AN ABSTRACT OF THE THESIS OF

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Title: Arribada Nesting of Olive Ridley Sea Turtles (*Lepidochelys olivacea*) at La Escobilla, Mexico

Abstract approved:

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Olive ridley sea turtles (*Lepidochelys olivacea*) present an interesting case study of the conservation of wildlife species that aggregate in high densities and have served as resources for human consumption. Ridleys exhibit synchronized mass-nesting behavior, during events called "arribadas," where thousands of females lay eggs together in a small area over the span of a few consecutive nights. Some of the largest arribadas occur at La Escobilla, Mexico, with over a million nests estimated per season. These aggregations have made olive ridleys vulnerable to negative impacts from harvest and density-dependent influences on nest success. There are many interconnected determinants of nest success, including intraspecific competition for space, temperature, and predation. Nest destruction by conspecifics is an apparent potential impact of high density nesting, as later-arriving turtles often dig up previously laid nests. Nest destruction is the main scientific argument for "sustainable" egg harvest, since local communities could utilize eggs otherwise destroyed as an economic resource. In 2009 at La Escobilla, I explored 1) the historical context of harvest and community members' current perceptions of turtles through 12 semi-structured interviews with key informants; 2) nest destruction rates during arribadas through a

field study to quantify nesting behavior. My first objective was to understand the shifting human-turtle relationship and how it informs current community dynamics and future conservation and research at arribada beaches. Historical research and interviews indicated that many local residents are familiar with turtle behavior and agree on the importance of conservation efforts for turtles and the local community. Nevertheless, residents struggle for economic stability within what has largely been an externally-imposed protectionist framework. Future efforts should integrate long-term employment with local involvement in research, conservation, and non-consumptive use. The second objective of my project was to quantify nesting activity and investigate the relationship between nest densities and nest destruction. Nesting behavior of 1293 turtles was observed in 26 sample plots during two consecutive arribadas. Cumulative nest densities estimated over two arribadas ranged from around 1 to 8 nests/m^2. The odds of a turtle digging up eggs increase 21% for every additional nest in a 1m^2 area surrounding a nesting turtle. No hatchlings emerged from the arribadas I studied, likely due to unfavorably warm temperatures in 2009 and widespread beetle predation. Estimation of hatchling production at the beach level is necessary for accurate projection of the population's status; the empirical findings and methodologies considered in this project can be used in such future models. My field study illustrates the complexity of predicting hatchling production because of temporal and spatial variation, as indicated by cumulative effects of multiple arribadas on incubating nests.

Arribada Nesting of Olive Ridley Sea Turtles (*Lepidochelys olivacea*) at La Escobilla, Mexico

by
Melissa Ann S. Ocana

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APPROVED:

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Major Professor, representing Wildlife Science

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Head of the Department of Fisheries and Wildlife

____

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Melissa Ann S. Ocana

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CHAPTER 1: INTRODUCTION

The olive ridley turtle (*Lepidochelys olivacea*) is the world's most abundant sea turtle, with nesting beaches in the Atlantic, Pacific, and Indian Ocean basins. The species has a remarkable aggregation behavior that results in synchronized mass-nesting of thousands of females together over a few consecutive nights during "arribadas" (Bernardo & Plotkin 2007). The largest aggregations have hundreds of thousands of females nesting on beaches at La Escobilla, Mexico; Ostional, Costa Rica; and Orissa, India. The abundance of this species has led to a long history of exploitation by humans for eggs and meat. My research focuses on a nesting population of olive ridleys at La Escobilla in the state of Oaxaca, Mexico, and the local community that has depended on the turtles.

Large aggregations of wildlife are becoming an increasingly rare occurrence, partly due to accrued human activities and interest in the resource potential of such gatherings. The mass-nesting behavior of olive ridleys has made them particularly vulnerable because aggregations are predictable in space and time (Cornelius 1985). Despite being the most abundant species of sea turtle, olive ridleys are listed as Vulnerable throughout their range by the IUCN Red List (Abreu-Grobois & Plotkin 2008). The coast between central Mexico and Panama is probably the region that has seen the greatest decline in nesting olive ridleys (Cornelius et al. 2007). This is likely in part due to the extensive industrial harvest of olive ridleys in the Pacific in the 1960s- 80s. Pre-1950 estimates put the number of nesting olive ridleys at 10 million in Mexico (Cornelius et al. 2007). The Mexico breeding population has increased in response to a 1990 ban on turtle harvest, with 1,193,609 nests estimated in 2008-2009 (Albavera et al. 2009). This population is still distinctly classified as endangered by the U.S. Endangered Species Act (USFWS & NMFS 2007).

