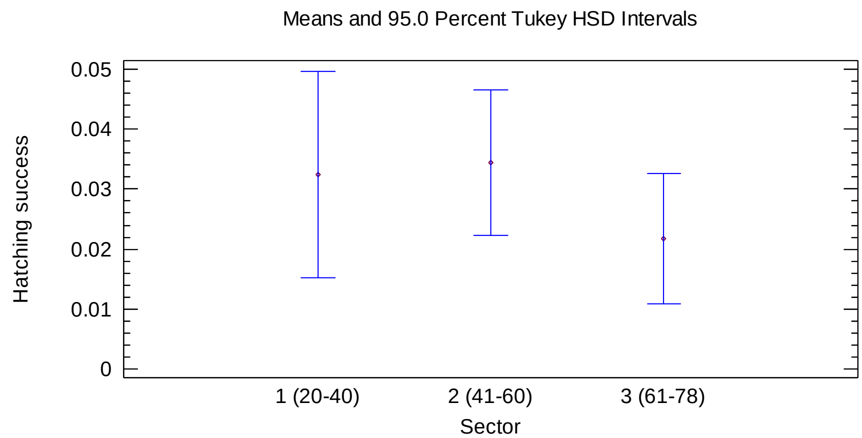

Figure 2.14. Hatching success of olive ridley clutches from sector at Ostional National Wildlife Refuge in 2009 and 2010-11. Error bars show Tukey Confidence interval (95%).

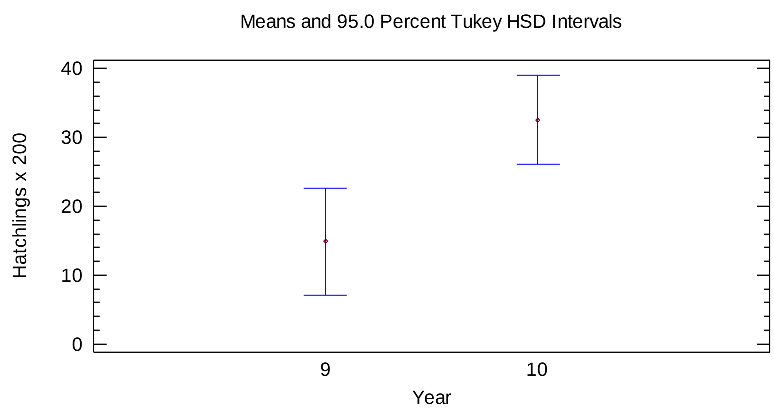

Figure 2.15. Interactions between year and production of olive ridley hatchlings (VI) at Ostional National Wildlife Refuge, Costa Rica, 2009 and 2010-11. Error bars show Tukey Confidence interval (95%).

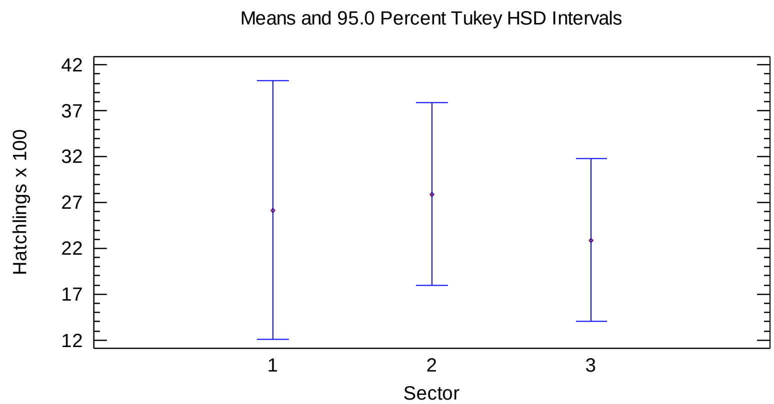

Figure 2.16. Interactions between sector and production of olive ridley hatchlings (VI) at Ostional National Wildlife Refuge, Costa Rica, 2009 and 2010-11. Error bars show Tukey Confidence interval (95%).

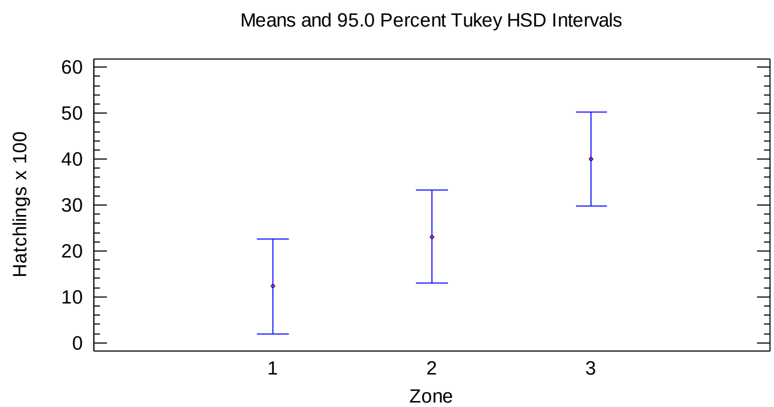

Figure 2.17. Interactions between zone and production of olive ridley hatchlings (VI) at Ostional National Wildlife Refuge, Costa Rica, 2009 and 2010-11. Error bars show Tukey Confidence interval (95%).

CHAPTER 3: HATCHING SUCCESS, HATCHLING PRODUCTION AND THE FUTURE OF OLIVE RIDLEY ARRIBADAS AT OSTIONAL, LA FLOR AND CHACOCENTE PROTECTED AREAS, CENTRAL AMERICA

Abstract

This study indicated that the harvest of eggs from three beaches in Costa Rica and Nicaragua appears to be not sustainable. Hatchling production at Ostional and La Flor appears to be insufficient to maintain the current populations of adults and production at Chacocente is marginal. When combined with the removal of adults from the population by fishing I expect that there will be sharp declines in these populations.To help to ensure the stability of the regional olive ridley population it will be necessary to produce as many hatchlings as possible from the beachs and to reduce at sea mortality of the turtles for the foreseeable future. To produce more hatchlings from these beaches we need to understand the factors controlling hatchling production. Hatching success and the production of hatchlings were controlled by the same spatial, temporal, human and environmental factors on all three beaches so those controls appear to be general in nature, at least in Pacific Central America. Density of eggs did not have a significant effect on hatching success or hatchling production. Spatial and temporal management measures should include systematic and long-term monitoring of arribada parameters and large-scale experiments on the effect of sand cleaning on hatching rates, and hatchling production. There should be no new development at Ostional, La Flor and Chacocente beaches because it will cause an increase in disturbance to the arribadas and an increase in impact from people and dogs. A control program is necessary to remove dogs from

the three beachs by educating people about the impact of dogs, euthanizing feral dogs, and euthanizing dogs that cannot otherwise be removed. It will require interinstitutional strategies to eliminate the effect of dogs and poaching on the beaches. Strict enforcement of controls by permanent patrolling from MINAE, ADIO and police in Costa Rica and MARENA and the military in Nicaragua over the whole beach and year is necessary. Harvesting eggs, legally or illegally, does not improve hatching success and justifies and increases poaching of olive ridley and other sea turtle eggs throughout Costa Rica and Nicaragua. That is a major reason why the harvest should stop. Initially the harvest should shift in intensity towards the dry season when hatching success is very low because of high temperatures and a lack of moisture in the sand.

Harvest of olive ridley eggs throughout the world is linked with very poor coastal communities and lack of economic alternatives. Therefore, the impact on the local people who rely on the harvest for a portion of their income needs to be considered and effective measures need to be implemented to provide alternative sources of income for the people negatively affected by the closure. It will be useful to implement a participatory environmental management (PEM) program at La Flor and Chacocente as now exists at Ostional. Ecotourism now produces more income at Ostional than the legal egg harvest. By working with all of the stakeholders it should be possible to develop alternative sources of income for people near La Flor and Chacocente while promoting management measures to increase the production of hatchlings from those beaches. The comparison of the biology of the olive ridley arribadas at three beaches in Pacific Central America indicated that marine protected areas can be effective at both protection of nesting turtle populations and provision of socioeconomic benefits to the local human populations. However, managers have to implement strict controls to eliminate poaching activity and dog predation to increase the hatchling production. Therefore, establishment and effective management of marine protected areas around the world will be an important tool to help recover populations of migratory species such as sea turtles. Each MPA should evaluate the biology of the species being protected/managed and establish an adaptative management plan that takes into account ecological, social, and economic factors to keep the MPA sustainable over the time. It should also develop a clear management framework to take into account all stakeholders without compromising conservation protections. Finally, an integral strategy of management should be protection of sea turtles at sea to reduce the adult mortality because all lifestages are needed to keep a stable sea turtle population.

Introduction

Marine Protected Areas (MPAs) can be effective management tools to protect and conserve marine biodiversity (Botsford, et al., 2009; Nel, et al., 2013). In an analysis of 70 MPAs Halpern (2003) reports that MPAs increase density (63 %), increase biomass (90-96 %), increase mean size (80-89 %), and increase diversity (59-76 %) of fish. However, while resident fish populations may benefit from reduced fishing effort inside MPAs, migratory marine species may receive only marginal benefits if only a part of their life cycle is protected by MPAs (Botsford, et al., 2009). There are little unequivocal data on the effectiveness of MAPs in aiding the recovery of migratory marine species including sea turtles (Nel, et al., 2013). Sea turtles offer a test case to assess the contribution of local conservation efforts on a migratory species.

Most sea turtle MPAs include nesting beaches and nearby seas. Long-term conservation efforts have contributed to the recovery of green turtles, *Chelonia mydas,* at Tortuguero Costa Rica (48 years) (Troeng and Rankin, 2005) and loggerhead turtles, *Caretta caretta*, in South Africa (44 years) (Nel, et al., 2013). However, impacts of MPAs on the recovery of most sea turtle populations are uncertain since (1) most monitoring programs have been running for less than one turtle generation (<25 yr), and (2) because the relative contributions of conservation efforts and threats at different life stages still need to be quantified. The survival of sea turtles is affected by oceanic and terrestrial threats that include natural causes such as predation, tidal inundation and erosion of nests, disease, as well as anthropogenic causes such as poaching, incidental capture in fisheries, hunting and habitat loss and degradation (Seminoff, 2004; Welicky, et al., 2012). While threats to older life history stages are considered of greatest importance (Crouse, et al., 1987), loss of recruitment of hatchlings reduces later age classes (Congdon, et al, 2001) and ultimately can cause a population collapse (Santidrián Tomillo, et al., 2010).

One of the most commonly used parameters to assess sea turtle population status and trends is nesting activity. Sea turtle populations are most easily monitored on the nesting beach (Santidrián Tomillo, et al., 2008) because all adult females should eventually come ashore to lay their eggs. For sea turtles, the annual number of females at nesting beaches has been used as an index of abundance (Troëng, et al., 2004; Eguchi, et al., 2007). Because the proportion of the total females nesting in any one season may vary from year to year (Broderick, et al., 2001; Shanker, et al. 2004; Dutton, et al., 2005; Chaves, 2007; Valverde, et al., 2012) inter-annual variability in nesting abundance does not necessarily reflect actual changes in population abundance (Eguchi, et al., 2007). It is thus essential to understand natural and anthropogenic effects on nesting activity at sea turtle conservation sites in order to make inferences about conservation needs and the effectiveness of MPAs for sea turtles. In this study I determined the reproductive parameters of olive ridley turtles (*Lepidochelys olivacea*) at three Central American nesting sites that were protected to varying degrees as wildlife refuges. By comparing the hatching success and hatchling production to the number of nesting turtles and the amount of local egg extraction I sought to assess the effectiveness of the refuges in sustaining the turtle populations.

The olive ridley turtle, the second-smallest sea turtle species (Miller, 1997) has a wide distribution in both tropical and subtropical regions throughout the world's oceans. Although they are the most abundant sea turtles in coastal and oceanic waters (Pritchard, 1997; Limpus, 1995; Eguchi, et al., 2007), like other sea turtles, olive ridleys have been affected by a variety of anthropogenic activities such as direct harvesting of eggs and turtles, nesting habitat destruction and fishery bycatch (Cheng and Chen, 1997; Pritchard, 1997, Pandav, et al., 1998; Eguchi, et al., 2007). Olive ridley turtles are considered "vulnerable" to extinction, according to the IUCN Red List categories (Abreu- Grobois and Plotkin, 2008).

The olive ridley turtle and Kemp's ridley turtle (*Lepidochelys kempii*) are the only sea turtles that are characterized by three different types of reproductive strategies within a given population, namely, a number of females nest solitarily, some nest gregariously in synchronized emergences, and some utilize a mixed strategy (Bernardo and Plotkin, 2007). The synchronized emergences are called, in Spanish, "arribada" or "flota". An arribada consists of hundreds to thousands of female sea turtles nesting at the same time on a beach during a period of several days. The first arribada known to science was in a film by Andres Herrera taken at Rancho Nuevo, Mexico in 1947 of a Kemp's ridley arribada in which approximately 40,000 turtles came on shore (Hildebrand, 1963). There are only a few nesting beaches in the world where olive ridleys still nest in arribadas (Cornelius, et al., 1991). Major arribada nesting beaches are in Costa Rica (Playa Ostional and Playa Nancite), Mexico (La Escobilla), and India (Gahirmatha). Minor arribada nesting beaches are in Nicaragua (Playa Chacocente and Playa La Flor), Panama

(Isla Canas and La Marinera), Mexico (Ixtapilla) and India (Barunei River beach) (Spotila, 2004).

Arribada nesting is the most important form of olive ridley nesting since the vast majority of clutches are deposited during arribadas. Generally, olive ridleys lay two clutches of eggs per reproductive year, remaining close to shore for approximately one month between nesting events (Plotkin, et al., 1994). Mean clutch size of females may differ slightly from beach to beach. For Mexican olive ridley populations the average clutch size is 105 eggs, whereas for two nesting beaches in Costa Rica the mean clutch size is 95 eggs for Playa Ostional and Playa Nancite (Orrego, 2014, Chapter 2). In Nicaragua, the mean clutch size is 95 eggs at Playa La Flor (Honarvar, et al., 2008). Incubation requires 50-80 days. Embryos from nests in shady, vegetated areas may take 70 days or more to hatch (Hughes and Richard, 1974).

The spatial distribution of sea turtle nests on beaches is one of the most important factors affecting hatching success. Selection of the nesting site is affected by two factors: firstly, microhabitat in the sand, including physical factors such as substrate, temperature and humidity; and secondly, macrohabitat, including threats that affect the survival of sea turtles or their reproductive success, such as natural or human depredation (Spencer, 2002; Zavaleta-Lizarraga and Morales-Mavil, 2013). The selection of healthy and long lasting nesting sites can have a strong, positive impact on fitness. Oviposition-site choice is a way by which females can affect the survival and phenotype of their offspring. Among oviparous species, the criteria to select egg-laying sites often differ (Refsnider and Janzen, 2010; Zavaleta-Lizarraga and Morales-Mavil, 2013). In reptiles, such as sea turtles, that do not have parental care, the physical conditions of the nest play an essential role in the success of hatchling production (Broderick, et al., 2003).

On certain arribada beaches, hatching success is often low and even so poor that the value of these beaches for sustained recruitment into the population has been questioned (Cornelius, et al., 1991; Cornelius, et al., 2007). High egg mortality is due to very high nesting density during arribadas, when the turtles themselves physically disturb 20% to 40% of deposited clutches. If there are successive arribadas before the end of the incubation period, these result in additional disturbances of in situ nests. Further mortality may occur as a result of proliferation of fungi and bacteria, reduced O_2, increased CO_2 from microbial respiration, and increased sand temperature, that limit embryo development (Cornelius, et al., 1991; Cornelius, et al., 2007; Valverde, et al., 1998; Wallace, et al., 2004; Clusella Trullas and Paladino, 2007; Honarvar, et al., 2008; Brenes, 2013). Arribada beaches may lose quality as optimal nesting beaches over time, such that some beaches may only constitute temporary nesting habitats (Bernardo and Plotkin, 2007).

Because of the large number of eggs laid during arribadas and the destruction of nests by later nesting turtles it has been argued that harvesting of eggs by local people has little impact on the population (Cornelius, et al., 1991) and may actually improve hatching. However, recent research at Ostional shows that hatchling production is not improved by egg collection (Orrego, 2014, Chapter 2). Therefore, it is necessary to conduct further studies about the effects of olive ridley harvesting during arribadas on hatching success and hatchling production to develop a better understanding of the population status of these turtles and the effect of the egg harvest on the long term viability of the population (Cornelius, et al., 2007).

In Costa Rica, aerial surveys carried out during 1970 discovered a large arribada at Playa Ostional (Richard and Hughes, 1972). In 1983 the Ministry of Environment and Energy (MINAE) created a national wildlife refuge at Ostional and egg collecting was legalized and institutionalized in 1985 (Cornelius, et al., 1991). The nesting population at Ostional appeared to be increasing in the 1990s, but Valverde, et al. (2012) estimated the arribada size at Ostional from 2006 to 2010 and concluded that it was declining when compared with historical data. Arauz (1995) cited by Honarvar, et al. (2008) suggested that the Ostional population may have reached the "local egg-carrying capacity in the sand", which could lead to long-term nesting declines.

In Nicaragua, olive ridleys nest in arribadas at two beaches on the Pacific coast, Playa Chacocente and Playa La Flor. Both are national wildlife refuges under the administration of the Ministerio del Ambiente y Recursos Naturales (MARENA) (Campbell, 2007; Honarvar, et al., 2008). The national wildlife refuge at Chacocente was established in 1983 as a protected area by the Sandinista government as a political decision to use natural resources for community benefits (Campbell, 2007). The national wildlife refuge at La Flor was established in 1996. Before that time, protection was provided by a private family in cooperation with MARENA (Hope, 2002). The history of these beaches was reviewed by Campbell (2007).

Controlled egg harvest has been part of the management plan for the wildlife refuges at Playa Ostional, Playa Chacocente and Playa La Flor. The idea was that removal of excess eggs would increase the hatching success of the remaining eggs (Cornelius, et al., 1991, 2007). A controlled egg harvest took place at Chococente between July-January during the main nesting season, with no control during the rest of the year (Hope, 2002). A controlled harvest of sea turtle eggs took place at La Flor during the nesting season from July until February, removing about 4% of the eggs since 1993 (Hope, 2002). However, a legal harvest and poaching removed up to 40% of eggs. The egg harvest represented an important income for the communities surrounding La Flor (Honarvar, et al., 2008). The arribada size in La Flor increased from 46.000 in 1999-2000 to 187,000 in 2006-2007 (Honarvar, et al., 2008). During recent years Fauna and Flora International (FFI) has been monitoring the arribada size in La Flor and Chococente beaches (personal observation 2010-11).

The effectiveness of wildlife refuges as MPAs for olive ridley turtles depends upon whether or not those refuges produce sufficient numbers of hatchlings to sustain the at sea population of adult turtles. The model at all three refuges was one of sustainability, in which local people obtained an income from egg collecting while most eggs were protected. Whether or not the model worked from a socioeconomic perspective, the important biological question was whether it worked to sustain the turtle populations (Campbell, 2007). A study at Playa Ostional indicated that the egg harvest tended to increase hatching success but did not affect hatchling production. Natural causes such as position on the beach and time of year had a greater effect on hatching success and hatchling production than did harvest or related anthropogenic factors like poaching and dogs. In addition, there was an insufficient production of hatchlings there to sustain the population (Orrego, 2014, Chapter 2). The purpose of this study was to replicate the Ostional research at the Nicaragua refuges and compare the data from all three refuges to determine how the similarities and differences in management, and natural and anthropogenic factors on the beach affected hatchling production and population sustainability.

Methods

Study sites

Ostional National Wildlife Refuge

Ostional National Wildlife Refuge (ONWR) was limited to a small area in Guanacaste Province, Costa Rica (from 85^{o} 43’50” W and 10 01’00” N to 85^{o} 40’40” W and 09^{o} 54’30” N), corresponding to the marine-terrestrial zone (MTZ) of Ostional, Nosara, Peladas and Guiones beaches. The total area of Ostional Refuge was 13,390 km^2 with 12,875 km^2 in the ocean and 515 km^2 on land (MINAE, 2003). The land portion consisted of a thin area 200 m wide and 19 km long (Figure 3.1). The ONWR belonged to the life zone of the basal humid rain forest transitioning to dry forest. The dry season lasted from December to April. The rest of the year corresponded to the rainy season. The annual mean precipitation was 210 cm and the annual mean temperature 27.5 °C (22- 33 °C) (Barrantes et al. 1985; Orrego, 2014, Chapter 2).

Playa Ostional had an available nesting area of approximately 19,000-52,000 m^2, which changed between nesting events due to erosion, run off and tidal influence. Ostional was divided into seven nesting areas with posts every 50 m, from Punta India (North) to Nosara river mouth (South): Rayo1 (approximately 850 m, posts 1-17), Rayo

2 (approximately 550 m, posts 18-29), Rayo 3 (approximately 500 m, posts 30-40), Rayo 4 (approximately 900 m, posts 41-59), Main Nesting Beach (MNB, approximately 900 m, post 60-78), Nosara 1 (approximately 2,300 m, posts 79-125), and Nosara 2 (approximately 700 m, posts 126-140). The MNB, had the greatest nesting activity. The beach was free of human development and was located between two estuaries. However, the trend from 1992 to 2012 was a shift in nesting to other parts of the nesting beach where the frequency of arribada was increasing (Cornelius, et al., 1991; Ballestero, et al., 1998; Chaves, 2007; Orrego, 2014, Chapter 2). The village of Ostional was behind the beach along posts 35 to 60 (ADIO, et al., 2007, 2012). There were two estuaries that during the rainy season often broke through the beach into the ocean as result of heavy rains, and destroyed many turtle clutches. Based on the spatial distribution of nesting from previous studies, I established three consecutive sectors on the beach from north to south with a total of 2,800 m of beach. Number posts were fixed in the vegetation area every 50 m. Sector 1 included Rayo 2 and 3 (posts 20-40 approximately 1000m), Sector 2 included Rayo 4 (approximately 950 m, posts 41-60) and Sector 3 included MNB (approximately 850m, posts 61-78). The access to the refuge was easy throughout the year (Orrego, 2014, Chapter 2).