The purpose of this thesis is to provide a greater understanding of arribada nesting dynamics and potential density-dependent factors that affect hatchling production. I want to build on previous and current research activities to improve plans and methodologies for future conservation and management of La Escobilla, Mexico's nesting turtles. Another goal of my work is to continue to build relationships and promote exchange of research knowledge among and within regional arribada beaches. As this project also represents one of few recent international research efforts at La Escobilla, it provides fresh perspective for all involved.

This thesis begins by exploring the human-turtle relationship at La Escobilla, both past and present. The history of this interaction constrains current and future conservation and management efforts. This relationship, which has changed dramatically over the last century, also provides essential context for my research project and has implications for how my research results could contribute in the future. Many Escobilla residents remember well the period of industrial turtle harvest and the resulting fallout, and they speak of the ongoing economic difficulties faced by communities trying to "live peacefully" with turtles. Thus, the purpose of this chapter is to delve into how humans and turtles have interacted in the past at Escobilla as well as place my ecological research questions in the larger context of the field site. My research is just a snapshot of a long dynamic history of resource use but exploring current perceptions of residents and researchers through interviews can help us move forward with continued management efforts. The bulk of the chapter is roughly organized into four chronologically ordered sections: from historically subsistence or small-scale commercial turtle use (1), to the industrial harvest period (2), through the lead up and transition after the 1990 Mexican ban on sea turtle use (3), and ends with an assessment of where we are now (4). In each section, I will discuss the scale of human activities (e.g. harvest, conservation strategies), the beneficiaries and controllers of the turtle resource, important regulations, and the effects on the turtle population. At the close of the chapter, I will present the current picture of Escobilla and how community members' needs and perceptions of turtles fit in with turtle conservation and research discussions.

The next chapter evaluates factors affecting nest productivity through a field study undertaken in 2009. Arribada nesting dynamics are complex, with a web of factors combining to affect nest success. As one of the largest olive ridley arribada sites in the world, La Escobilla, is an ideal location to consider how factors associated with nest density might affect productivity. Nest destruction, also known as superimposition, is the most observable potential consequence of arribada nesting, as later arriving females dig up previously laid eggs. Nest destruction is also the main scientific argument in support of "sustainable" egg harvest; proponents argue that eggs that would otherwise be destroyed can instead serve as an economic resource for local communities. The main study objective is to determine the pattern of nesting activity, nest densities in the most frequently used portion of the beach, and probability of nest destruction by females at La Escobilla. Previous studies have considered destruction and density (of adults and nests) for other sea turtle species at solitary beaches, but the relationship between these variables is not quantified for arribada beaches.

Density-dependence has not been well-quantified for ridley turtles because it is difficult to identify which key variables are essential for data collection and to devise appropriate methodologies, given restraints imposed by the site (e.g., geographic variability, local community resource needs) and unique arribada behavior (e.g., large volume of turtles in small temporal windows, nesting areas with varying density). For this study, I took into account the turtles' biology, my familiarity with site-specific limitations and discussions with local researchers In order to meet the demands of data collection associated with a project of this scope, I assembled an international team that included three volunteers from the U.S. and Ecuador, two Mexican students, and roughly 15 hired local community members. I received logistical assistance from CMT researchers and student volunteers. This project aligns with Mexican researchers' goals to identify where to focus research efforts as well as how to standardize yearly data collection. A greater understanding of their inter-relatedness of factors affecting nest success at La Escobilla is a first step towards improved modeling of beach productivity. For example, the ability to predict destruction levels based on nest density could be a useful tool for the arribada conservation toolbox. Improving our understanding of basic nesting ecology has strong conservation implications and can inform protection strategies.