La Flor National Wildlife Refuge

The La Flor National Wildlife Refuge was located in Rivas Province, on the Nicaraguan Pacific Coast, 22 km south of San Juan, close to the border with Costa Rica.

The limits were Punta Brasilito in the north and Punta Clavo in the south. The nesting beach was about 1.1 km long (Hope, 2002) (Figure3.1).

Playa La Flor had an available nesting area of approximately 15,729 -33,361 m², which changed between nesting events due to erosion, run off and tidal influence. The beach was free of human development and was located between two estuaries. While the greatest nesting activity was concentrated within some 400 m, the whole beach was 1,100 m long. However, my study used only 1,000 m, since the last 100 m southern end were across an estuary with very difficult access conditions during the rainy season, when the nesting season took place. I defined three sectors from north to south covering a total of 1,000 m. Numbered posts were fixed in the vegetation area every 50 m (sector 1: posts 1-6, sector 2: posts 7-14 and sector 3: posts 15-20). Although most nesting occurred in sector 2 there was nesting activity in sectors 1 and 3 too. La Flor was free of human development inside the wildlife refuge, but it had communities in the surrounding area from which people came to the beach to enjoy its ecosystem services, such as surfing, swimming, and fishing. Several community members engaged in egg poaching. During the duration of this study there was no legal egg harvest program in La Flor. The access to the refuge was easy throughout the year.

Chacocente River National Wildlife Refuge

The Chacocente River National Wildlife Refuge was located in the Carazo Province on the Pacific Coast of Nicaragua, with a beach length of about 12 km. The nesting beach itself was about 1.5 km**.** The annual precipitation ranged from 140 to 160 cm. The average temperature was 27 °C**,** with a maximum of 34 °C in April, the driest month (MARENA, 2008) (Figure 3.1).

Chacocente beach had an available nesting area of approximately 17,367 – 28,633 m^2, which changed between nesting events due to erosion, run off and tidal influence. The beach had 1.5 km available for nesting, but the greatest nesting activity occurred within 700 m. The beach was free of human developments inside the refuge, but some families lived surrounding the protected area. It was located between two estuaries. My study used three sectors oriented north to south with a total of 1,500 m, divided every 50 m by numbered posts fixed in the vegetation area: sector 1 (posts 1-8), sector 2 (posts 9-16) and sector 3 (posts 17-30). Although most nesting occurred in sector 3 there was nesting activity in sectors 1 and 2 too. During the dry season visitors came to the beach by walking or driving to enjoy the ecosystem services such as surfing, swimming and fishing. Several visitors engaged in egg poaching. During this study, there was no legal harvest program in Chacocente. During the rainy season, the access was difficult and only possible by boat.

Data collection

Arribada nesting activity

It is difficult to get an accurate estimate of the size of an arribada nesting population because there are often so many turtles on the beach that they are hard to count (Eguchi, et al., 2007). However, a new method developed by Gates and Valverde (Gates, et al., 1996; Valverde and Gates, 1999) was effective in getting an accurate count of arribada turtles (Valverde, et al., 2012) and I used that strip transect in time method in this study. I used the definition of Gates et al. (1996) to declare an arribada as the presence of 100 or more nesting olive ridley females on the beach at any one time during a nesting session. From July 2010 to March 2011, I only counted turtles that displayed egg-laying activity, so a turtle was equivalent to one clutch.

Experimental Plots

On all three beaches I defined two beach zones from the vegetation to the sea: Zone 1 – high beach (vegetation), and Zone 2 - mid beach (open sand). Due to a high number of clutch losses by erosion, open estuaries and tides in zone 3 (Orrego, 2014, chapter 2) I eliminated zone 3 for this research to avoid losing information (Figure 3.2). From July 2010 to March 2011 at Ostional I placed six plots in each zone, within each sector in each arribada, half open and half closed. Closed plots were fenced to keep out people and predators. At La Flor and Chacocente I placed five plots in each sector in each arribada, three in zone 1 and two in zone 2, three open and two closed. There were fewer plots at La Flor and Chacocente because the beaches were smaller. Plots were 2 m x 2 m. Open plots were unprotected, delimited by four small posts, one in each corner of the plot, which emerged 10 cm from the sand surface (Figure 3.3). Closed plots were surrounded with a wire fence of 3 cm x 3 cm mesh, 8 m long x 1.5 m high, and kept in place from days 2 to 55 of the incubation to keep out predators and humans (i.e. no egg extraction) (Figure 3.4). I marked study nests inside each plot with a numbered 30-cm-long plastic flagging tape within the nest chamber before the turtle finished nesting (one color code for each arribada).

Plot monitoring

I started monitoring all plots on day 2 of the incubation process until the end of incubation for each arribada (day 55). I inspected each plot four times/ day (06:00, 12:00, 18:00 and 00:00 h) and recorded: plot number, sector, zone, sand temperature at 35 cm depth for each plot, presence of new nests and false nests (i.e. when a sea turtle came to the beach but did not nest), predation and/or loss of eggs by insect larvae or vertebrates such as dogs and raccoons, erosion, legal or illegal human harvest, encroachment by an open estuary, nesting turtles, and other general observations relevant to incubation dynamics. The presence of a loose flagging tape on the surface of the sand during or after an arribada was recorded as an indication that the nest had been destroyed by other nesting females. If flagging tape was found at any other time, I checked to determine whether the clutch was destroyed by predation and/or erosion from tidal action or an open estuary.

Excavations and hatching rate

All nests in plots from each beach were excavated 55 d after oviposition. I dug to 70 cm deep, removed all eggshells and hatchlings, and took a sand sample of about 100 g from the center of each plot at 35 cm deep to analyze for organic matter. Excavation data for each plot included number of: a) empty shells (the criterion used was > 50% shell - 1 egg), b) dead and live hatchlings, c) emerged hatchlings, d) eggs with or without apparent embryo development, and e) neonates that had been predated upon by worms, beetle larvae, and larvae of flies. Eggs found were classified into embryonic development stages according to Crastz (1982), Ackerman (1997) and Chacón, et al. (2007): Stage 0 (no apparent embryonic development), stage I (embryo filled 1- 25% of amniotic cavity), stage II (26-50%), stage III (51-75%), stage IV (76-100%), and stage V (empty eggs shells). However, to enhance the resolution of the plot production data, I included an additional stage that put together all neonates depredated on by larvae of flies or beetles. I defined this as Stage V, thus the former Stage V, and (empty eggs shells, from hatched turtles) became my Stage VI. I calculated hatching rate for each surviving plot that escaped from natural or anthropogenic egg loss as follows:

Hatching rate (%) = Number of Empty Egg Shells x 100 / Total Number of Eggs

Hatchling production

I estimated hatchling production for each plot by zone and sector for each beach during the excavation. I calculated the percent hatchling emergence based on observations of marked plots. I estimated the proportion of clutches destroyed by predation, erosion, open estuaries, subsequent nesting females, poaching or legal harvest, and other causes. I estimated the number of successful clutches (i.e. clutches with at least one hatchling that emerged). Percent emergence was estimated according to the formula:

$$P (\%) = H \times 100 / E$$

Where P was the percent emergence, H was the number of emerged hatchlings, and E was the number of eggs per clutch.

I estimated the total nesting area for each sector by arribada, calculated the hatchling production for that sector based on the production per m^2 and extrapolated that area to the total nesting area available for each arribada at each beach. Ostional had a nesting area of approximately 19,000-52,000 m², La Flor a nesting area of 15,729-33,361 m², and Chacocente a nesting area of 17,367 – 28,533 m², which changed over time from erosion, run off and tidal influence.

Natural and anthropogenic causes of eggs loss

I estimated the proportion of clutches destroyed by natural causes (i.e. sand erosion-high tide, opened estuaries, raccoon predation and nesting turtles) and by anthropogenic causes (i.e. harvest, poaching or dog predation).

Morphometric measurements

For each arribada I selected at least 30 turtles to take morphometric measurements such as curved carapace length (CCL) and curved carapace width (CCW), total eggs/turtle, and time spent laying eggs.

Statistical analysis

My data had a normal distribution. I tested for homogeneity of variance with Cochran's C test. I used parametric, two and three way ANOVAs to estimate differences between means. I used parametric, three-way ANOVAs to estimate differences in mean hatching success by beach zone, plot type (open or closed), blocking on individual plots. I used two-way ANOVAs to estimate differences in mean number of eggs lost by nesting activity between beach zone and sectors.

I used a General Linear Model (GLIM) to test for differences in mean; a) hatching success between beach zones and sectors; b) number of total of eggs laid between zones and sectors; c) number of hatchlings (Stage VI) produced between zones and sectors; d) number of hatchlings (Stage VI) produced between zones and types of plots (open or enclosed); e) number of hatchlings (Stage VI) produced between sectors and types of plots (open or enclosed) and interactions with organic matter. *A posteriori* comparisons between means were carried out with Least Significant Difference (LSD), Tukey or Scheffe tests. Statistical procedures followed Sokal and Rohlf (1995). Statistical analyses were completed with Statgraphics Centurion XV 15.1.02 software by Statpoint Technologies, Inc.

Results

General Information

There were 5 arribadas at Ostional, 5 at La Flor and 4 at Chacocente during the study period July 2010 to March 2011, a La Niña year. At Ostional there were 489,940 nesting females or nesting events, since some females may have nested more than once, at La Flor there were 72,854, and at Chacocente there were 17,696 (Table 3.1). Data from Ostional, collected during this study, were published in Valverde et al. (2012).

From July 2010 to March 2011, I placed 291 plots among the three sections of all beaches. There were 156 plots at Ostional, between posts 20-78 (Sectors 1, 2, and 3). In the fifth arribada turtles only nested in sector 3. At La Flor there were 75 plots, between posts 1- 20 during five arribadas and at Chacocente there were 60 plots, between posts 1-30 during four arribadas. I monitored 3,968 study clutches with an average of 95 eggs per clutch on every beach (N = 978; range = 2 – 193; SD = 2.14) and a total of 376,769 eggs. There were 193,482 eggs laid on Playa Ostional, 127,720 eggs laid on Playa La Flor, and 55,567 eggs laid on Playa Chacocente. Sector 3 had the highest density of eggs at

Ostional, followed by sector 2 and 1, with most eggs laid in the mid-beach zone. Sector 2 had the highest density at La Flor followed by sector 3 and 1 with most eggs laid in the high beach zone. Sectors 2 and 3 had the highest density at Chacocente, followed closely by sector 1, with most eggs laid in the high beach (Table 3.2).

Natural and anthropogenic clutch loss

Of the 3,968 marked clutches, 1,871 (47.2%) were lost to natural and human causes. Of those clutches, 552 (29.5%) were lost due to natural causes. At Ostional nesting activity accounted for 80.6 % of study clutches that were lost to natural causes and erosion-open estuary-tides accounted for 18.1%. At La Flor nesting activity accounted for 92.1 % of study clutches that were lost to natural causes and erosion-open estuary-tides accounted for 7.9 %. At Chacocente erosion-open estuary-tides accounted for all of the natural clutch loss (Table 3.3).

Nesting activity at Ostional had the greatest impact in sector 3 (50%) and zone 2 (56.9 %), and at La Flor had the greatest impact in sector 1 (52.0 %) and zone 1 (52.0%). Raccoons removed 6 clutches at Ostional (Table 3.4). No clutches were destroyed by coati (*Coati mundi*), coyotes (*Canis latrins*), or other wild mammals. Crabs and avian predators removed eggs at Ostional and La Flor once a nest was opened. Black vultures (*Coragys atratus*), turkey vultures (*Cathartes aura*), crested caracara (*Caracara cheriway*), frigate birds (*Frigata magnificenses*), and chickens came to nests after they were dug up by dogs (*Canis familiaris*), raccoons, and people, or exposed by natural causes such as: erosion due to open estuaries and tides, and nesting activity. Wood storks

(*Mycteria americana*) and black vultures (*Coragyps atratus*) also foraged on emerging turtle hatchlings.

Anthropogenic causes destroyed 1,319 study clutches (70.5% of total losses). Most of those clutches were at La Flor (80.4%) with 19.6% at Ostional. Chacocente was free from human loss (Table 3.5). Illegal harvest (poaching) by humans had the greatest impact, removing 647 clutches (49.0 % of anthropogenic losses, but 16.3 % of total clutches) followed by dog predation (42.9 % of anthropogenic losses, but 14.3 % of total clutches) and legal harvest (8.0 % of anthropogenic losses, but 2.7 % of total clutches). Poaching activity at Ostional removed 12.4% of clutches lost by anthropogenic causes and most of that activity was in sector 2 (71.4%) in front of Ostional village and in the mid beach (zone 2) (57.1%). Poaching activity at La Flor removed 58.0 % of clutches lost by anthropogenic causes and that activity was spread fairly equally along the beach with more activity in the high beach (zone 1) than the mid beach (zone 2). Dogs destroyed 566 clutches (42.9% of anthropogenic losses, but 14.3 % of total clutches). Dog activity was highest at La Flor (446 clutches) and was concentrated in sectors 1 and 2 along the high beach. At Ostional dogs destroyed 120 clutches primarily on the high beach in sector 2 in front of the village and sector 3, the MNB (Table 3.6).

Embryonic Development

In the 2,097 clutches (52.8%) that survived natural and anthropogenic disturbance, there were 199,199 eggs (Table 3.7). The vast majority of the eggs (172,376) did not show any signs of development. That included 92.1 % of eggs at Ostional, 80.8 % of eggs at La Flor and 75.4 % of eggs at Chacocente. At Ostional most of those eggs were in sectors 2 and 3 and were evenly distributed in both zones (Table 3.8). At La Flor and Chacocente stage 0 eggs were fairly evenly distributed in all sectors, but more in the high beach.

Hatching Success

A total of 12,670 eggs (6.4%) finished the incubation process and produced hatchlings (Table 3.9). Ostional produced 3,064 hatchlings (2.4 % of total surviving eggs), La Flor produced 1,328 hatchlings (6.3 %), and Chacocente produced 8,278 hatchlings (16.0 %). At Ostional 41 plots produced hatchlings, primarily in sectors 3 (53.7 %) and 2 (39.0 %) in the mid beach zone (58.5%). At La Flor 57 plots produced hatchlings and they were fairly evenly distributed in all three sectors primarily in the high beach. At Chacocente 52 plots produced hatchlings and they were fairly evenly distributed in all three sectors primarily in the high beach (Table 3.9).

Since there was variance was not homogeneous, I transformed data to log 10 for statistical tests. There was a statistically significant difference in hatching success between beaches ($F = 41.46$; $df = 2, 149$; $P < 0.0001$), with the highest success at Chacocente (16.0 %) and the lowest in Ostional (2.4 %) (Table 3.9, Figure 3.5).

A Two Way ANOVA estimated the effects of beach and sector on mean hatching rate. There was a significant difference in hatching rate due to beach, sector and their interactions respectively ($df = 2, 289$; $F = 70.87$, $P < 0.0001$), ($df = 2, 289$; $F = 12.99$, $P < 0.0001$), ($df = 2, 289$; $F = 7.98$, $P < 0.0001$). Chacocente had the highest hatching success and all three beaches were significantly different (Figure 3.6). At Chacocente, the difference in hatching success between sectors of different densities was apparent, whereas there were no differences at La Flor and Ostional. Hatching success was highest in the high density sector and lowest in the low density sector. (Figure 3.6)

A Two Way ANOVA for hatching success by beach and zone - indicated that there was a statistically significant effect of beach on hatching rate ($F = 69.17$; $df = 2; 289$; $P < 0.0001$), a statistically significant effect of zone on hatching rate ($F = 8.37$; $df = 1; 289$; $P = 0.0041$), and statistically significant effect of interactions ($F = 4.86$; $df = 2; 289$; $P = 0.0084$), (Figure 3.7). The mid beach (zone 2) at Chacocente had a higher hatching success than the high beach (zone 1), but there were no significant differences at Ostional or La Flor.

Hatching success was affected by season and by arribada. A Two Way ANOVA for hatching success by beach and season indicated that there was a statistically significant effect of beach on hatching rate ($F = 64.37$; $df = 2; 289$; $P < 0.0001$), and of season on hatching rate ($F = 2.76$; $df = 1; 289$; $P = 0.0059$), as well as of their interactions ($F = 3.89$; $df = 2; 289$; $P = 0.0215$) Hatching rate was greater during rainy season arribadas than dry season arribadas at Chacocente (Figure 3.8) but hatching success was so low at the other beaches that season did not affect it. At La Flor, there was a statistically significant effect of arribada on hatching success (One Way ANOVA, $F = 4.29$; $df = 4; 74$; $P = 0.0037$) (Figure 3.9). At Chacocente there was no statistically significant effect of arribada on hatching success (One Way ANOVA, $F = 2.33$; $df = 3; 59$; $P = 0.0842$) (Figure 3.10). At Ostional, there was a statistically significant effect of arribada on hatching rate (One Way ANOVA, $F = 2.66$; $df = 4; 154$; $P = 0.0352$) (Figure

3.11). Consistently, across the three beaches studied, hatching rates were lower during arribadas in the dry than in the rainy season.

A Two Way ANOVA for hatching success by beach and type of plots - indicated that there was a statistically significant effect of beach on hatching success, but not by type of plots (open or closed) ($F = 42.02$; df = 2; 289; $P < 0.0001$) (Figure 3.12). This suggests that, either exclusion of predators and humans did not have an important effect on hatching success or that predation by animals and/or humans was at such negligibly low levels that the experimental treatment did not reveal significant differences in hatching success.

A Two Way ANOVA for organic matter by beach and zone indicated that there was a statistically significant effect of beach on organic matter content of the sand ($F = 19.69$; df = 2; 289; $P < 0.0001$) but no statistically significant effect of zone or the interactions of beach and zone on organic matter (Figure 3.13). Chacocente had much less organic matter in the sand than the other two beaches. A Two Way ANOVA for organic matter by beaches and densities indicated that there was a statistically significant effect of beach on organic matter content of the sand ($F = 19.69$; df = 2; 289; $P < 0.0001$) but not of density of clutches. The interaction of beach and sector was statistically significant ($F = 5.09$; df = 4; 289; $P = 0.0006$) (Figure 3.14). A Two Way ANOVA for organic matter contents by beach and season indicated that there was a statistically significant effect of beach on organic matter ($F = 26.93$; df = 2; 289; $P < 0.0001$) but not of season ($F = 0.0$; df = 1; 289; $P = 0.9715$). The interaction of beach and season was statistically significant ($F = 12.83$; df = 2; 289; $P < 0.0001$) (Figure 3.15).

A Two Way ANOVA for organic matter content by beach and type of plot revealed a statistically significant effect of beach on organic matter contents ($F = 12.93$; $df = 2; 289$; $P < 0.0001$) but not of type of plot ($F = 1.38$; $df = 1; 289$; $P = 0.2403$) or of their interactions ($F = 0.35$; $df = 2; 289$; $P = 0.7059$) (Figure 3.16). Hence, exclusion of humans and predators did not seem to have a strong effect on organic matter contents. Past nesting activity as well as natural and anthropogenic disturbances set the organic matter content of the beaches before the plots were established in this study. The experimental manipulations in this study did not affect the organic content of the beaches.

Hatchling production

Hatchling production (Table 3.10) showed the same trend as hatching success (Figure 3.17) for each beach. A One Way ANOVA indicated that there was a statistically significant effect of beach on hatchling production ($df = 2$; $F = 40.58$; $P = 0.001$). Chacocente produced many more hatchlings than Ostional and La Flor although it had the fewest eggs (Figure 317). A Two Way ANOVA indicated that there was a statistically significant effect of season and arribada on hatchling production ($df = 4, 289$; $F = 3.58$; $P = 0.072$) and a statistically significant effect of the interaction of season and arribada ($df = 4, 289$; $F = 3.01$; $P = 0.0187$). Hatching production was greater during the rainy season than the dry season ($df = 1$; $F = 4.15$; $P = 0.0425$) (Figure 318) and was greater in the earlier arribadas that were in the wet season (Figure 3.19).

A Two Way ANOVA indicated that there was a statistically significant effect of density on hatching production ($df = 1, 289$; $F = 7.73$; $P = 0.0058$) (Figure 3.20). There were more hatchlings produced in the high density sectors than in the medium density sectors. There was no significnat difference in hatchling production in the two beach zones. There was no statistically significant difference in numbers of hatchlings produced in open vs closed plots (df = 1, 289, F = 2.70, p = 0.1013). There was also no statistically significant effect of number of eggs per plot on hatchling production. Thus, disturbance by turtles digging other nests and exposing plots to harvest, poaching and dogs did not increase hatchling production. A One Way ANOVA indicated that there was a statistically significant effect of % organic matter on hatchling production (df = 66, 289; F = 1.60 ; P = 0.0061) (Figure 3.21). It was apparent that many clutches did not produce hatchlings no matter what the organic matter content of the sand. Of those clutches that did produce hatchlings, those clutches in sand with low organic matter content produced more hatchlings than those with high organic matter content.

Discussion

Population status

Playa Ostional had 489,940 nesting olive ridley females, and clutches, during this study, a La Niña year. Between 2006 and 2010 arribadas ranged in size between 3,564 and 476,550 nesting females (Valverde, et al., 2012). Contrary to previous studies (Cornelius, et al., 2007; Eguchi, et al., 2007), my data and those of Valverde, et al. (2012) indicate that there were large intra and interannual fluctuations in size of arribadas and no recent trend (Orrego, 2014, Chapter 2). The best data indicate that between 1988 and 1997 the nesting population was about 588,501 and fluctuated between 232,318 and 1,147,969 turtles (Ballestero, et al., 1998). Data in this study and in Valverde, et al. (2012) indicate that the arribadas at Ostional recently fluctuated between 3564 and

476,550 turtles and the effective yearly nesting population was about 200,000 to 860,000. So the arribada size population has decreased in abundance since the early 1990s.

There were 72,854 nesting female turtles at Playa La Flor in 2010/11. In 1999/2000 there were 46,000 and in 2006/07 there were 187,000 (Honarvar, et al., 2008). There were 17,696 nesting female olive ridleys at Playa Chacocente in 2010/11. In 2009/10 a direct count indicated 42,591 turtles and Torres and Romero (2010) reported that the 2009/10 nesting arribada was 16.1% smaller than the 2008-09 nesting season. Despite the same difficulties counting turtles at Playas La Flor and Chacocente in the past as at Ostional, it appears that those populations are declining as well, espcially since 2010/11 was a La Niña year when more turtles would be expected.

Variation in size of arribadas is probably related to climatic variation as is the size of the nesting leatherback turtle (*Dermochelys coriacea*) population at nearby Playa Grande (Saba, et al., 2007; Reina, et al, 2009). However, it appears that all three arribadas are in decline. Because the decrease is occuring on all three beaches that are geographically separated there are probably related causes affecting all three populations. The decrease may be due to the low hatchling production on the beaches related to past harvest, other anthropogenic effects, and high density of nests. Another common negative factor is fishing pressure. The Costa Rican longline fishery caught 699,600 olive ridleys, including 92,300 adult females from 1999 to 2010 (Dapp, et al, 2013). It is reasonable to assume that the fishing fleets of Nicaragua and other Central American and South American countries also caught large numbers of olive ridley turtles. The impact of that fishing pressure appears to be contributing to the decline of the regional population of olive ridley turtles.

The strip transect in time method (Valverde and Gates, 1999) of counting turtles during an arribada used in this study only counts turtles that are laying eggs and is the most accurate way to assess the population (Valverde, et al. 2012). In order to determine the trends in these turtle populations it will be necessary to continue counting turtles with this method for at least one turtle generation (13 years) (Avens and Snover 2013). Scientists and managers at La Flor and Chacocente should use this method because not only is it the most accurate way to count turtles, but it is also easier to implement than the direct counting method and will provide comparable data from all three beaches.

Eggs and hatchlings

During this study olive ridley turtles laid fewer eggs per clutch (95) on all beaches than they did in the past at Ostional (107.4) (Cornelius, et al., 1991) and fewer eggs per clutch than for Mexican populations (105), Indian populations (124) and for Playa Nancite in Costa Rica (100) in the past (Marquez, 1990; Cornelius, et al., 1991; Kumar, et al., 2013). However, clutch size was similar to recent data from Playa La Flor (95) (Honarvar, et al., 2008). It is not clear why this reduction has occurred. Perhaps it is related to the high recent population sizes of turtles and the uncertain resources in the Eastern Pacific related to El Niño and La Niña cycles (Saba, et al., 2007). The number of eggs laid varied by sector and zone. The greatest number of eggs was laid in Zone 1, near the vegetation, of all sectors for Chacocente and La Flor. At Ostional turtles laid the most eggs in zone 2, the mid beach, of the main nesting beach (MNB).

There was no significant difference in hatching success in the two zones or three sectors at Ostional and La Flor, probably because hatching success was so low on those beaches and there was considerable variation among plots. Hatching success was lower at Ostional 2.4% than reported by Valverde et al. (2012) (18.4 %) but they did not include clutches with no hatchlings produced. It was similar to that reported by Cornelius, et al., (1991) (6.0 %) so it appears that Ostional has had a low hatching rate for many years. There was a difference in hatching success at Chacocente with better success in zone 2 and the high density sector, followed by the low and medium density sectors. The high density of clutches at Chacocente was lower than the high density of clutches at Ostional so we cannot conclude that high density improves hatching success. Honarvar et al. (2008) found that experimental plots with high density of clutches (9 m^{-2}) at Playa Nancite had lower hatching success (29.5%), than plots with medium (5 m^{-2}) and low density (2 m^{-2}) (55.9 % and 71.6 %). However, hatchling production was similar in high (192 m^{-2}) and moderate (189 m^{-2}) density plots and higher than in low (100 m^{-2}) density plots. Hatching success was higher at La Flor in 2006/07 (16 % in low density area and 10 % in high density area) (Honarvar, et al. 2008) than in this study (6.3 %). Honarvar, et al. (2008) reported, based on simulations of nest density for the local number of nesting females for the whole 2006/2007 nesting season, that high density of nests on Playa La Flor was 10-16 m^{-2}. Hatching success for the December 2006 arribada at La Flor was 12 % with a density of 5-7 m^{-2}. Hatching success at Playa Nancite was 8 % in 2006/07 with a nest density of 4-5 m^{-2} (Honarvar, et al., 2008). In this study, Playa La Flor ranged in nest density inside plots between 2-43 nests FOR PLOT OR PER M2, Ostional ranged between 1-31, and Chacocente ranged between 4-23. The estimated of number of nests m^{-2} by sector, zone and beach showed Ostional ranged between 10-19, La Flor 15-31, and Chacocente 8-14 (Table 3.9).

Hatchling production was highest in zone 1 of sector 1 for La Flor and Chacocente (high density areas) and was highest in zone 2 and sector 3 for Ostional. The high density of clutches in zone 1 of sector 3 at Ostional was probably responsible for the low hatching success there (see below). The large number of eggs laid in zone 2 of sector 3 meant that the area produced more hatchlings than zone 1 of sectors 1 and 2 in Ostional. The high productivity at Ostional of zone 2 and sector 3 was probably due to large number of eggs and the fresh sand present there from frequent erosion and accretion of sand from high tides and openings of the estuaries and the limited number of clutches laid in sectors 1 and 2. The high productivity at La Flor and Chacocente of zone 1 and was probably due to the fresh sand in the high beach near the vegetation. Zone 2 in all beaches also had fresh sand present there from frequent erosion and accretion of sand from high tides and openings of the estuaries. Cornelius, et al. (1991) found greater hatchling production near the water and associated it with a positive effect of the wave wash.

There was no statistically significant difference in hatching success or in numbers of hatchlings produced in open and closed plots. There was also no statistically significant effect of number of eggs per plot on hatchling production. Thus, disturbance by turtles digging other nests and exposing plots to harvest, poaching and dogs did not increase hatchling production. In addition, density of eggs also did not affect hatchling production. Other factors such as zone and sector appeared to play a more important role in hatchling production than whether a plot was open to harvest and other anthropogenic effects. These results do not support the unpublished claims of local biologists that the egg harvest, by reducing egg density, would increase hatchling production. Arauz and Mo (1994) found that the egg harvest did not increase hatchling production as compared to areas with no harvest.

There was variation in hatching success for the different arribadas and that was probably due to the number of clutches deposited in an arribada, the amount of harvest (Valverde, et al. 2012) and environmental factors (Valverde, et al., 2010). Hatching success was highest in arribadas in the wet season as opposed to arribadas in the dry season. Thus, environmental factors and sand quality played the key roles in controlling the number of hatchlings produced on arribada beaches.

Natural clutch loss

Natural causes removed 13.9 % of experimental clutches. That was lower than the estimates for Nancite (36.7 %) and Ostional (20 %) by Cornelius et al. (1991). Erosion from estuaries and high tides removed 22.1 % of clutches and nesting by other turtles destroyed 76.8 % of the clutches lost to natural causes. Most clutches lost to erosion were in zone 2 of sector 3 at Ostional, La Flor, and Chacocente. Cornelius et al. (1991) reported a similar loss due to erosion at Ostional. Torres and Romero (2010) reported losses from nesting activity of about 52.0 % at Chacocente. Honarvar et al. (2008) in simulations predicted nest destruction on La Flor at 40.2% in a high density section, and predicted a nest destruction for the 2006-2007 nesting season of 87.2%. In this study

Chacocente was free from nesting activity losses because the arribada size was declining and the overdigging or nest destruction had a direct relationship with density (Honarvar, et al., 2008; Ocana, 2010). However, losses of clutches from erosion/ open estuaries and tides was about 23% at Chacocente in 2009/2010 (Torres and Romero, 2010). Losses from erosion are also high for leatherback turtle clutches at Tortuguero, on the Caribbean coast of Costa Rica (Leslie, et al., 1996) and at Sandy Point on St Croix in the US Virgin Islands (Boulon, et al., 1996). Both are high energy beaches where sand is often removed and redeposited during the nesting season. Nesting by other turtles destroyed 80.6 % of clutches lost due to natural causes at Ostional. Not surprisingly most of the loss was in sector 3 where most of the clutches were laid, but was also high in sector 1 and 2. The effect of excavation by turtles was much lower in zone 1 than in zone 2.

Losses from natural predators was minimal. Racoons only removed 6 clutches at Ostional and other wild mammals had no effect. There were no people and no harvest at Chacocente and yet there were no natrual predators there. Perhaps natural predators have not adjusted their behavior in response to the recent removal of humans and dogs from that beach. There were no natural predators at La Flor because it was dominated by people and dogs. Natural predators usually have a great effect on turtle clutches and in freshwater turtles can remove up to 84 % of eggs (Burke, et al., 1998). On many nesting beaches natural predators have a large impact on sea turtle nesting success (Heithaus, 2013). More than 90 % of nests were depredated by foxes in northeastern Australia before introduction of predator control (Limpus and Limpus, 2003). In Turkey, foxes and golden jackals depredate up to 75 % of green turtle (*Chelonia mydas*) nests (Brown and

MacDonald, 1995). Racoons and armadillos (*Dasypus novemcinctus*) destroy up to 95% of sea turtle nests at Hobe Sound in Florida (Engeman, et al., 2006). At Nancite beach in Costa Rica natural predators including coatis, vultures, coyotes, and others destroy many olive ridley nests (Cornelius, 1986; Cornelius, et al., 1991; Plotkin, et al., 1997; personal observation). Natural predators have been removed from the food web on the beaches of Ostional and La Flor because of the presence of humans and dogs.

Anthropogenic clutch loss

Anthropogenic effects accounted for 70.5 % of total losses of nests. Poaching had the greatest impact (49.0 %), followed by dog predation (42.9%) and legal human harvest (8.0 %), but only at Ostional and La Flor. The government of Nicaragua closed in 2006 Playa Chacocente from egg harvest and it was free from human impact during this study. Enforcement was not the main reason. Chacocente was only accessible by boat during rainy season and local communities were far from Chacocente. In contrast, la Flor and Ostional had easy access all year. Dog predation at Ostional had the greatest impact in sectors 2 and 3. Sector 2 was in front of the village and sector 3 received the greatest number of clutches. Predation by dogs at La Flor had the greatest impact in sector 1 that was close to a village and route of access, sector 2 that received the greatest number of clutches, and zone 1, the high beach near vegetation. Poaching in Ostional was highest in sector 2 in front of the village and low in sector 1. There was no poaching in sector 3 due to patrolling by ADIO-MINAE and police on the MNB. In La Flor poaching was highest in sector 1 because it was farthest away from MARENA control, but also occurred in sectors 2 and 3. Both beaches had more poaching activity in zone 1 because the vegetation was a refuge for poachers.

Poaching of sea turtle eggs is high on most unprotected beaches in Costa Rica (Spotila, 2011). This included green turtle clutches on unprotected Playas Nombre de Jesus and Zapotillal 50 km north of Ostional (Blanco, et al., 2012) and leatherback turtle clutches from Playa Grande in the same area from about 1970 to 1990 (Santidrián Tomillo, et al., 2008). The effect of poaching (3 %) on green turtle nests on Playa Cabuyal, a non protected beach north of Playa Grande, was reduced by the presence of scientists who discouraged the taking of eggs (Santidrián Tomillo, et al., 2014). It is important that guards from ADIO and MINAE in Costa Rica and from MARENA and the police and military in Nicaragua expand their activity into all sectors of sea turtle beaches to reduce the impact of humans in the areas where incubation conditions are favorable for embryonic development.

The ONWR human population in 2012 was about 600 people and there has been a legal egg harvest program for subsistence since 1987 (Spotila, 2011; Valverde, et al., 2012). In the early 1980’s, 350 families lived surrounding Chacocente. They were living in poverty, had few basic services and traveled to Chacocente to collect turtle eggs in the legal harvest program for consumption (Hope, 2002; Campbell, 2007). Arauz (1995) stated that harvest by humans at La Flor was small before the creation of the wildlife refuge and after that it increased when people were excluded when the Chacocente legal harvest closed. Hope (2002) stated that the egg harvest benefits were divided among 598 families. However, MARENA prohibited the controlled egg harvest program in

Nicaragua in 2005, except for indigenous communities in the Caribbean that had an annual sea turtle harvest quota, and after that the military helped MARENA to protect the marine protected areas. Since then people invaded La Flor claiming a right for communities and the legal harvest changed into illegal harvesting or poaching. There were about two thousand people living around the refuge in 2010/11. Torres and Romero (2010) reported the same situation during 2008-2009 nesting season at Chacocente and La Flor. Torres and Romero also reported that poaching removed 80% of clutches at Chacocente in 2009 due to an invasion of the protected area.

A legal harvest still existed at Ostional after more than 35 years. In 2010/2011 the harvest took 106 out of 3,968 experimental clutches (2.7%). However, when dogs and poaching were added the number of clutches removed at Ostional and La Flor increased to 1,319 (33.2 %). Natural causes eliminated 552 clutches. Once those 552 clutches were removed from the count, then harvest removed 3.1 % of the remaining clutches from all experimental plots. This harvest estimate was lower than those of Ballestero, et al.(1998) and Valverde, et al. (2012) who calculated harvest as 21.2% for Ostional alone based on information from ADIO. An analysis of information from ADIO during my study showed a harvest in 4.7% of the total of eggs deposited for all nesting females. All anthropogenic causes removed 38.6 % of the remaining clutches from both open and closed plots on the three beaches overall. These values probably underestimated the effect of anthropogenic impacts since half the clutches were protected in closed plots. Future estimates should be based on careful data collection from well placed experimental plots distributed throughout the arribada area on all three beaches.

On undisturbed beaches sea turtles transfer significant amounts of energy and nutrients to the terrestrial ecosystem by laying their eggs in the beach (Bouchard and Bjrondal, 2000; Hannan, et al., 2007; Vander Zanden, et al., 2012). Nutrients and energy are transferred into natural predators that in turn cycle it into the ecosystem. At Ostional and La Flor, and previously at Chacocente, the transfer of energy and nutrients from sea turtle eggs to natural predators was short circuited and diverted to the human dominated ecosystem. Therefore, the natural ecosystem suffered a loss of resources and that undoubtedly affected populations of mammals, birds and other animals.

Dogs destroyed 42.9% of clutches lost to human causes at Ostional and La Flor. That was more than harvest and almost the same impact as poaching. As humans live closer to protected areas around the world free roaming dogs create increased problems for wildlife protection. In many protected areas domestic dogs from adjacent villages prey on endangered willife (Izaguirre, et al., 2014). In Costa Rica domestic animals are prohibited from protected areas. However, that law is not enforced at Ostional or in most other protected areas (Spotila, 2011) where dogs detroy many clutches. For example, at Playa Grande in Parque Nacional Marino Las Baulas dog predation on leatherback turtle eggs and hatchlings increased directly with the human population and increasing development (Santidrián Tomillo, et al., 2010). During 2005-2006 only 8% of the nests were disturbed at Playa Grande, but in 2007-2008 and 2008-2009 dogs dug up more than 50% of nests. Despite these data dogs still roamed free on Playa Grande because of the delay and ineffectiveess of protection measures (J. R. Spotila, unpublished data). At

Playa Cabuyal dogs detroyed 12 % of clutches (Santidrián Tomillo, et al. 2014). Similar problems occur in Mexico (Izaguirre, et al., 2014).

At Ostional depredation by dogs is now much higher than that caused by dogs and pigs in the 1980s (Cornelius, et al., 1991) and is the greatest anthropogenic impact on turtle reproduction. A similar situation existed at Playa La Flor. A control program is necessary to eliminate the dog problem through education, remove all of them from ONWR or euthanize them. The latter option was effective at Tortuguero in the 1950s (Carr, 1968), although dogs continue to be a problem there (Tiwari, 2004; Tiwari, et al., 2006).

Embryonic development

Only 12,670 out of 199,199 eggs in study clutches that survived natural and anthropogenic disturbances hatched. Most eggs (86.5 %) showed no visible signs of development and they were distributed in all sectors and zones. That did not mean that they were unfertilized (Bell, et al., 2004) because an early embryo is not visible to the naked eye after an eggs has been burried for 55 days. In addition, there are similar numbers of males and females captured in the longline fishery (Dapp, et al., 2013). Cornelius, et al. (1991) found that 52 % of eggs at Ostional and 75 % of eggs at Nancite showed no development. Ocana (2010) reported similar results from olive ridleys at the arribada nesting beach at Escobilla, Mexico. Torres and Romero (unpublished data) reported similar results at Chacocente for arribdas in the dry season. There were very few eggs at developmental stages I to V (0.9 to 2.0 %) so whatever agents worked to kill eggs did so soon after they were laid. High organic content, microbial activity, soil moisture, temperature and gas exchange have all been hypothesized as causes of embryonic mortality (Cornelius, et al., 1991; Acuna et., al 1999. Honarvar, et al., 2008, 2011; Valverde, et al., 2012; Brenes 2013). In this study there was a statistically significant effect of zone and interaction on organic content of the beach and a strong tendency for it to differ with sector, season and type of plots. Ostional and La Flor had a higher concentration of organic matter in the sand than Chacocente, which had a higher hatching success and hatchling production. The mechanism by which organic matter would kill eggs in the earliest stage of development is unknown. It is not due to a reduction in O_2 or increase in CO_2 because concentrations of those gases do not change enough to affect egg development (Honarvar, et al., 2008). Arribada beaches may lose quality as optimal nesting beaches over time, such that some beaches may only constitute temporary nesting habitats (Bernardo and Plotkin, 2007). However, few studies have addressed these hypotheses experimentally. Clusella Trullas and Paladino (2007) moved eggs from the beach at Nancite to a hatchery with clean sand and found that hatching success and hatchling production improved. So it appears that sand quality or organic content plays a role in successful embryonic development, hatching success and hatchling production. Honarvar, et al. (2008) report that high nest density results in lower O_2, higher CO_2 and higher temperatures in the nest and reduced hatching success.

Successful nests at Ostional, La Flor and Chacocente were associated spatially with the estuary and zone 2 because sand in this area changed frequently during the wet season when the estuary opened. That removed all organic matter, old eggs, new eggs, and shells, and created a healthier microclimate for successful embryonic development (Cornelius, et al., 1991; Valverde, et al., 2012).

Hatchling production through time

In this study there were an estimated 175,437 hatchlings produced in Ostional, 152,938 hatchlings produced in La Flor and 512,408 hatchlings in Chacocente. Those numbers of hatchlings appear insufficient to ensure continuation of these populations. It takes about 1000 hatchlings to produce two adult turtles, a male and a female (Leslie, et al.,1996). At Ostional with a population of about 200,000 to 500,000 females and assuming a reproductive life of 20 years, that means that Ostional needed to produce between 10,000,000 and 25,000,000 hatchlings a year to maintain the population. There were 2,410,402 hatchlings produced in 1984 from two arribadas (Cornelius, et al., 1991). So if there were five arribadas then Ostional probably produced enough hatchlings then to support today's population. It no longer does.

At La Flor with a population of about 50,000-100,000 females and assuming a reproductive life of 20 years, La Flor needed to produce between 2,500,000 and 5,000,000 hatchlings a year to maintain the population. At Chacocente with a population of about 10,000-30,000 females and assuming a reproductive life of 20 years, Chacocente needed to produce between 500,000 and 1,500,000 hatchlings a year to maintain the population. So it is the only beach producing close to enough hatchlings to maintain its population. Therefore, we can expect sharp population declines in the populations at Ostional and La Flor over the lifetime of the current adult populations and expect that Chacocente may be threatened as well.

Conservation implications

Harvest of olive ridley eggs is common at arribada beaches around the world and is implicated in the decline of many such populations (Cornelius, et al., 2007). Egg harvest and capture in fisheries caused the decline in Mexican and Central American olive ridley populations (Cornelius, 1982; Cornelius, et al. 2007). The decline of the olive ridley population at Terengganu, Malaysia was due to long-term overharvest of eggs (Limpus, 1995). This study indicated that the harvest of eggs from three beaches in Costa Rica and Nicaragua is not sustainable. Hatchling production at Ostional and La Flor is insufficient to maintain the current populations of adults and production at Chacocente is marginal. When combined with the removal of adults from the population by fishing we expect that there will be sharp decline in these populations.To help to ensure the stability of the regional olive ridley population it will be necessary to produce as many hatchlings as possible from the beachs and to reduce at sea mortality of the turtles for the foreseeable future.

To produce more hatchlings from these beaches we need to understand the factors controlling hatchling production. Hatching success and the production of hatchlings were controlled by the same spatial, temporal, human and environmental factors on all three beaches so those controls appear to be general in nature, at least in Pacific Central America. Density of eggs did not have a significant effect on hatching success or hatchling production. Plots open to harvest, dogs and poaching did not have higher hatching success or higher hatchling production. Thus, removal of eggs by humans and their animals is not an effective means to increase the number of hatchlings produced from these beaches. However, removal of eggs did not decrease the number of hatchlings produced.

Spatial and temporal management measures should include systematic and long-term monitoring of arribada parameters and large-scale experiments on the effect of sand cleaning on hatching rates, and hatchling production. The harvest should shift in intensity towards the dry season when hatching success is very low because of high temperatures and a lack of moisture in the sand (Valverde et al., 2012).

There should be no new development at Ostional, La Flor and Chacocente beaches because it will cause an increase in disturbance to the arribadas and an increase in impact from people and dogs.

A control program is necessary to remove dogs from the three beachs by educating people about the impact of dogs, euthanizing feral dogs, and euthanizing dogs that cannot otherwise be removed.

It will require interinstitutional strategies to eliminate the effect of dogs and poaching on the beaches. Strict enforcement of controls by permanent patrolling from MINAE, ADIO and police in Costa Rica and MARENA and the military in Nicaragua over the whole beach and year is necessary.

Harvesting eggs, legally or illegally, does not improve hatching success and justifies and increases poaching of olive ridley and other sea turtle eggs throughout Costa Rica and Nicaragua (Spotila, 2011; Blanco, et al. 2012; Santidrián Tomillo, et al. 2014). That is a main reason why the harvest should stop. Harvest of olive ridley eggs throughout the world is linked with very poor coastal communities and lack of economic alternatives (Campbell, 2007). Therefore, the impact on the local people who rely on the harvest for a portion of their income needs to be considered and effective measures need to be implemented to provide alternative sources of income for the people negatively affected by the closure.

It will be useful to implement a participatory environmental management (PEM) program at La Flor and Chacocente as now exists at Ostional (Orrego, 2014, Chapter 4). Ecotourism now produces more income at Ostional than the legal egg harvest (Orrego, 2014, Chapter 4). By working with all of the stakeholders it should be possible to develop alternative sources of income for people near La Flor and Chacocente while promoting management measures to increase the production of hatchlings from those beaches.

The comparison of the biology of the olive ridley arribadas at three beaches in Pacific Central America indicated that marine protected areas can be effective at both protection of nesting turtle populations and provision of socioeconomic benefits to the local human populations. However, managers have to implement strict controls to eliminate poaching activity and dog predation to increase the hatchling production. Therefore, establishment and effective management of marine protected areas around the world will be an important tool to help recover populations of migratory species such as sea turtles. Each MPA should evaluate the biology of the species being protected/managed (Nel, et al., 2013) and establish an adaptative management plan that takes into account ecological, social, and economic factors to keep the MPA sustainable over the time (Agardy, et al., 2003). It should also develop a clear management framework (Olsen and Christie, 2000) to take into account all stakeholders without compromising conservation protections (Klein, et al., 2008). An integral strategy of management should be protection of sea turtles at sea to reduce the adult mortality because all lifestages are needed to keep a stable sea turtle population.

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TABLES

Table 3.1: Arribada size estimated using the strip-transects- in -time method (Gates et al. 1996; Valverde and Gates 1999) at Ostional, Costa Rica, La Flor and Chacocente, Nicaragua. National Wildlife Refuges, 2010/11.

# Arribada	Arribada Size (Date)		
	Ostional	La Flor	Chacocente
1	19,946 (07/10)	12,861 (09/10)	12,684 (10/10)
2	337,832 (10/10)	29,269 (10/10)	2,191 (11/10)
3	75,706 (11/10)	20,253 (11/10)	1,561 (12/10)
4	49,470 (01/11)	8,359 (12/10)	1,260 (01/11)
5	6,986 (03/11)	2,112 (01/11)	-
Total	489,940	72,854	17,696

Table 3.2. Number of eggs deposited in Ostional, La Flor and Chacocente by sector and zone National Wildlife Refuges in 2010-2011.

Beach	Total eggs	Spatial distribution			
		Sector	Eggs	Zone*	
				High beach	Mid beach
Ostional	193,482	1	62,640	25,898 (11)	36,742 (16)
		2	50,603	23,308 (10)	27,295 (12)
		3	80,239	43,700 (19)	36,539 (16)
La Flor	127,120	1	54,521	34,929 (31)	19,592 (26)
		2	44,004	24,752 (22)	19,252 (25)
		3	28,595	16,743 (15)	11,852 (16)
Chacocente	55,767	1	22,188	15,656 (14)	6,532 (9)
		2	18,633	11,655 (10)	6,978 (9)
		3	18,171	12,243 (11)	5,928 (8)

* (Number of nests per m^2 by zone)

Table 3.3. Number of clutches lost during the incubation process to natural causes at Ostional, La Flor and Chacocente National Wildlife Refuges, 2010-11.

Natural causes	Ostional	La Flor	Chacocente	Total
Erosion-open estuary-tides	82 (18.1 %)	5 (7.9%)	35 (100.0%)	122
Nesting activity	366 (80.6%)	58 (92.1%)	0	424
Raccoon predation	6 (1.3%)	0	0	6
Total	454 (100.0%)	63 (100.0%)	35 (100.0%)	552

Table 3.4. Spatial distribution of plots with a total of 552 clutches lost to natural causes by zone and sector at Ostional, La Flor and Chacocente National Wildlife Refuges, 2010-11.

Cause	Study area	n	Spatial distribution				
			Sector			Zone*	
			1	2	3	1	2
Erosion/open estuaries/tides (122 clutches / 22.1%)	Ostional	5 plots (82)	-	2 (40.0%)	3 (60.0%)	1 (20.0%)	4 (80.0%)
	La Flor	1 plot (5)	-	-	1 (100%)	-	1 (100%)
	Chacocente	20 plots (35)	8 (40.0%)	6 (30.0%)	6 (30.0%)	10 (50.0%)	10 (50.0%)
Raccoon predation (6 clutches / 1.1%)	Ostional	3 plots (6)	-	-	3 (100%)	3 (100%)	-
	La Flor	0	-	-	-	-	-
	Chacocente	0	-	-	-	-	-
Nesting activity (424 clutches / 76.8%)	Ostional	58 plots (366)	17 (29.3%)	12 (20.7%)	29 (50.0%)	25 (43.1%)	33 (56.9%)
	La Flor	25 plots (58)	13 (52.0%)	10 (40.0%)	2 (8.0%)	13 (52.0)	12 (48.0%)
	Chacocente	0	-	-	-	-	-

*Zone 1: High beach; Zone 2: Mid beach

Table 3.5. Number of clutches lost during the incubation process to human causes at Ostional, La Flor and Chacocente National Wildlife Refuges, 2010-11

Human causes	Ostional	La Flor	Chacocente	Total
Poaching activity	32 (12.4%)	615 (58.0%)	0	647
Legal harvest	106 (41.1%)	0	0	106
Dog predation	120 (46.5%)	446 (42.0%)	0	566
Total	258 (100.0%)	1,061 (100.0%)	0	1,319

Table 3.6. Spatial distribution of plots with a total of 1,319 clutches lost to anthropogenic causes by zone and sector at Ostional, La Flor and Chacocente National Wildlife Refuges, 2010-11.

Cause	Study area	n	Spatial distribution				
			Sector			Zone*	
			1	2	3	1	2
Poaching activity (647 clutches / 49.0%)	Ostional	7 plots (32)	2 (28.6%)	5 (71.4%)	-	3 (42.9%)	4 (57.1%)
	La Flor	72 plots (615)	25 (34.7%)	24 (33.3%)	23 (31.9%)	42 (58.3%)	30 (41.7%)
	Chacocente	0	-	-	-	-	-
Legal Harvest (106 clutches / 8.0%)	Ostional	18 plots (106)	5 (27.8%)	6 (33.3%)	7 (38.9%)	8 (44.4%)	10 (55.6%)
	La Flor	0	-	-	-	-	-
	Chacocente	0	-	-	-	-	-
Dog predation (566 clutches / 42.9%)	Ostional	39 plots (120)	4 (10.3%)	17 (43.6%)	18 (46.1%)	20 (51.3%)	19 (48.7%)
	La Flor	63 plots (446)	24 (38.1%)	22 (34.9%)	17 (27.0%)	39 (62.0%)	24 (38.0%)
	Chacocente	0	-	-	-	-	-

*Zone 1: High beach; Zone 2: Mid beach

Table 3.7. Embryonic development stages of Olive Ridley eggs at Ostional, La Flor and Chacocente, National Wildlife Refuges, 2010/11 upon exhumation, after completing the incubation period.

Embryonic Stage	Ostional	La Flor	Chacocente	Total
Stage 0 (Non development)	115,964 (92.1%)	16,924 (80.8%)	39,488 (75.4%)	172,376
Stage I	1,522 (1.2%)	1,219 (5.8%)	1,090 (2.1%)	3,831
Stage II	829 (0.7%)	686 (3.3%)	320 (0.6%)	1,835
Stage III	2,366 (1.9%)	564 (2.7%)	975 (1.9%)	3,905
Stage IV	327 (0.3%)	179 (0.9%)	2,083 (4.0%)	2,589
Stage V	1,787 (1.4%)	43 (0.2%)	163 (0.3%)	1,993
Stage VI	3,064 (2.4%)	1,328 (6.3%)	8,278 (16.0%)	12,670 (6.4%)
Total	125,859 (100.0%)	20,943 (100.0%)	52,397 (100.0%)	199,199 (100%)

Table 3.8. The spatial distribution of plots with 199,199 eggs with at least one embryonic development stage by zone and sector at Ostional National Wildlife Refuge, 2009 -10

Cause	Study area	n	Spatial distribution				
			Sector			Zone*	
			1	2	3	1	2
Stage 0: No apparent embryonic development (172,376 eggs)	Ostional	139 plots (115,964)	40 (28.8%)	43 (30.9%)	56 (40.3%)	68 (48.9%)	71 (51.1%)
	La Flor	67 plots (16,924)	22 (32.8%)	24 (35.8%)	21 (31.3%)	39 (58.2%)	28 (41.8%)
	Chacocente	59 plots (39,488)	19 (32.2%)	20 (33.9%)	20 (33.9%)	36 (61.0%)	23 (39.0%)

Table 3.8 (*continued*)

Cause	Study area	n	Spatial distribution				
			Sector			Zone*	
			1	2	3	1	2
Stage I: embryo filled 1-25% of amniotic cavity (3,831 eggs)	Ostional	56 plots (1,522)	13 (23.2%)	17 (30.4%)	26 (46.4%)	22 (39.3%)	34 (60.7%)
	La Flor	45 plots (1,219)	15 (33.3%)	15 (33.3%)	15 (33.3%)	24 (53.3%)	21 (46.7%)
	Chacocente	12 plots (1,090)	-	8 (66.7%)	4 (33.3%)	6 (50.0%)	6 (50.0%)
Stage II: embryo filled 26-50% of amniotic cavity (1,835 eggs)	Ostional	49 plots (829)	13 (26.5%)	11 (22.4%)	25 (51.0%)	19 (38.8%)	30 (61.2%)
	La Flor	52 plots (686)	21 (40.4%)	16 (30.8%)	15 (28.8%)	29 (55.8%)	23 (44.2%)
	Chacocente	34 plots (320)	10 (29.4%)	14 (41.2%)	10 (29.4%)	21 (61.8%)	13 (38.2%)
Stage III: embryo filled 51- 75% of amniotic cavity (3,905 eggs)	Ostional	53 plots (2,366)	14 (26.4%)	12 (22.6%)	27 (51.0%)	20 (37.7%)	33 (62.3%)
	La Flor	35 plots (564)	13 (37.1%)	11 (31.4%)	11 (31.4)	16 (45.7%)	19 (54.3%)
	Chacocente	46 plots (975)	18 (39.1%)	16 (34.8%)	12 (26.1%)	31 (67.4%)	15 (32.6%)
Stage IV: embryo filled 76-100% of amniotic cavity (2,589 eggs)	Ostional	24 plots (37)	5 (20.8%)	7 (29.2%)	12 (50.0%)	12 (50.0%)	12 (50.0%)
	La Flor	15 plots (179)	6 (40.0%)	4 (26.7%)	5 (33.3%)	7 (46.7%)	8 (53.3%)
	Chacocente	47 plots (2,083)	18 (38.3%)	16 (34.0%)	13 (27.7%)	29 (61.7%)	18 (38.3%)

Table 3.8 (*continued*)

Cause	Study area	n	Spatial distribution				
			Sector			Zone*	
			1	2	3	1	2
Stage V: predated by larvae of fly or beetle (1,993 eggs)	Ostional	38 plots (1,787)	9 (23.7%)	14 (36.8%)	15 (39.5%)	10 (26.3%)	28 (73.7%)
	La Flor	4 plots (43)	2 (50.0%)	-	2 (50.0%)	2 (50.0%)	2 (50.0%)
	Chacocente	15 plots (163)	4 (26.7%)	6 (40.0%)	5 (33.3%)	11 (73.3%)	4 (26.7%)
Stage VI: empty eggs shells, from hutched turtles (12,670 eggs)	Ostional	41 plots (3,064)	3 (7.3%)	16 (39.0%)	22 (53.7%)	17 (41.5%)	24 (58.5%)
	La Flor	57 plots (1,328)	19 (33.3%)	18 (31.6%)	20 (35.1%)	33 (57.9%)	24 (42.1%)
	Chacocente	52 plots (8,278)	17 (32.7%)	18 (34.6%)	17 (32.7%)	35 (67.3%)	17 (32.7%)

*Zone 1: High beach; Zone 2: Mid beach

Table 3.9. Hatching success during period of study at Ostional, La Flor and Chacocente, National Wildlife Refuges, during 2010-11.

Indicators	Ostional	La Flor	Chacocente
Total eggs	193,482	127,720	55,567
Eggs loss to natural/human causes	67,623 (35.0%)	106,777 (83.6%)	3,370 (6.0 %)
Eggs with embryonic' stage	125,859 (65.0%)	20,943 (16.4%)	52,397(94.0%)
Total of plots	156	75	60
Open plots	78	45	36
Close plots	78	30	24
Max #eggs per plot	2,903 (31*)	4,007 (43*)	2,157 (23*)
Min # eggs per plot	60 (1*)	187 (2*)	360 (4*)
Average of clutch	95	95	95
Hatching success	2.4%	6.3%	16.0%

*Number of clutches, average 95 eggs.

Table 3.10. Hatchling production (12,670 neonates) during period of study at Ostional, La Flor and Chacocente, National Wildlife Refuges in 2010-11.

	Ostional	La Flor	Chacocente
Hatchilings	3,064 (2.4%) (2,800 m²)	1,328 (6.3%) (1,000 m²)	8,278 (16.0%) (1,500 m²)
Available nesting area (m²)	160,321	115,164	92,850
Extrapolated on whole beach	175,437	152,938	512,408

FIGURES

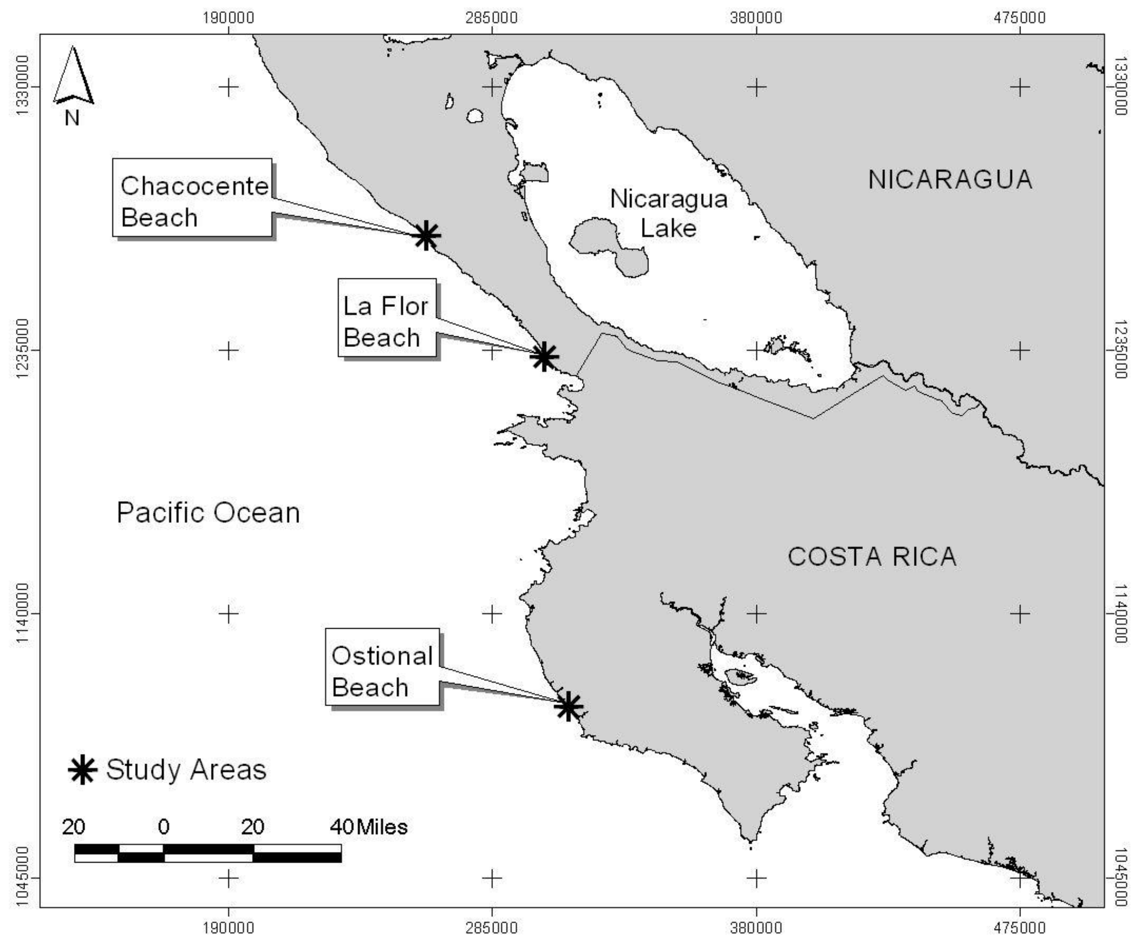

Figure 3.1. Coastal-Marine view of Playa Ostional, Costa Rica and Playas La Flor and Chacocente, Nicaragua National Wildlife Refuges, 2010/11.

Figure. 3.2. Example of the spatial distributions of plots by sector (north to south) and zone at Ostional beach. Plots in La Flor and Chacocente beaches followed the same pattern.

Figure 3.3. Example of an “Open Plot” (2 x 2 m) located in zone 2 (mid beach) sector 3 of La Flor. The same type of plots were used in Ostional and Chacocente beaches.

Figure 3.4. Example of a “Closed Plot” (2x2 m) located in zone 2 (mid beach) sector 1 of the Ostional beach in Northwest Costa Rica. The same type of plots were used in La Flor and Chacocente beaches, Nicaragua.

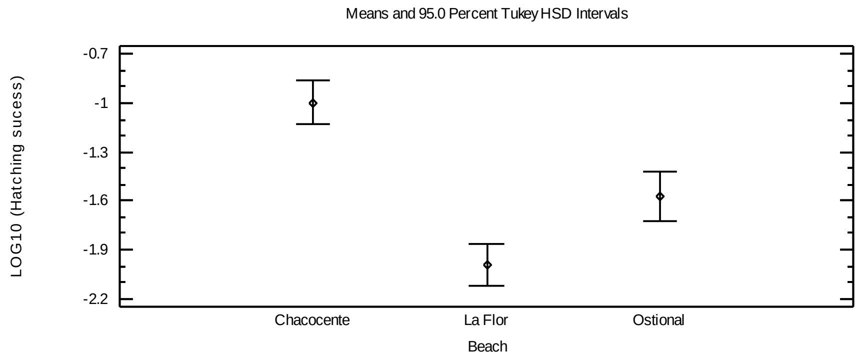

Figure 3.5. Mean hatching rates for olive ridley arribada clutches at Ostional, La Flor and Chacocente National Wildlife Refuges 2010/11. Vertical error bars show Tukey confidence interval (95%).

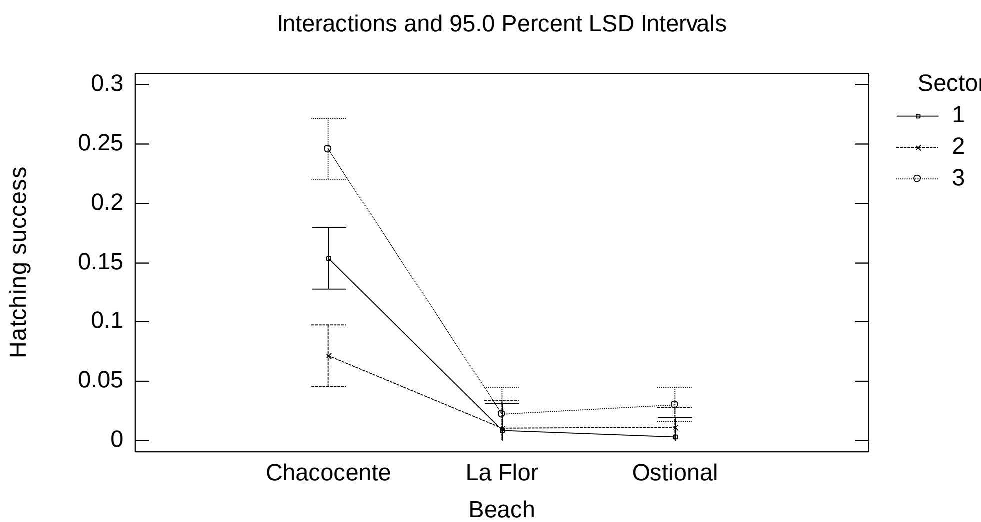

Figure 3.6. Mean hatching success for olive ridley arribada clutches at Ostional, La Flor and Chacocente National Wildlife Refuges 2010/11 and interactions with sector of each beach. Vertical error bars show Tukey confidence interval (95%).

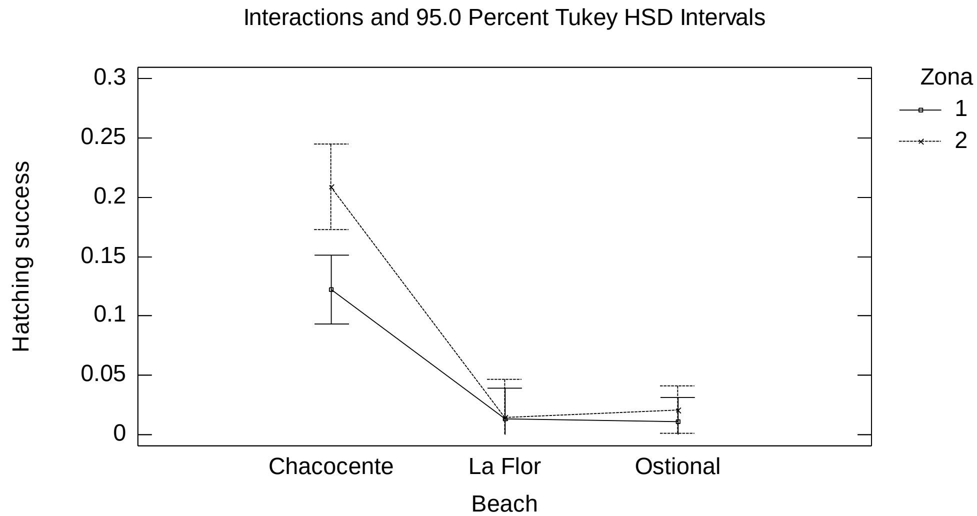

Figure 3.7. Hatching success for olive ridley arribada clutches at Ostional, La Flor and Chacocente National Wildlife Refuges 2010/11and interactions with zone of each beach.. Vertical error bars show Tukey confidence interval (95%).

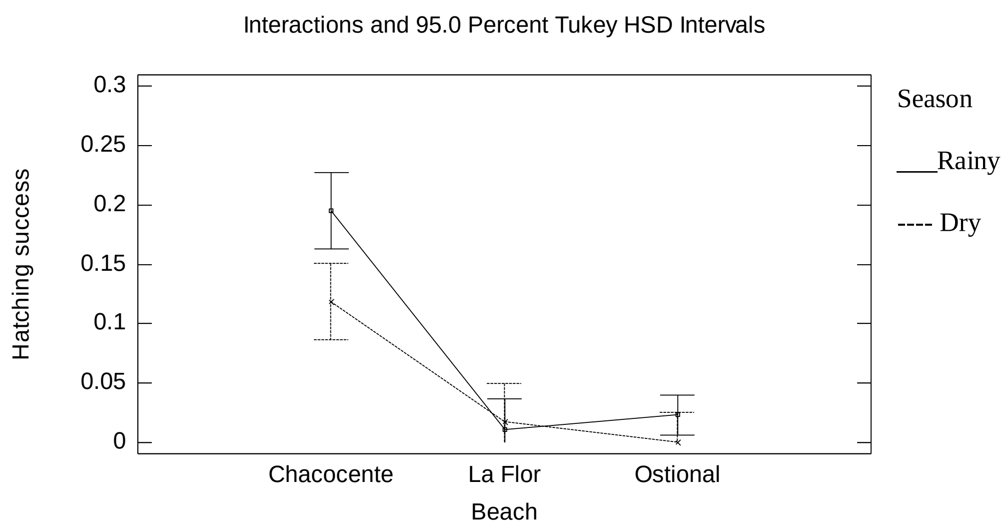

Figure 3.8. Mean hatching rates for olive ridley arribada clutches at Ostional, La Flor and Chacocente beaches 2010/11 and their interaction with season. Vertical error bars show Tukey confidence interval (95%).

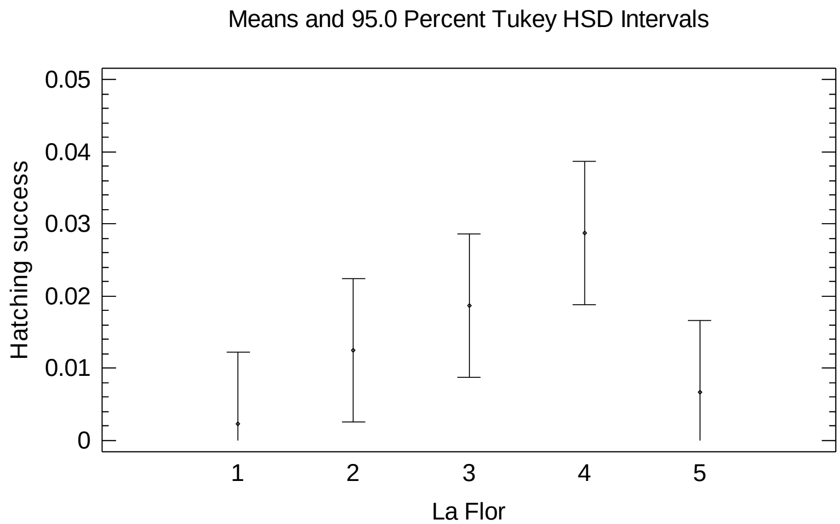

Figure 3.9. Mean hatching success for olive ridley arribada clutches at Playa La Flor. 2010/11. Vertical error bars show Tukey confidence interval (95%).

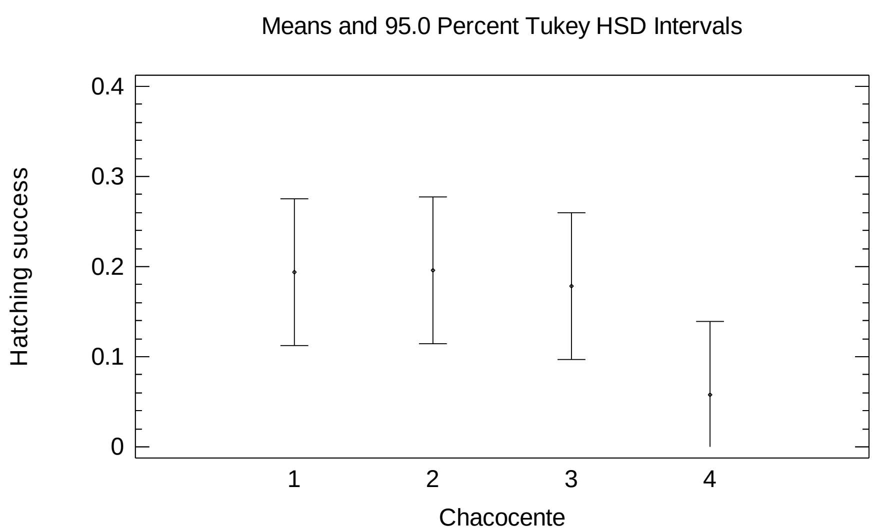

Figure 3.10. Mean hatching success for olive ridley arribada clutches at Playa Chacocente 2010/11. Vertical error bars show Tukey confidence interval (95%).

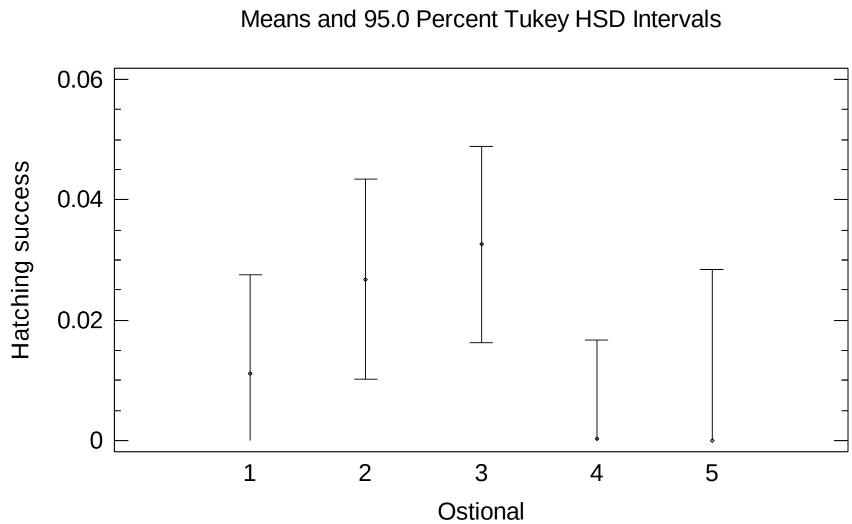

Figure 3.11. Mean hatching success for olive ridley arribada clutches at Playa Ostional 2010/11. Vertical error bars show Tukey confidence interval (95%).

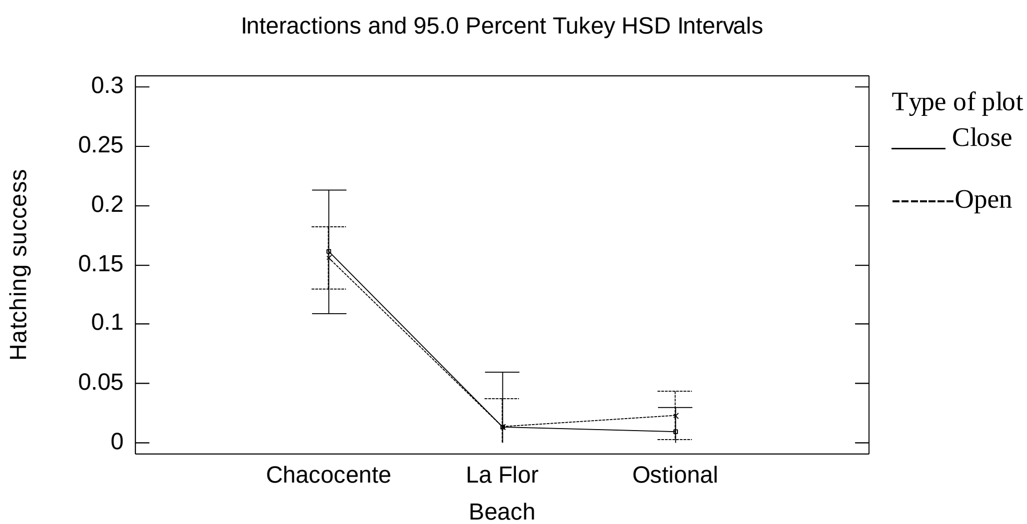

Figure 3.12. Mean hatching success for olive ridley arribada clutches at Ostional, La Flor and Chacocente beaches and interactions with type of plots. 2010/11. Vertical error bars show Tukey confidence interval (95%).

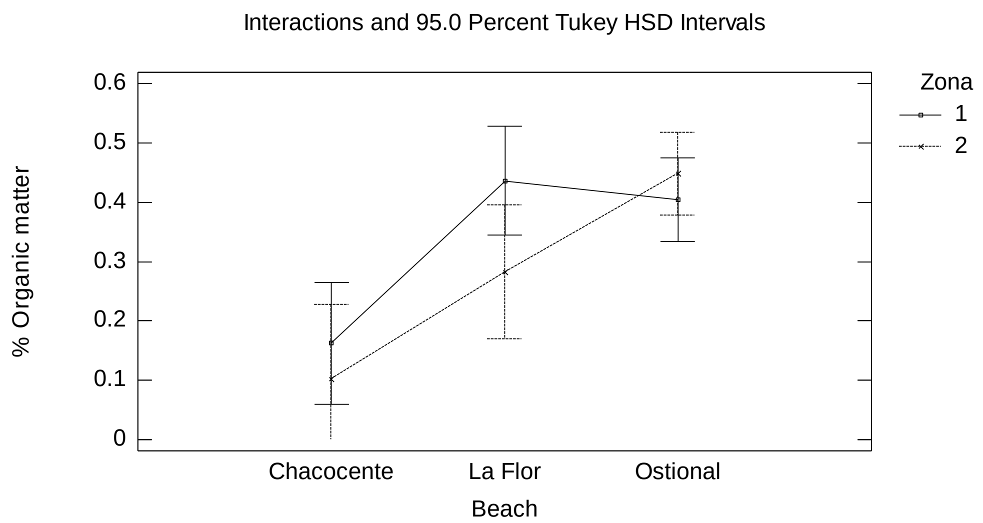

Figure 3.13. Percentage of organic matter by beach and their interaction with zone of the beach. 2010/11. Vertical error bars show Tukey confidence interval (95%).

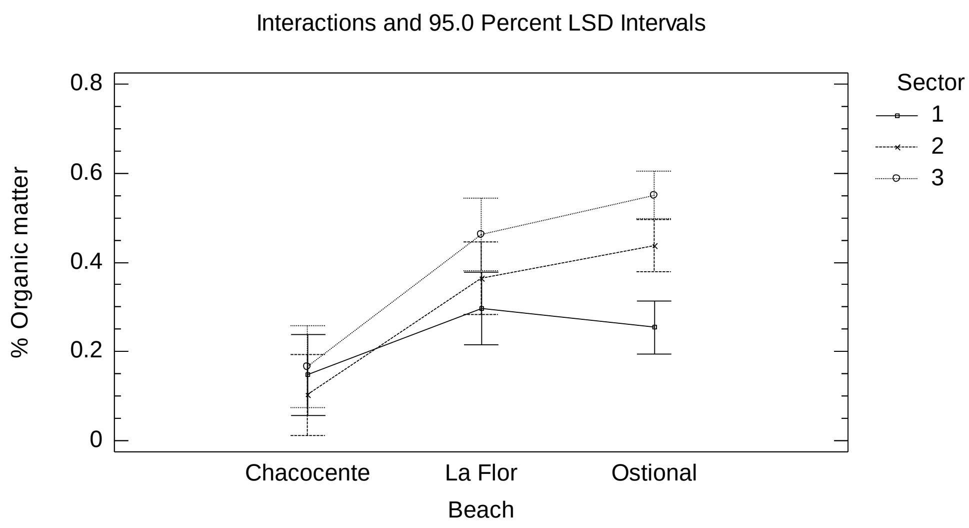

Figure 3.14. Percentage of organic matter contents and their interaction with beach and sector of the beach. Vertical error bars show Tukey confidence interval (95%).

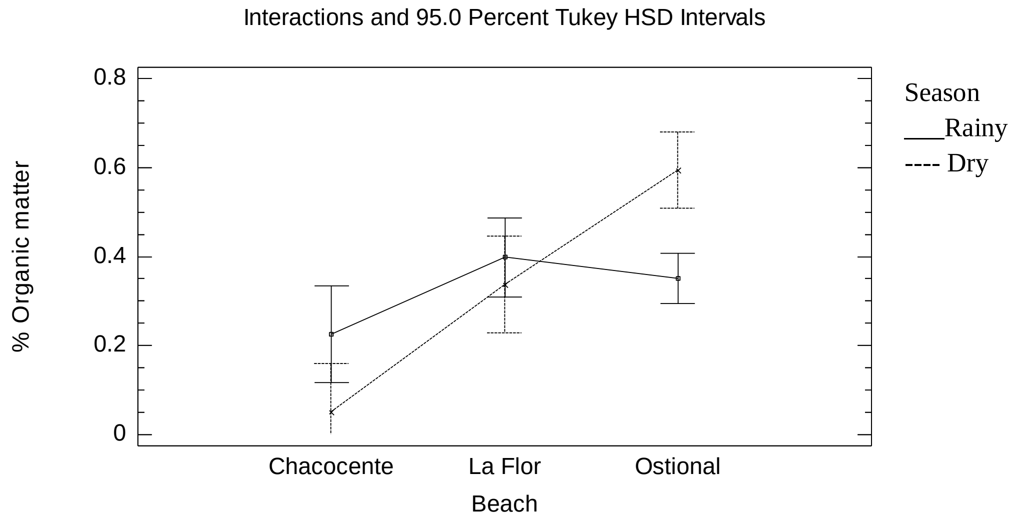

Figure 3.15. Percentage of organic matter contents and interaction with beach and season. 2010/11. Vertical error bars show Tukey confidence interval (95%).

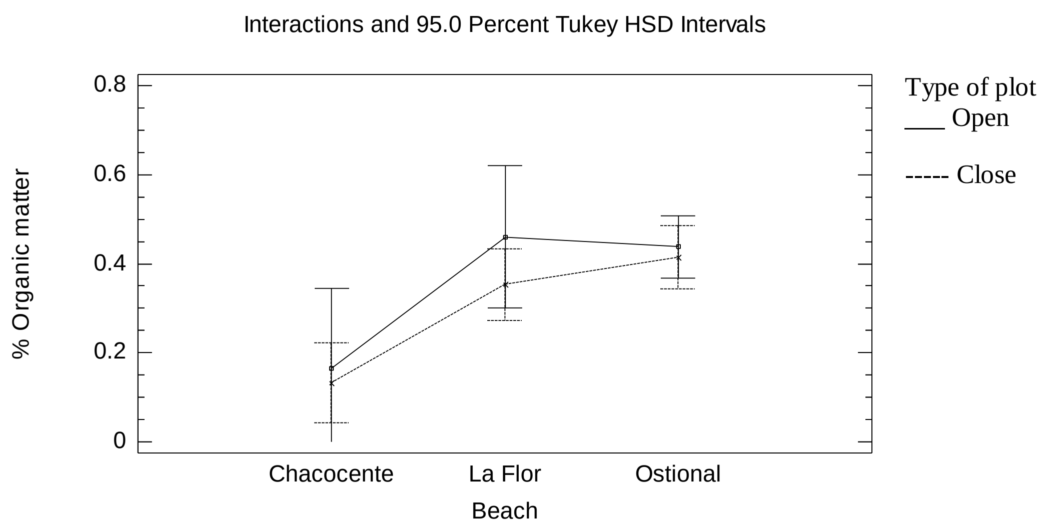

Figure 3.16. Percentage of organic matter content and their interaction with beach and type of plots. 2010/11. Vertical error bars show Tukey confidence interval (95%).

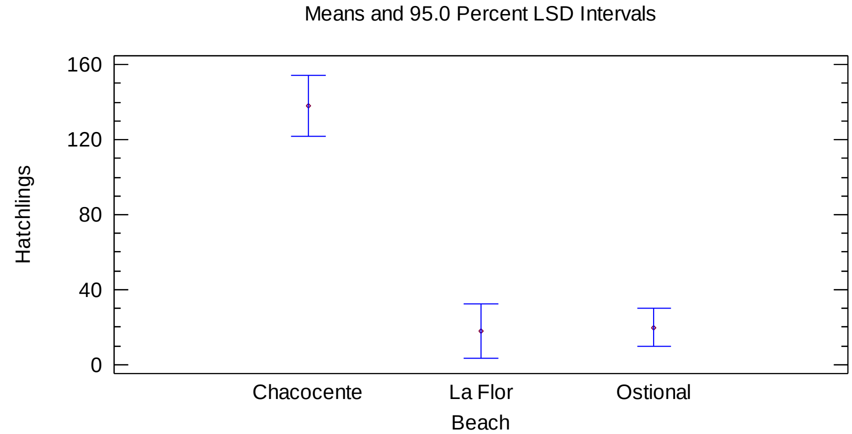

Figure 3.17. Hatchlings by beach. 2010/11. Vertical error bars show Tukey confidence interval (95%).

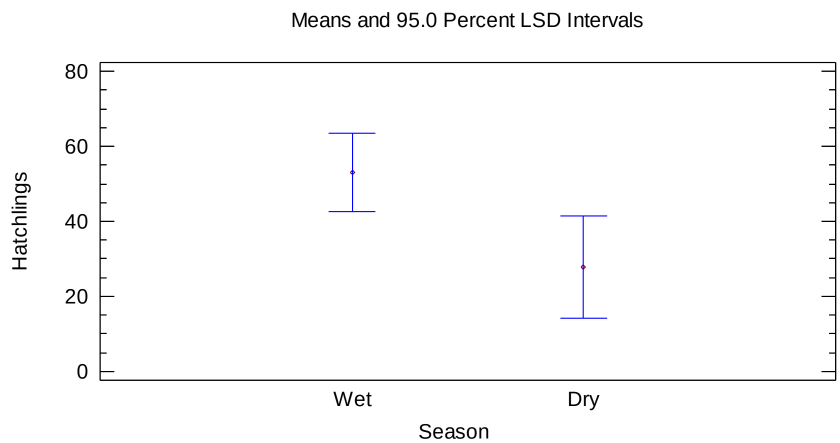

Figure 3.18. Hatchlings by season. 2010/11. Vertical error bars show Tukey confidence interval (95%).

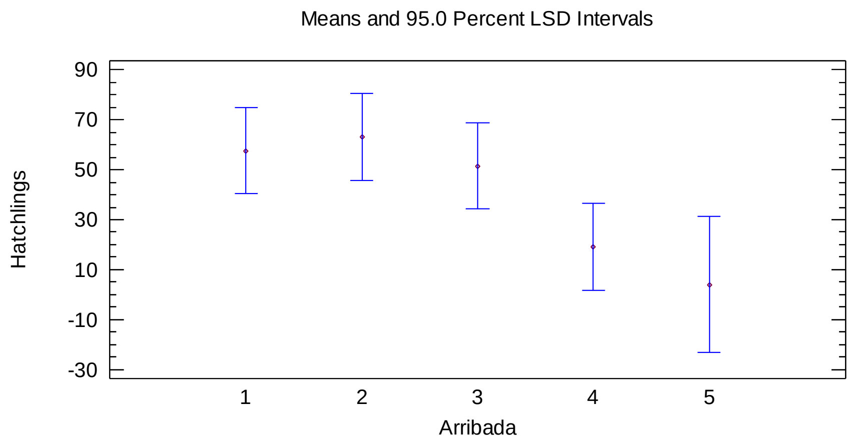

Figure 3.19. Hatchlings by arribadas. 2010/11. Vertical error bars show Tukey confidence interval (95%).

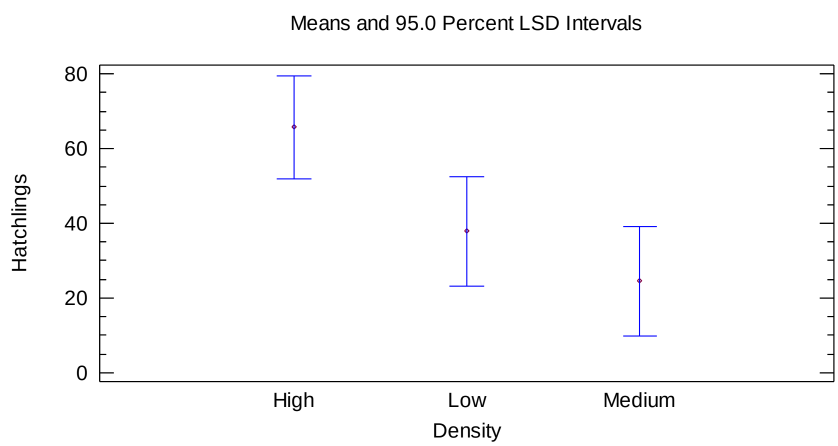

Figure 3.20. Hatchlings by density 2010/11. Vertical error bars show Tukey confidence interval (95%).

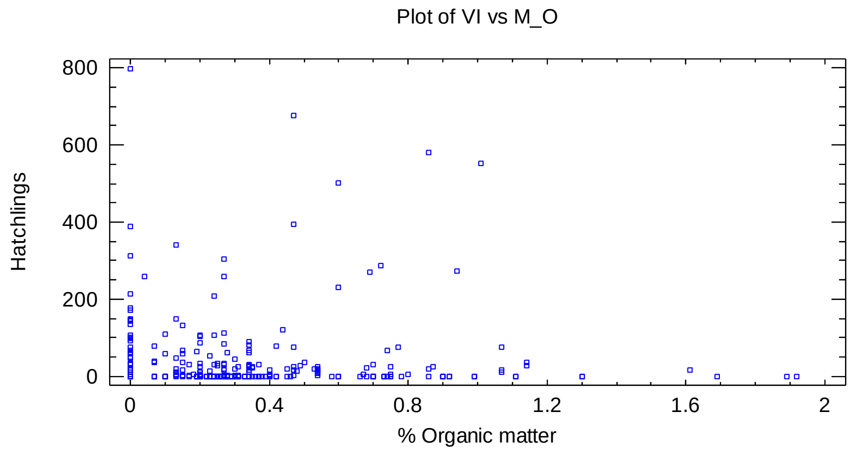

Figure 3.21. Hatchlings and their interaction with organic matter content of the sand at Playas Ostional, La Flor and Chacocente in 2010/11.

CHAPTER 4: ARE PARTICIPATORY ENVIRONMENTAL MANAGEMENT AND COMMUNITY BASED CONSERVATION OPTIMAL STRATEGIES TO MANAGE OSTIONAL NATIONAL WILDLIFE REFUGE? A CASE STUDY PROVIDES POSITIVE LESSONS LEARNED

Abstract

In 1983 the Ministry of Environment and Energy (MINAE) established the Ostional National Wildlife Refuge (ONWR) to protect sea turtle nesting at Playa Ostional, Costa Rica. The objective was to manage the resource indefinitely for sustainable use while the community benefited and participated in the conservation process, through planning, investigation, protection, control, ecotourism, and environmental education. An executive decree authorized the community to use eggs of olive ridley turtles (*Lepidochelys olivacea*) for its subsistence. However, there were many conflicts between different stakeholders. For many years the local community lacked confidence in the government. The community lived solely on the profits received from the sale of eggs, and living conditions and the well-being of the community were threatened by their precarious legal situation inside the refuge. Residents in the refuge did not legally own their land and houses, the majority of which were poorly constructed and deteriorating. There was a lack of scientific knowledge about the sustainability of the resource. There was no physical presence of MINAE personnel and buildings in the refuge, no prior legal framework, no management plan, a lack of public order, and a lack of budget to implement management strategies. In 2003 MINAE, with stakeholders including the fisheries agency INCOPESCA, the community, the University of Costa Rica, local municipalities, local guides and fishermen, began implementing a

participatory environmental management (PEM) plan. It was a tool that, by including knowledge from many sources - traditional, scientific, technical and administrative, among others, would permit an integrated approach to problems and priority activities. It was to make the management of the Ostional ecosystem more efficient, effective and lasting, in social, environmental and economic terms. By 2012, all stakeholders in Ostional came to understand that for the PEM to consolidate with community actors, there needed to be an improvement in the quality of life from increased profit from egg sales and eco-tourism. The PEM provided economic, social, and biological benefits and stable and sustainable conservation. Administration of the protected areas was not viable without the recognition of local actors and the participation of civil society in making decisions. Without development mechanisms that secure financial sustainability of all protected areas, objectives and goals of the protected areas can become threatened. In order to stop the non-sustainable use of resources it is necessary to change attitudes and perceptions about the over use of resources.

Introduction

Humans have long had a great impact on natural ecosystems (Mowat, 1984) and that is especially true in the marine realm (Saenz-Arroyo, et al., 2006). Conservation biology is now focused on maintaining and restoring what is left of the earth's natural systems that are often exploited by people. Archie Carr, the famous sea turtle biologist and conservationist (David, 2007) long ago wrote "A workable plan for restoration and maintenance of a landscape is not easy to devise. The factors involved are complex and the interrelationships are almost endless." He advised that conservationists should stop courting the bureaucrats and politicians and deal directly with the people who are on the land, the poor people who are suffering from economic distress. "The ministers are not suffering; they don't need our help." (Carr, 1953, p. 47-48). Those sentiments have translated into the concept that the best way to conserve wildlife is to give rural people and communities greater control over the management of animal populations living around them (Adams and McShane, 1992). The thesis of Adams and McShane was that rural people would be more protective of wildlife if they had greater control over it and made a living from it. Human economic development and conservation became linked.

Sustainability is a key concept in both conservation and economics. Sustainable use is now a common idea in wildlife conservation (Frazier, 1997, Campbell, 1998) and has gained in importance since the World Conservation Union (IUCN) adopted the idea of the sustainable use of nature (IUCN/UNEP/WWF 1980, 1991). This idea is key to the IUCN conservation concept, i.e "the management of human use of organisms or ecosystems to ensure such use is sustainable. Besides sustainable use, conservation includes protection, maintenance, rehabilitation, restoration, and enhancement of populations and ecosystems" (IUCN 1980, p.1). Wildlife can be used in different ways, for instance, fishing, hunting, capturing, trapping, gathering, and watching (Campbell, 1998). Use can be direct or consumptive when the whole animal or its products are exploited (Freese, 1996). Indirect or non-consumptive use does not involve direct removal and is typified by wildlife watching and photographing that can provide benefit to subsistence and /or commercial purposes (Campbell, 2007). The IUCN approach stresses the importance of giving local communities an important role in the design and management of conservation and development plans that are integrated.

Unfortunately, this concept has not always worked to promote conservation of wildlife and the emphasis on economic development has often increased destructive pressures on wildlife and its habitats (Oates, 1999). The concept that biodiversity can be bought and sold and that conservation is just another form of business (Nicholls, 2004) tends to support short-term profits at the expense of long-term ecosystem protection. Thus, it is not clear that extractive uses of biodiversity that are economically sustainable can be compatible with sustainability of the natural system itself. In response, Terborgh (1999) recommends strictly protected areas for conservation.

There is a practical difficulty in relying on strict protection alone in biodiversity protection. Historically, governments that have created protected areas without completely incorporating local communities have caused conflict between different stakeholders. The establishment of conservation reserves is often seen as a top-down process in most of the tropics. It is often externally driven by the central government or non-governmental organizations (NGOs) and seen as a foreign intervention. Resentment by local people often makes them reluctant to support restrictions on their means of livelihood in the name of biodiversity protection. However, local people often express support and interest in effective democratically based conservation (Ghazoul and Sheil, 2010, p 397). Therefore, involvement of local communities is important in any form of protection. Some of the best examples of efforts to involve local communities in biodiversity protection are found in marine ecosystems and have involved the development of marine protected areas.

Marine protected areas (MPAs) have become an important tool for the management of marine ecosystems (Agardy, 2000; Botsford et al., 2009; Nel et al., 2013). They are typically focused on fisheries management, biodiversity conservation, habitat restoration and tourism development (Christie and White, 2007; Nel et al., 2013). The most successful examples involve both area protection and local community participation. For example, empowering small scale fishermen was critical to protecting loggerhead turtles, *Caretta caretta*, in the waters of Baja California Sur (Peckham and Diaz, 2012) and working with local people was the key to nesting beach protection for sea turtles along the Pacific coast of Mexico (Barragán, 2012). In Kenya, MPAs play an important role in biodiversity protection and are essential components in an integrated coastal zone management program (ICZMP). In Belize MPAs are important in the ICZMP (Tuda and Omar, 2012).

Sea turtles are important and very visible components of tropical marine ecosystems. People have exploited sea turtles for thousands of years (Troëng and Drews, 2004; Cornelius, et al., 2007; Barragán 2012). Local communities often live along beaches where sea turtles come ashore to lay their eggs. Protection of those beaches, therefore, either involves removing the people from a new protected area or involving the people in the protection itself. Community-based MPA management is a governance model that is frequently employed in such situations when there are weak formal higher-level institutions, decentralization of decision-making, or where community-rights activism is strong. In these cases, that are common through much of the tropics, bottom–up governance regimes may be the only feasible option. Thus, community based conservation and participatory environmental management are often central to successful conservation of the biodiversity (Campbell, 2007). However, community-based initiatives may also be destabilized when communities surrounding the protected area and leaders do not support MPA implementation (Christie and White, 2007).

Ostional National Wildlife Refuge (ONWR) in Costa Rica has been cited as both an excellent example of community participation in biodiversity protection (Campbell, 2007) and as an example of misguided exploitation of marine resources (Spotila, 2011). Ostional is the site of the second largest nesting assemblage, “arribada” in Spanish, of olive ridley turtles (Lep*idochelys olivacea*) in the world. To protect that nesting beach and to provide benefits and incentives to the local community of Ostional to protect the turtles, The Ministry of the Environment (MINAE) and Fish and Aquaculture Institute of Costa Rica (INCOPESCA) established a wildlife refuge there in 1983 and authorized the Ostional Development Association (ADIO) to use olive ridley eggs as a way of subsistence (consumption and selling) in 1987. The decision to allow the harvesting of olive ridley eggs was based on the results of social and biological studies performed by the University of Costa Rica and other national and international universities suggesting that the population could be stable with some egg collection (Cornelius and Robinson, 1985; Cornelius, et al., 1991; Chaves, et al., 1987, 2003). The ONWR mission was to manage and achieve the sustainable use of this resource and gain community support through its participation in the conservation process, including strategies such as planning, research, protection, control, ecotourism, and environmental education (MINAE, 2003; ADIO, et al, 2007; ADIO, et al, 2012).

There was a basic problem in the establishment of the ONWR, some people were already living there and exploiting the turtle eggs. By Costa Rican law people cannot live in a national wildlife refuge. What was to happen to the people that were living there before the protected area creation? What about the Ostional community that was economically dependent on the resources in the area that now had legal protection by the government? The original solution proposed by Douglas Robinson of the University of Costa Rica was to include the people in the management of the refuge and to allow them to continue to collect some eggs from the great arribadas that took place there (Cornelius, et al., 1991). That provided a workable solution, but also led to many problems in protection and management because of conflicts among local people and between local people and the government (Valverde, 1999; Orrego, 2008**).**

Conflicts between the government and local people in the ONWR occurred because of: 1) a lack of confidence in government officials, 2) the importance of economic profits from the sale of olive ridley eggs, 3) harsh living conditions (i.e.

deteriorated homes), 4) the possibility of people being displaced from the refuge, and 5) lack of research and publications documenting sustainable use of the natural resources (Orrego, 2008). Other factors leading to disagreements included lack of a physical presence of MINAE personnel and infrastructure in the refuge (Campbell, 1998, 2003, 2007; Valverde, 1999; Orrego, 2008), an unclear legal framework, lack of a management plan, conflict between local and national government, and a lack of a budget and human resources to implement management strategies (Orrego, 2008). The problems in management at ONWR have been reported by Campbell and her colleagues (Campbell, 1998; 2003; Campbell and Mattila 2003; Campbell, 2007; Campbell, et al., 2007).

The egg commercialization program provided relatively good socio-economic benefits to the community (Campbell, 1998; 2003, 2007; Troeng and Drews, 2004; Campbell, et al., 2007; Campbell and Mattila, 2003; Valverde, 1999; Hope, 2002; ADIO, et al., 2007; 2012; Orrego, 2008). However, the egg commercialization program had inherent and additional conflictive elements that were common throughout Ostional's history due to the lack of solid organizational structure of the egg harvesting program and lack of inter-institutional coordination between government and non-governmental entities. It resulted in a disorganized situation in the refuge, which included violent behavior from some of Ostional's inhabitants (Campbell, 1998; Valverde, 1999; Cornelius, et al., 1991; C. Orrego, personal observation and threats 2000- 2013).

Valverde (1999) compiled all recommendations from academic institutions, government and international conservation organizations and scientists for addressing these Ostional problems. Those recommendations offered research based solutions toward biological issues in the maintenance of the olive ridley population, and organizational solutions for management of the egg harvest program and the refuge. Research needed included accurate counting of the turtles (Valverde, et al., 2012) and assessment of the impact of the egg harvest on the sustainability of the turtle population (Orrego, 2014, Chapter 2). Recommendations for improvement of management included direct presence of MINAE personnel, rangers, and facilities at Ostional and development of a strong participatory management program.

The objective of my project was to foster the research program and develop the participatory management program in order to assure the sustainability of the biological, economic and social components of the ONWR. Here I report the lessons learned at Ostional in implementing this program from 2003 through 2014.

Methods

Ostional National Wildlife Refuge

Ostional National Wildlife Refuge (ONWR) was established in 1983. It was limited to a small area in Guanacaste Province of Costa Rica (from 85 43’50” W. 10 01’00’ N to 85 40’40” W. 09 54’30”N), corresponding to the marine-terrestrial zone (MTZ) of Ostional, Nosara, Peladas and Guiones beaches. The total area of Ostional Refuge was 13,390 km^2 with 12,875 km^2 in the ocean and 515 km^2 on land. The land portion consisted of a thin area 200 m wide and 19 km long and associated wetlands (Figure 4). The ONWR was in the life zone of the basal humid rain forest transitioning to dry forest. The dry season lasted from December to April and the rest of the year was the wet season. The annual mean precipitation was 2,100 mm and the annual mean temperature was 27.5 °C (22 to 33 °C) (Barrantes, et al., 1985; Orrego, 2014, Chapter 2).

Arribada nesting behavior only occurred in the Ostional and Nosara areas inside ONWR within 7 km that were marked every 50 m between two points, sector 1 in the north "Punta India " and sector 140 in the south, the Nosara River Mouth. The other beaches provided conservation, recreation (surfing, swimming, etc.) and ecosystem services to local residents and visitors.

Ostional was a very dynamic beach that changed in the size of the berm or sand dune, in its slope and in presence of flora (Chaves, 2007). There were several estuaries and mouths of streams and rivers (Cornelius and Robinson, 1985). The flora along the beach included almond trees (*Terminalia catappa*), majagua (*Hibiscus tiliaceus*), columnar cactus (*Stenocereus aragonii*) and beach vine (*Ipomoea pes caprea*). Vegetation was dominated by the spiny *Bromelia pingui* that was used by people for building fences. In the wet season the mouths of the estuaries created dunes more than 2 m high in different sectors of the beaches and sometimes the estuaries opened with connection to the sea.

In 1987 MINAE and INCOPESCA published an executive decree # 28203 to authorize the olive ridley sea turtle eggs harvest only to ADIO with monitoring of the biological population status by UCR.

Management Process

In 2003, MINAE assumed leadership in the process of participatory environmental management (PEM) and community based conservation (CBC) and decided to reopen the management process. It invited all the stakeholders that had a direct relationship with the refuge, such as INCOPESCA, ADIO, UCR, Municipalities, local guides, and local fishermen, to work together. By consensus the stakeholders created a co-management commission as a framework to legally establish executive decree DAJ-020-2005 in order to work together, and the co-management group implemented a PEM-CBC plan to allow for an integrated approach to identify priority objectives, solve potential problems and fulfill the goal of the mission statement.

MINAE assigned the director and three rangers to the refuge and built a headquarters and research facility. MINAE became the facilitator of the PEM-CBC process and every month held a meeting with all stakeholders in its refuge headquarters. Participants analyzed all management issues in Ostional, to implement the different management strategies such as: protection and control, environmental education, ecotourism, research, legislation, and management. In addition, MINAE fostered the research program on eggs and adult turtles and rangers were active participants in the research. The director conducted a historic analysis of the egg collection program as a consumptive use and eco-tourism as a new important economical alternative for non-consumptive use and development of the community. The director also made qualitative observations of the community and its interactions with the turtles with both uses and the refuge. Finally, the director and the stakeholders jointly completed an annual self-evaluation of criteria for success of the refuge.

Results

Management Process

In 2003 MINAE assigned a director and three rangers to the ONWR. Previously the refuge was managed from a distance by personnel in MINAE offices in Santa Cruz or Nicoya, 70-80 km away. The director was a former student who did his master thesis in the refuge and had the confidence of the local population. The director invited all the stakeholders to work together and they created a co-management commission. The commission was formalized in executive decree DAJ-020-2005 and was the basis for a PEM-CBC process. The commission then implemented an integrated approach to manage the refuge. A draft management plan provided for strategies to implement this plan in ecotourism, environmental education, protection and control, research and management. The annual self-evaluation conducted by the commission, working under the leadership of the refuge director, assessed the success of meeting those goals.

Under the new management practices, MINAE and the stakeholders together made important advances in all areas of the Ostional management plan (Table 4.1). In ecotourism, advances included creation of a local ecotourism guides association, a sustainable volunteer program to support all the management strategies and provide economic benefits to the community, and a family program to host volunteers that came to help in conservation and that also brought economic benefits to local families and provided for cultural exchange. In addition, there was the establishment of wetlands tours, tours on the beach to observe the nesting turtles, and tours to watch sea turtles on the sea before they came ashore to nest.

Advances in environmental education included workshops on several topics, conferences in management and conservation of the turtles, hatchling releases, and design of environmental education strategies of regional importance. Advances in protection and control included joint patrols by MINAE, ADIO, and local police to protect the nesting turtles and their eggs, training and certification of local people for environmental protection, reduction in illegal trade in turtle eggs, and improved turtle protection at sea. Advances in research included development of a transect methodology for accurately counting arribada turtle populations now used worldwide (Valverde, et al., 2012), analysis of environmental factors affecting egg development (Valverde, et al., 2010), analysis of effects of natural, anthropogenic, spatial and temporal factors on hatching success and hatchling production (Orrego, 2014, Chapter 2), undergraduate and masters theses one Ph.D. Dissertation (Appendix), and various presentations at national and international scientific meetings.

Advances in the legal framework of the refuge included an executive decree providing rules for turtle visitation, an executive decree establishing the management commission, establishment of a management plan for turtle harvest, establishment of a research plan and regulations, and development of a draft management plan for marine management. Advances in management included the construction of a headquarters and facilities for MINAE personnel, consistent monitoring of the protected area and its wildlife resources for sea turtle tagging and arribada and solitary nesting, improved interactions between stakeholders and MINAE, development of a five year management plan (ADIO, et al., 2007; ADIO, et al., 2012), obtaining donations from national and international sources, establishment of a volunteer program, establishment of the family visitation program, and establishment of a reforestation program with local stakeholders.

The Five Year Management Plan for ONWR was an important tool for the PEM-CBC process. It was obligatory under the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC) that recognized subsistence use in local communities as in the case of Ostional. The Plan was signed by all stakeholders on February 23th, 2007 during the World Day of Wetlands in Costa Rica and renewed in 2012. It set goals for research, protection and all aspects of management of the egg harvest to insure the sustainability of the turtle population. The Plan also summarized the advances in economic, ecological, and social benefits in the refuge.

There were some problems in implementing the PEM plan for the refuge. The long absence of MINAE from the refuge empowered some stakeholders to assume competence in management that they did not have by law. Therefore, some local community leaders resented the appearance of MINAE personnel and attempted to undermine the PEM program. That even led to violent acts against rangers on the part of some individuals. Local residents were reluctant to work with MINAE personnel because they were uncertain of their legal right to be in the refuge and they viewed MINAE as an enemy that would displace them from the refuge. That issue remained in the courts at the time of this dissertation, but more people participated in the PEM as time went on. A lack of confidence in MINAE made some people reluctant to work with MINAE. Only extensive communication and interaction with the local people overcame that obstacle. Some local residents attempted to stop research on the beach in fear that it would provide information that would justify closing of the egg harvest. The research still went on because of the strong support of MINAE and the requirement for research in the Five Year Plan.

Historic analysis of the egg collection program

By analyzing the data in reports by ADIO and UCR and recent data in the Five Year Plans, I determined the growth in numbers of people in the refuge, the number of eggs collected by ADIO members, income from the harvest program, income from ecotourism and changes in price of eggs. In 1985 there were 50 people in the refuge and in 2012 there were 600. However, only ADIO members could participate in the harvest program and their numbers were relatively stable from 2004 to 2014. Before 1983 the harvest did not have any control because Ostional was an unprotected area, so almost all eggs were harvested. After the ONWR was established there was little regulation of egg harvest distribution and commercialization. The community started an organizational process and in 1987 MINAE and INCOPESCA signed a decree to authorize eggs harvest by ADIO members. In 1987, 150 ADIO members collected 2,000,000 eggs, in 2004, 235 ADIO members and 66 intermediaries collected 4,137,000 eggs, and in 2013, 240 ADIO members collected 3, 648,830 eggs (Figure 4. 2). The income from the harvest program grew from $203,703 in 1987 to $400,000 in 2004 (Troeng and Drews, 2004) and to $371,640 (estimated from sale of 3,648,830 eggs x 55 colones unit price per egg = 200,686,650 million of colones, at $1 = 540 colones, = $371,640) in 2014. (Figure 4.3). The price per egg went from 2 colones in 1987 to 50 colones in 2010 (Figure 4.4). The 2014 price was about 55 colones.

Socioeconomic aspects of the harvest program and ecotourism

The income from the harvest program was managed by ADIO. Income was divided into 70% that was provided to members of ADIO and for local community development and 30% that went to pay the local biologist who monitored the nesting population and all aspects of the harvest program. By ADIO records there was more money spent in the economics of conservation than was obtained from the harvest (Figure 4.5). The cost of conservation included: time spent in patrolling the beach, money spent to clean the beach of debris, and habitat improvement. ADIO also invested in local development, and from 2007 to 2012 it spent approximately $ 248,000 on social development, infrastructure such as roads, bridges, elementary and secondary schools, a health clinic, and in scholarships for students.

Ecotourism provided new economic alternatives to residents who made more money from being guides than they could in collecting eggs. Ecotourism also increased in the Ostional buffer zone. In 2003 there were 3 little cabins, 2 hotels, and one camping site. The price per night for a room was $10. In 2013 there were 10 cabins, 4 hotels and 3 camping sites and the price rose to $20 - $200 per night. Before 2011 access to Ostional was only possible in the dry season unless a person had a 4 x 4 vehicle that could ford several rivers. In 2011 a better road and bridges connected Ostional to the outside world. Visitation began to grow and was possible all year. That gave the community an economic alternative that reduced pressure on the egg harvest. In 2004, the family host program began with six families and in 2013 there were 15 families in the program and income was $175,598 (Figure 4.8).

In 2002 there were 1200 visitors to Ostional and in 2014 there were 8,000 (Figure 4. 6). Income from the 8000 visitors to the refuge in 2013 was about $800,000 from lodging, food and related items. In 2002, 20 local residents decided to work in ecotourism, and that number grew to 40 in 2014. Between 2003-2014 guides raised approximately $682,000 from tour services (Figure 4.7). Members of the local guides association became strong supporters of the refuge and the PEM.They supported all management strategies, and their help in conservation included time spent in tours when they were at the same time patrolling the beach, cleaning the beach of debris, habitat improvement, protecting hatchlings from dog and avian predation before hatchlings reached the sea and implementing visitor regulations.

Discussion

Historic analysis of the egg collection program

The number of eggs harvested between 2004 and 2014 fluctuated, reaching a peak of 6,000,000 in 2008, dropping to 3,000,000 in 2010 and rebounding to 3,600,000 in 2013. These changes were partly due to changes in numbers of turtles laying eggs due to El Niño and La Niña cycles (Orrego, 2014, Chapter 2) and market fluctuations. Costa Rica had a cultural history of use of sea turtle eggs (Chacon, 2002; Hope, 2002; Troeng and Drews, 2004). However, recently the trend changed among young people who reduced their consumptive use and began to favor non-consumptive use of the resource (i.e. ecotourism as local guides in Ostional) because it provided more income. In addition, many young people began to leave Ostional looking for jobs with higher income because turtle eggs did not provide enough income to satisfied their needs.

One goal of the Ostional harvest program was sale of eggs in the whole country to keep prices low to reduce the black market in turtle eggs from all beaches and all sea turtle species (Campbell, 2007). The price of Ostional eggs actually dropped in real terms. It was 3 colones in 1987 and 55 colones in 2014. However, with inflation the actual cost in dollars dropped from 40 cents to 10 cents an egg. The price in San Jose, the capital, was $1-2 per egg due to intermediaries. To increase income to the egg cooperative ADIO assumed the entire distribution network (Arauz Almengor, et al., 2001; Hope, 2002; Campbell, 2007; C. Orrego, personal observation). The main problem was that the egg project at Ostional had no impact on reducing illegal poaching of eggs on other beaches in Costa Rica. Every beach that was not protected suffered from extensive poaching of eggs (Spotila, 2011; Santidrián Tomillo, et al., 2014). The legal market from Ostional appeared to be decreasing while illegal harvest was growing all around the country. It was hard to obtain exact data on the illegal harvest, but it became essential to stop the illegal harvest because there was increasing pressure to shut down the Ostional harvest because it provided a justification and a "cover" for the illegal harvest. Sea turtle eeggs of all species, including large leatherback eggs, were for sale in markets and labeled as eggs from Ostional.

The legal framework of the Ostional harvest project and the PEM program made the harvest program there more stable than those in Nicaragua, Mexico and Panama (Campbell, 2007; Plotkin et al., 2012). In Ostional there were 220 members of the cooperative, while in Nicaragua at Playa La Flor there were people from eight villages involved and at Playa Chacocente 1, 070 people from 17 villages collecting eggs (Hope, 2002). The Ostional population was growing, but the ADIO membership was stable or decreasing because the young people were leaving Ostional to find jobs or for education because Ostional only had an elementary and high school. The harvest of olive ridley eggs throughout the world is linked with very poor coastal communities and lack of economic alternatives (Campbell, 2007). Only by providing economic alternatives for the local people will it be possible to eliminate the harvest.

Socioeconomic aspects of the harvest program and ecotourism

There are several socioeconomic case studies about sea turtle egg use in countries such as Costa Rica (Campbell, 1998; Hope, 2002; Troeng and Drews, 2004), Honduras (Lagueux, 1991; Campbell, 2007), Nicaragua (Hope, 2002; Troeng and Drews, 2004) and Panama (Campbell, 2007). No harvest is as organized as Ostional and none provides as much income as the Ostional project.

A summary of the 2007 Ostional egg harvest showed that the total number of ridley eggs gathered for commercialization was 3,993,800 (Morera, 2007). With an average of 95 eggs per clutch in Ostional (Orrego, 2014, Chapter 2) this number represented the reproductive effort of 42,040 nesting females. The potential economic benefit equivalent for this commercialization was calculated based on the fact that a commercial bag from Ostional had 200 eggs and it was sold by the ADIO for 7,000 colones ($1 = 556.31 colones), so the total income generated by the sale of eggs was 139,783,000 million colones or $251,268. From 2003 to 2012 the income from the egg harvest ranged from $250,000 to $ 600,000 per year. During the same time income from non-consumptive use of turtles in the form of ecotourism increased to $970,000 in 2013. So the value of ecotourism had surpassed the value of the egg harvest.

Ecotourism in Tortuguero National Park raised $ 6,714,483 (Troeng and Drews 2004). Castro et al. (2000) estimated the income from green turtle tourism along the Caribbean coast of Costa Rica at $1,142 per sea turtle. In 1994 income from tourism from leatherback nesting at Playa Grande was $900,460 (Gutic, 1994) but increased in 2004 to $2,113,176 (Troeng and Drews). Costa Rica is a country with high tourism and all tourists need local guides to enjoy nature inside protected areas and places to sleep and eat. People surrounding coastal marine protected areas are beginning to understand that they may receive more income from ecotourism services than through consumptive use. Local communities where sea turtles nest receive more economic benefits from indirect sea turtle use as ecotourism including souvenirs, shops, restaurants and bed and breakfast than through direct consumptive use. That appears to be the case in Ostional as well.

The change from direct to indirect use provided a new economic alternative for the community that guaranteed at least the same income as the egg harvest. However, those economic benefits did not come to the members of ADIO. It will be important to include the members of ADIO in non-consumptive enterprises in order for them to obtain a share of that income. Ecotourism is a good economic alternative to direct use of sea turtles. However, it is important to determine the carrying capacity for visitation, and its impacts on wildlife (Campbell, 2007). The change from direct use to ecotourism is difficult and slow due to cultural and educational differences among members of the local community. It should be combined with other economic alternatives in the form of artisanal and light industrial activities to increase opportunities for all local people. There will also be a need for political compromise in moving from consumption to nonconsumption.

Success of the PEM

The PEM program at Ostional was a success. It resulted in a great increase in positive activities, an increase in order on the beach and a better appreciation for the rule of law among the people living near the refuge. The PEM was established by an executive decree so there was a strong framework for the program. Such a framework is important in fostering participatory management (Olsen and Christie, 2000). By working together with the local people the refuge staff reached commonly defined goals that improved conservation of the resource. The turtles and their eggs were better protected on the beach and in the ocean. Marine protected areas such as Ostional that take into account all stakeholders without compromising conservation goals are more successful in protecting marine coastal ecosystems (Klein, et al., 2008). At Ostional we defined roles of all participants, made assumptions clear, set goals and carried out adaptive management of the marine protected area on land and in the ocean according to the existing conditions. This approach improved resources management with an understanding of the whole context of human relationships (Agardy, et al., 2003)

Barragan (2012) described the historic consumptive use of eggs and turtles by coastal communities in Mexico. At the beginning there was a good relationship and balance between consumption and reproduction, but when that balance was broken sea turtles declined and coastal communities lost an important income from sea turtle harvest.

Plotkin et al. (2012) concluded that overexploitation of sea turtles and their products on a large scale for a long time without regulations reduced the Mexican turtle population and the olive ridley arribada population collapsed. Valverde, et al. (2012) found that the olive ridley population at Ostional had decreased and I found that there were not enough hatchlings being produced to sustain the population (Orrego, 2014, Chapter 2). So while the egg harvest at Ostional may be a model for consumptive use of sea turtle eggs, it appears to be not succeeded from a biological point of view. It is not sustainable because the turtle population appers to be not sustainable at the current rate of hatchling production. The next challenge for the PEM program at Ostional will be to educate all participants about the implications of these findings so that action can be taken to improve the sustainability of the turtle population while continuing to generate income from the non-consumptive use of the resource.

Lessons learned

Lessons learned in Ostional between 2003 and 2014 through the implementation of the PEM/CBC were:

1) It is important to have a management plan for any PEM. In the case of Ostional it was urgent to approve the ONWR management plan to help to consolidate PEM/CBC
2) It was important to have diversified research on biological, socio-economical, legal and management issues to help improve the PEM/CBC
3) It was important to define a management framework to guarantee stakeholder participation in the PEM/CBC in a protected area

4) It was important to take into account that wildlife use is a dynamic process, and as such, the regulations that government enacts should be flexible and responsive to its dynamics.

5) Stakeholder roles need to be defined clearly at the beginning of the PEM/CBC process to maintain balance and keep the process healthy.

6) The wellbeing and quality of life of local people improved from increased profit from egg sales and ecotourism.

7) Economic, social, cultural, political, and scientific benefits led to stable and sustainable conservation.

8) Administration of protected areas is not viable without the recognition, support and participation of local actors in the decision-making process.

9) Objectives, goals, and effectiveness of a protected area can become threatened without proper funding to guarantee protection of natural resources.

10) Environmental education leads to changes in attitudes and perceptions of use of sustainable resources.

11) When biological data reveal that a central component of a PEM/CBC program is no longer viable then adaptive management must be applied to change that component.

12) In the case of Ostional the biology indicates that the sea turtle population appears to be not sustainable and other data indicate that the egg harvest increases rather than decreases poaching of eggs in Costa Rica. Therefore, the PEM/CBC program

needs to foster ecotourism as an alternative to the egg harvest as a source of income for local people.

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TABLES

Table 4.1. Summary of advantages in the administration of Ostional National Wildlife Refuge, Guanacaste, Costa Rica, Participatory Environmental Management (PEM) and Conservation Based Communities (CBC) during 2003 to 2013.

	Advantages
Ecotourism	Establishment and certification of local guide groups (20 people)
	Training local guides with national institutions and universities
	Tours of wetland, mangroves and beach
	Marketing in communication medias. Design and printing material to promote ecotourism.
	Radio communication and uniforms for local guides
	Support to consolidate local guide group
	Development building to local guides throw incomes by ecotourism
Environmental Education	Workshops: Recycling. Alternative energy (solar power). Hand crafts. Responsible fishing techniques for local fishermen. Orchid growth program.
	Design and printing of environmental materials.
	Conferences about management and conservation of sea turtles in schools in Ostional and neighboring towns.
	Release of hatchlings and cleaning beaches for nesting habitat.
	International Workshop for Pacific Eastern Design and evaluation programs of environmental education.
	Design environmental education strategy

Table 4.1 (*continued*)

	Advantages
Protection and Control	Alliances between nongovernmental and governmental institutions for marine and land control, and protection of natural resources. Design of Plan with routine patrols of marine and terrestrial areas. Established training and certification of local committees (COVIRENAS). Design strategy to reduce illegal traffic of sea turtle eggs. Certification of local security to protect nesting habitat of sea turtles from poachers. Communication radios, equipment and uniforms for local security.
Research	Thesis undergraduate and graduate students. Global Monitoring, Transect methodologies for arribadas (Mexico, India, Costa Rica. Ostional host the Latin-American Specialist Sea Turtle Meeting in 2004 One of seven successful experiences in sustainable use of wetland in the Americas (FUNGAP): www.fungap.com, During the IX Conference (COP IX, November, 2005, Uganda). First place as Graduate Student Humanity and Social Category 2008, Drexel. Poster "Advantages of Using PEM or CBC in Ostional National Wildlife Refuge, Costa Rica. Research on natural and anthropogenic causes of mortality of sea turtles in the Pacific coast of Costa Rica. Participation in Sea Turtle Symposium and published results such as: Orrego, C. M. 2008. Advantages of using participatory environmental management in the administration of Ostional National Wildlife Refuge, Costa Rica. Proceeding of the XXVIII Annual Symposium on In Sea Turtle Biology and Conservation. Baja California, Mexico. Orrego, C. M. and J. A. Morales. 2002. Discoveries of olive ridley turtles on the Pacific coast of Costa Rica . In proceeding XXII Annual Symposium on Sea Turtles Biology and Conservation. Miami, USA.

Table 4.1 (*continued*)

	Advantages
Research	Mario Santoro[1], Carlos Mario Orrego[2] & Giovanna Hernández Gómez[3]. 2006. Flora bacteriana cloacal y nasal de *Lepidochelys olivacea* (Testudines: Cheloniidae) en el Pacífico Norte de Costa Rica. Rev. Biol. Trop. (Int. J. Trop. Biol. ISSN-0034-7744) Vol. 54 (1): 43-48. Field lethal incubation temperature of olive ridley sea turtle *Lepidochelys olivacea* embryos at a mass nesting rookery. ENDANGERED SPECIES RESEARCH. Vol. 12: 77–86, 2010. Olive Ridley Mass Nesting Ecology and Egg Harvest at Ostional Beach, Costa Rica. Chelonian Conservation and Biology, 2012, 11(1): 1–11 g 2012 Chelonian Research Foundation.
Legislation	Public decree visitation Established management commission by executive decree Design Management and Use Plan for harvest of sea turtles eggs for every 5 years (2006-2011) and currently 2012 -2016. Research Plan with regulations Draft marine management plan
Management	Government Facilities building. Monitoring of management protected area. Communal infrastructure and library. Alliances between all stakeholders to consolidate refuge. National and International Economical Support for strategies of management. Draft Management Plan. Volunteer program to help with all activities in the administration of Ostional. Building infrastructure. Reforestation Program with native species with schools, local guides and volunteers.

FIGURES

Figure 4.1: Aerial view from Ostional National Wildlife Refuge (ONWR)

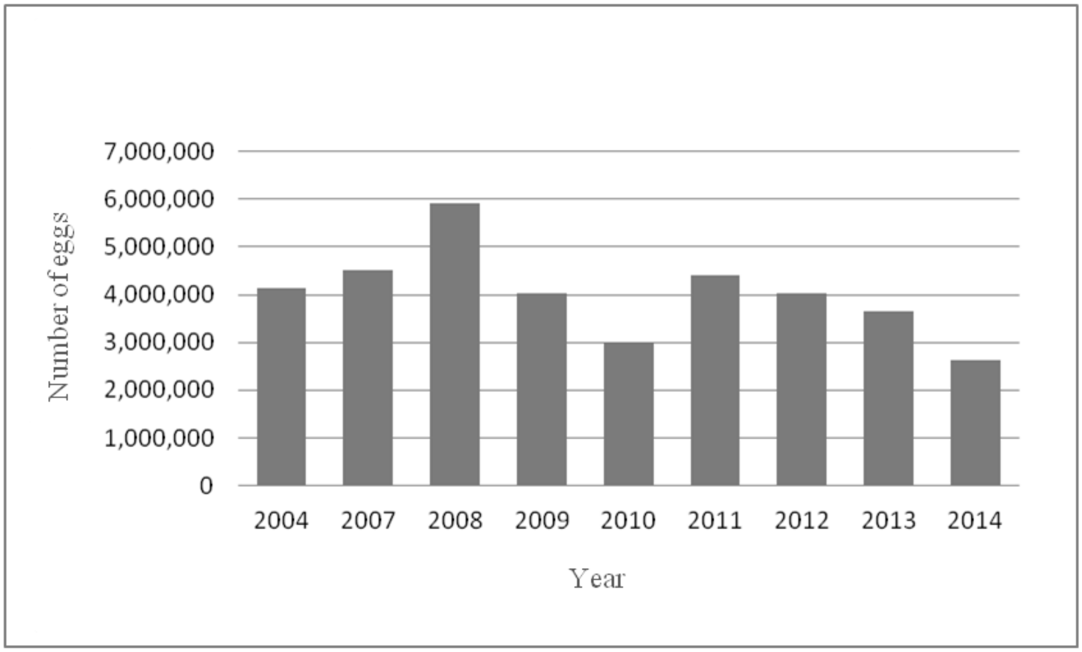

Figure 4.2. Number of eggs harvested 2004-2014 at ONWR

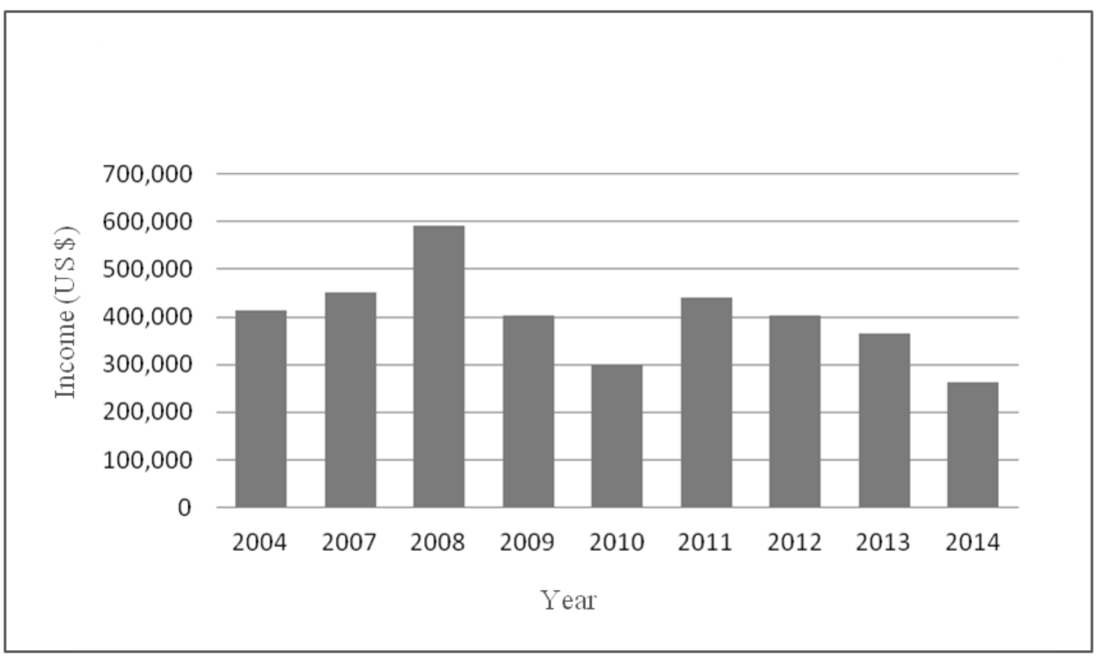

Figure 4.3. Summary of income by commercial harvesting program in ONWR throughout 2003- 2014 (US$)

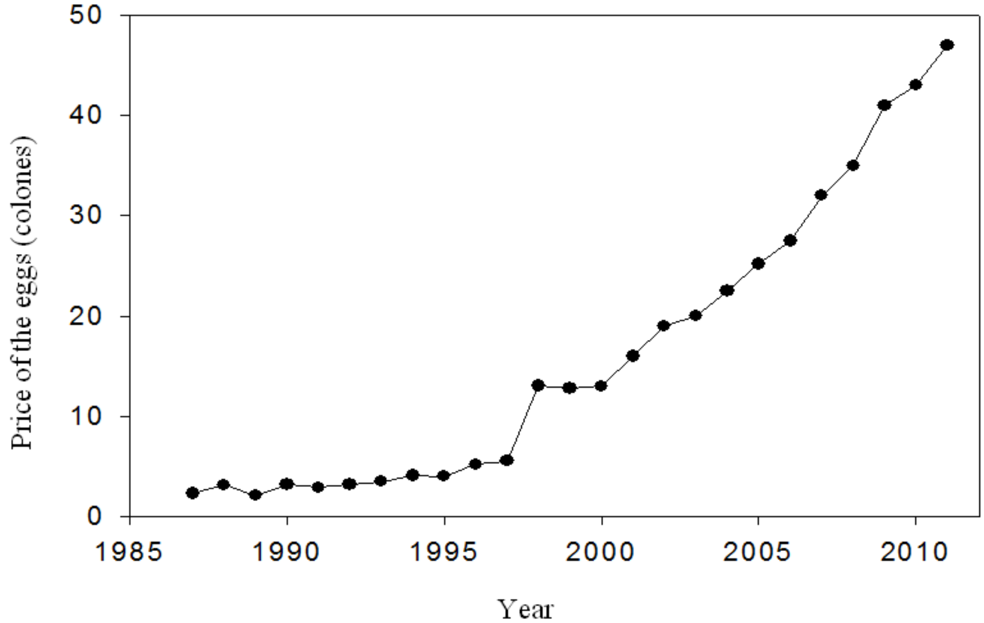

Figure 4.4. Summary of historical behavior of the price of the eggs in the sustainable use of olive ridley turtle eggs by the ADIO at Ostional RNVS (Update unit price 2014, at Ostional market 55 colones, US $ 0.10)

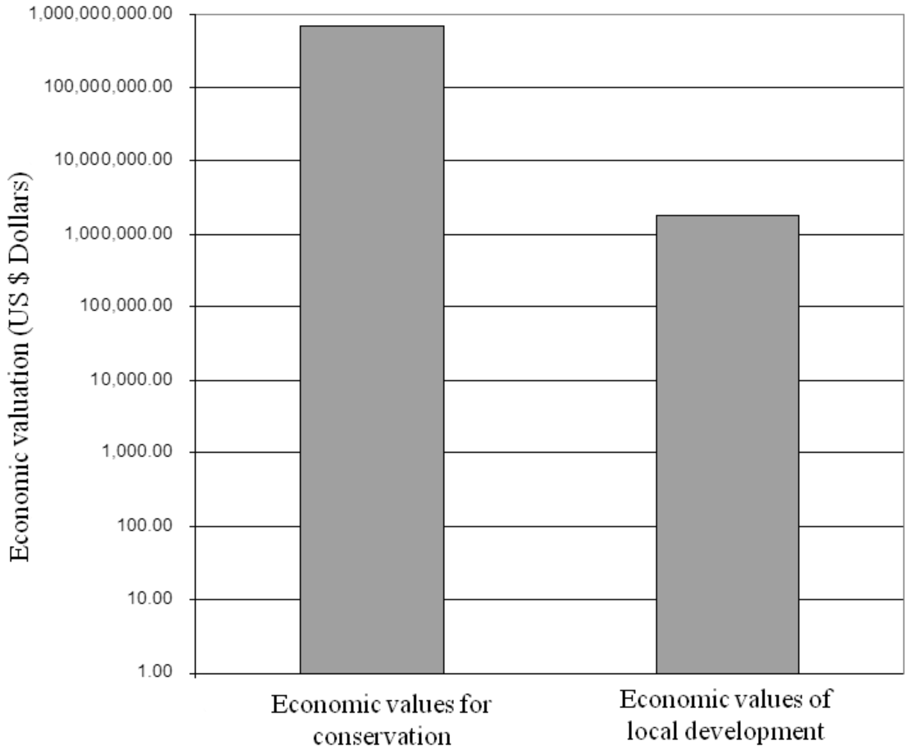

Figure 4.5. Total in dollars by income from ONWR commercial harvesting program and relationship of this with all management activities from Ostional community to protect sea turtle nesting habitat. Source: Plan Quinquenal 2007)

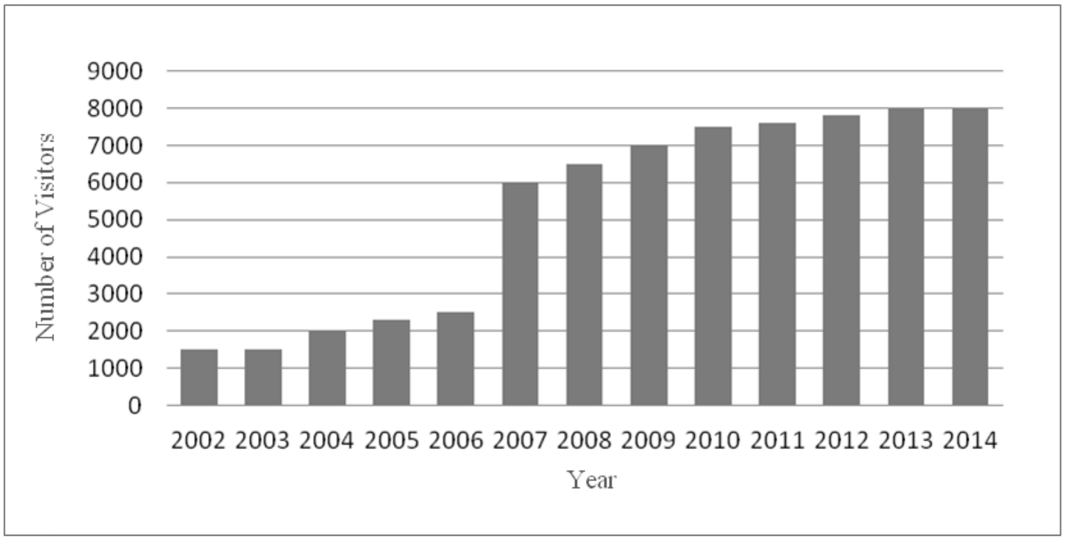

Figure 4.6. Increase of visitation at Ostional National Wildlife Refuge 2002-2014

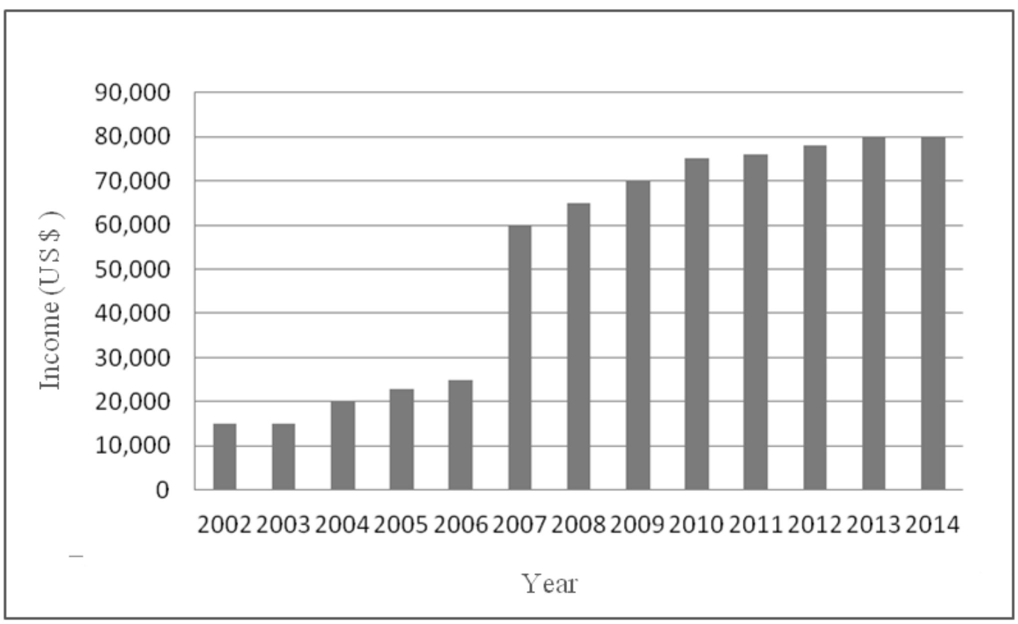

Figure 4.7: Income by ecotourism for Ostional Local Guides (10$ cost per foreign visitor tour)

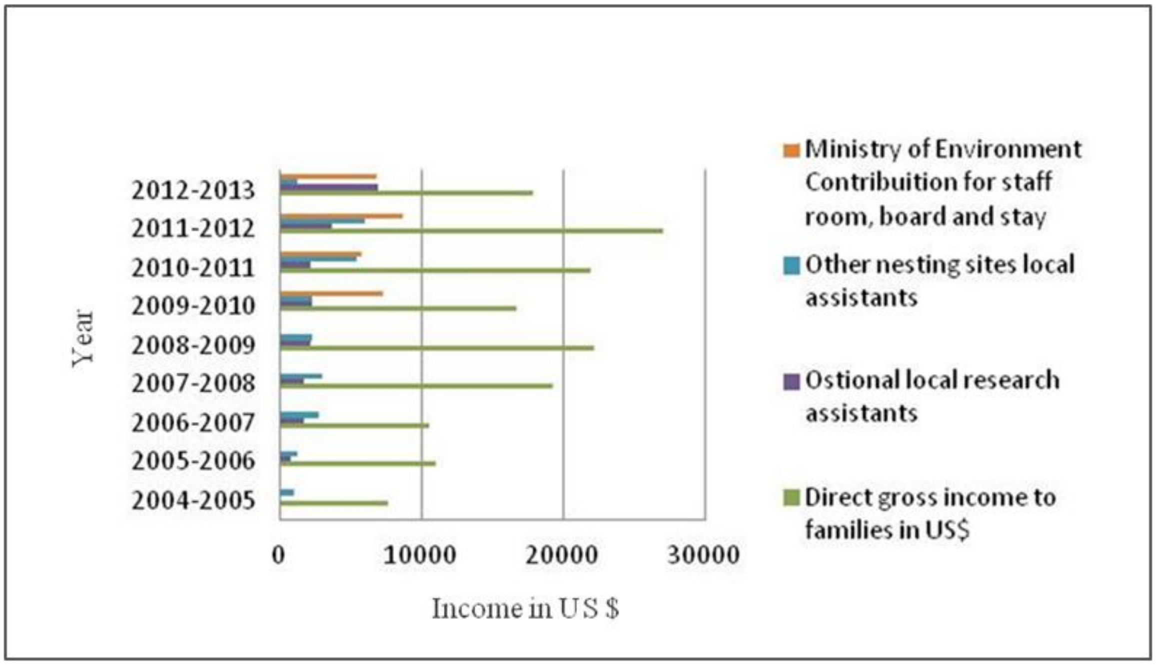

Figure 4.8. Total income from Family program to host volunteers from 2004 to 2013 ($ 175598.44)

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The overall purpose of this thesis was to develop an understanding of the applied biology of the olive ridley turtle nesting arribada at Playa Ostional, Playa La Flor and Playa Chacocente to determine how spatial, temporal, natural and anthropogenic factors affected hatching success and hatchling production and to understand if the harvest of eggs was of benefit to the turtle populations. I also assessed the effectiveness of the participatory management programs at these marine protected areas in sustaining the turtle populations.

Harvest of olive ridley eggs is common at arribada beaches around the world and is implicated in the decline of many such populations (Cornelius, et al., 2007). Egg harvest and capture in fisheries caused the decline of Mexican and Central American olive ridley populations (Cornelius, 1982; Cornelius, et al., 2007). The decline of the leatherback turtle population at Terengganu, Malaysia was due to long-term overharvest of eggs (Limpus, 1995). My study indicated that the harvest of eggs from three beaches in Costa Rica and Nicaragua appeared to be not sustainable. Hatchling production at Ostional and La Flor appeared insufficient to maintain the current populations of adults, and production of hatchlings at Chacocente was marginal for maintaining that population. When harvest and natural mortalities are combined with the removal of adults from the population due to bycatch in fisheries we can expect a large decline in these populations. To help ensure the stability of the regional olive ridley population it will be necessary to produce as many hatchlings as possible from the beaches and to reduce at sea mortality of the turtles for the foreseeable future.

To produce more hatchlings from these beaches we need to understand the factors controlling hatchling production. Hatching success and the production of hatchlings were controlled by the same spatial, temporal, human and environmental factors on all three beaches so those controls appear to be general in nature, at least on the Central American Pacific coast. Density of eggs did not have a significant effect on hatching success or hatchling production. Plots open to harvest, dogs and poaching did not have higher hatching success or higher hatchling production. Thus, removal of eggs by humans and their animals is not an effective means to increase the number of hatchlings produced from these beaches. On the other hand the harvest at Ostional did not decrease hatchling production on a per unit area basis either. The best way to increase hatchling production is to stop poaching, reduce dog predation, and find ways to increase hatching success. It is not practical to eliminate the harvest immediately at Ostional because the harvest provides important income for the members of ADIO. At this time the legal harvest can be restricted to the dry season when eggs typically die from heat and lack of water (Valverde, et al., 2010; 2012). In the wet season harvest can be restricted to eggs that are on the surface of the sand due to digging by turtles and eggs that are in danger of being washed away by the estuaries and tides. At the same time the members of ADIO can work with volunteers to relocate eggs to areas of clean sand to improve hatching success. The volunteers and tourists can pay to assist them in this activity, thus fostering the ecotourism business. As ecotourism becomes an important source of income the ADIO members can reduce and then eliminate their reliance on egg collection for income.

Spatial, temporal, natural and human management measures for all beaches should include systematic and long-term monitoring of arribada parameters, and large-scale experiments on the effect of sand cleaning on hatching rates and hatchling production since clean sand is associated with increased hatching success. Sand cleaning could then be integrated into the management measures at all arribada sites.

In Ostional, benefits from the marine turtles to the local people must be maximized, while at the same time ensuring best conditions for maximizing hatchling production to support turtle population stability. Conservation measures can be anchored in a commonly agreed management scheme between government and community. The legal harvest is desirable from the point of view of its contribution to local livelihoods and the positive custody it generates among community members over the sea turtle resource. Ideally, the community should seek to develop further the non-consumptive benefits from sea turtle ecotourism and share the responsibility and benefits as widely as possible within the community to avoid the creation of small monopolies (see also Orrego, 2014, Chapter 4). Olive ridley nesting in arribadas is a spectacular event with a great marketing and income potential. In general, nesting of solitary females can be frequent enough to allow for a reliable tourism experience on a majority of nights. For Ostional, therefore, a combination of a transitional well-managed harvest of doomed eggs and ecotourism could provide a conservation plan that would eventually provide new income for local residents and increase hatchling production.

There should be no new development at Ostional, La Flor and Chacocente beaches because it will cause an increase in disturbance to the arribadas and an increase in impact from people and dogs. A control program is necessary to remove dogs from the three beaches by educating people about the impact of dogs, euthanizing feral dogs, and euthanizing and other dogs that cannot otherwise be removed. Elimination of the impact of dogs and poaching on the beaches will require interinstitutional strategies. Strict enforcement of controls by permanent patrolling from MINAE, ADIO and police in Costa Rica and MARENA and the military in Nicaragua over the whole beach and year is necessary.

Harvesting eggs, legally or illegally, makes eggs available in local markets, bars and other retail points. These eggs legitimize turtle egg consumption and, in turn, incentivize poaching of olive ridley and other sea turtle eggs throughout Costa Rica and Nicaragua (Spotila, 2011; Blanco, et al. 2012; Santidrián Tomillo, et al. 2014). Strict anti-poaching measures nation-wide, consumer awareness and easy tracebility of eggs of legal origin are necessary ingredients to accompany the Ostional harvest scheme. The harvest of olive ridley eggs throughout the world is linked with very poor coastal communities and lack of economic alternatives (Campbell, 2007). Therefore, the impact of strict law enforcement measures on the local people who rely on the harvest for a portion of their income needs to be considered and alternative sources of income provided to compensate for losses from harvest restrictions.

It will be useful to implement a participatory environmental management (PEM) program at La Flor and Chacocente, similar to the one in place at Ostional (Orrego, 2014, Chapter 4). Ecotourism now produces more income at Ostional than the legal egg harvest (Orrego, 2014, Chapter 4). By working with all of the stakeholders it should be possible to develop alternative sources of income, particularly from sea turtle ecotourism, for people near La Flor and Chacocente while promoting management measures (i.e. control of dog predation, anti-poaching measures) to increase the production of hatchlings from those beaches.

The comparison of the biology of the olive ridley arribadas at three beaches in Pacific Central America indicates that marine protected areas can potentially be effective at both protection of nesting turtle populations and provision of socioeconomic benefits to the local human populations. However, strict anti-poaching measures nation-wide, consumer awareness in Ostional, La Flor and Chacocente, and an aditional control of tracebility of eggs of legal origin are necessary ingredients to accompany the Ostional harvest scheme. In addition dogs must be removed from the MPAs. The key for success, however, lies in the local ownership of the management plan and strict enforcement of the law.

Establishment of marine protected areas around the world can be an important tool to help recover populations of migratory species such as sea turtles. Each MPA should evaluate the biology of the species being protected/managed (Nel, et al., 2013) and establish an adaptative management plan that takes into account ecological, social, and economic factors to keep the MPA sustainable over the time (Agardy, et al., 2003). It should also develop a clear management framework (Olsen and Christie, 2000) to take into account all stakeholders without compromising best conservation practice and objectives (Klein, et al., 2008). An integral conservation strategy for sea turtles, however, must add to the management measures on the nesting beach and in the market places, firm protection of sea turtles at sea to reduce bycatch mortality, as well as adaptation measures to climate change. The Ostional experience provides a fundamental lesson for all such MPAs. Success of an MPA must first and foremost be judged by the sustainability of the sea turtle population, while also taking into account the socioeconomic realities affecting the local human population.

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APPENDIX

Appendix A:

Undergraduate and graduate theses at Ostional between 2002-2014:

Undergraduate's thesis:

1 Monitoreo y conservación de la tortuga lora (*lepidochelys olivacea*) en el refugio nacional de vida silvestre Ostional, Guanacaste, Costa Rica. Marvin Méndez González. Tesis para bachillerato en manejo de recursos naturales. UNED. Costa Rica.

2 Comparación del beneficio biológico de la anidación de manera-solitaria de la tortuga lora (lepidochelys olivácea) en playa Ostional, Costa Rica. Práctica profesional para optar por el título de bachillerato en manejo y protección de recursos naturales. Fabricio Alvarez Ramirez.

Master's thesis:

1 Causas naturales y entrópicas de mortalidad de Tortugas marinas en el Pacifico de Costa Rica. Carlos Mario Orrego Vásquez . Tesis sometida a consideración del Tribunal Examinador de Postgrado de la Universidad Nacional para optar al título de Magister Scientiae en Conservación y Manejo de Vida Silvestre. Costa Rica.

2 Caracterización de la anidación solitaria de la tortuga lora (*Lepidochelys olivacea*) para la época de verano en el Refugio Nacional de Vida Silvestre Ostional, Guanacaste Costa Rica 2009. Marcela Rodríguez Sánchez Heredia, Noviembre de 2010. Tesis sometida a consideración del Tribunal Examinador de Postgrado de la Universidad Nacional para optar al título de Magister Scientiae en Conservación y Manejo de Vida Silvestre. Costa Rica.

3 Evaluación de la importancia ecológica de la tortuga lora (*lepidochelys olivacea*) (Eschscholtz 1829) en el aporte de energía durante eventos de arribadas en playa Ostional, Guanacaste. Ricardo Hernández Sánchez. Costa Rica.

4 Histología gonadal para la determinación del sexo y hallazgos asociados a la mortalidad prenatal en neonatos muertos de tortuga lora (*Lepidochelys olivacea*) en playa Ostional, Costa Rica. Laura Brenes. Tesis en Manejo de Recursos Naturales de la Escuela de Ciencias Exactas y Naturales para optar por el grado Magister Scientiae con énfasis en gestión de la biodiversidad . Universidad Estatal a Distancia, UNED, Costa Rica.

PhD. Thesis:

1 Biology and management of olive ridley turtles (*Lepidochelys olivacea*) in Central America. Carlos Mario Orrego V. Ph.D. dissertation. Drexel University, Philadelphia. USA.

VITA
Carlos Mario Orrego Vasquez

EDUCATION

D.M.V. Doctor Medicine Veterinarian. Universidad de Antioquia, Medellin, Colombia.
M.Sc. Major in Management and Wildlife Conservation. National University, Costa Rica.
P.hD. Major in Environmental Science. Drexel University, Philadelphia, PA. USA.

PROFESSIONAL EXPERIENCE

- 2011-2014. Director of wildlife and conservation program and projects. Ministry of Environment and Energy. Costa Rica.
- 2003-207. Director Ostional National Wildlife Refuge. Ministry of Environment and Energy. Costa Rica.
- 2002-2007. Instructor Sea Turtles in Central America.

AWARDS AND SCHOLARSHIPS

- 2007-2014. Environmental Science. PhD. Drexel University.
- 2004. Professional Development Award by the Field Veterinary Program of the Wildlife Conservation for Society for to participate in Annual Symposium For Biology and the Conservation of the Marine Turtles. Miami, the USA.
- 2002. Wildlifetrust for the edition Manual on Biology of Turtles Marinas and Poster of First aid in Marine Turtles.
- 2000: INBio-SINAC - World Bank, Scholarship to finance Project of Investigation "natural and antrópicas Causes in the mortality of the marine turtles baula (*Dermochelys coriacea*), Olive ridley (*Lepidochelys olivacea*) and black (*Chelonia mydas agazzissi*) in the Pacifico of Costa Rica".
- 1995-1996: Government of Colombia, COLCIENCIAS, in quality of coinvestigator and tesista, Project of Investigation "Determination of the resistance to insecticides in *Anopheles pseudopunctipennis* in agricultural zones of the geographic Valley of the Cauca River and its possible relation with epidemic buds of malaria".

PUBLICATIONS

- Valverde, R.A., **C. M. Orrego**, M. T. Tordoir, F. M. Gomez, D. S. Solis, R. A. Hernandez, G. B. Gomez, L. S. Brenes, J. P. Baltodano, L. G. Fonseca, and J. R. Spotila. 2012. Olive ridley mass nesting ecology and egg harvest at Ostional beach, Costa Rica. Chelonian Conservation and Biology.11:1-11.

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- **Orrego, C. M**. 2008. Advantages of using participatory environmental management in the administration of Ostional National Wildlife Refuge, Costa Rica. Proceeding of the XXVIII Annual Symposium on In Sea Turtle Biology and Conservation. Baja California, Mexico.