The final chapter concludes by tying together results from the previous chapters to determine how best to move forward with conservation and management efforts. Given limited resources, it is important to define representative variables for regular measurement in monitoring plans and to improve data collection methodologies. The chapter also considers the importance of methods that would be necessary to estimate hatchling production at the beach level. From the field study, we found that nest density is related to nest destruction levels, warranting further research as the pattern is likely more defined in later season arribadas and higher nest densities. The cumulative effects of multiple arribadas on incubating nests increase the odds of destruction and present a challenge to estimating nest success. However, other factors merit future monitoring. Beetle predation and climatic conditions are what likely led to nest failure in our study plots. The disparate hatching outcomes in various parts of the beach indicate that estimating hatching production based on the above factors also requires spatial and temporal consideration. Local residents and researchers shared their thoughts on factors affecting nest success, and their logistical help made the project possible. I believe that increased participation by Escobilla residents in research activities will help to better conserve the turtles. However, the greatest safeguard for the turtles would be development of year-round income sources for residents tied to turtle protection. Mexico’s long history of turtle use emphasizes the need to consider the local community and their role in turtle protection.

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CHAPTER 2: THE IMPORTANCE OF HUMAN DIMENSIONS FOR OLIVE RIDLEY (LEPIDOCHELYS OLIVACEA) SEA TURTLE CONSERVATION AT LA ESCOBILLA, MEXICO

Introduction

Shifting uses of wildlife and sea turtles in particular

Wildlife harvest has been a vital part of human history (Mace & Reynolds 2001). However, the nature of the relationship between wildlife resources and those humans who live closest to them changes over time. Many communities have shifted from consumptive wildlife use, originally at subsistence levels and then at larger-scale commercial harvest levels, to non-consumptive protection as a result of wildlife population collapses and/or a burgeoning conservation paradigm. How wildlife is used as a consumptive or non-consumptive resource has implications for how populations are conserved or managed. Many conservation biologists attest that when people value wildlife as an utilitarian resource, local conservation efforts are more successful, though which types of uses serve conservation goals is debated (Robinson & Redford 1991).

Harvest patterns have changed over time for a variety of reasons, and there are countless examples of wildlife populations that have experienced shifting harvest pressures. Colonial nesting birds and ridley sea turtles (*Lepidochelys*) both receive benefits from their aggregations for reproduction; however, these behaviors have made them vulnerable to overharvest (Burger 1994; Cornelius 1985). Seabirds and ducks have been hunted as an important food source off Newfoundland and Labrador, Canada, for hundreds of years (Montevecchi 2008). Seabirds and their eggs were initially harvested for semi-subsistence, but intense commercial harvest for down began in the mid- 19th century (Montevecchi 2008; Blanchard 1995). As food security for human populations increased, seabird resources changed from a vital need to a recreational or cultural one (Montevecchi 2008). During the 20th century, hunting patterns varied for reasons similar to other harvest stories: technological advances increased hunting potential, while government policies affected how seabirds were harvested; for example, the rise of unemployment insurance meant Canadians had more money and time to invest in hunting (Blanchard 1995). Starting in the 1970s, researchers concerned about seabird resources pursued the goal of developing a conservation ethic through community-based work such as children's education and training former poachers to be wildlife guards. Their techniques emphasized the need to have local involvement and work within local cultural norms (Blanchard 1995).

Sea turtles have always been an important resource for humans, though how they have been utilized varies by geographic area and species and over time (Campbell 2003; Frazier 2003). Turtle eggs are a ready source of protein, and with batches of around one hundred eggs per nest, they provide more reward per effort than avian sources. Turtle meat is also an important protein source. Their tanned skins provide a durable fiber, and their shells fashion decorative or practical items. Because of their purported aphrodisiac qualities, eggs are consumed in bars. The value of sea turtle products as commodities has led to overconsumption in many parts of the world (Eckert et al. 1999).

Mexico's waters are home to 6 of the 7 species of sea turtles, making it an important area for a case study of turtle resource use. Olive ridleys (*Lepidochelys olivacea)* gather in remarkable synchronized nesting events, called arribadas, in only a few locations around the globe. Olive ridleys nest in low densities on many beaches along the coast of Oaxaca, but La Escobilla is distinctive for its massive arribadas; as home to one of the largest nesting populations in the world, it is a critical location for research on the status and trends of the olive ridley. As discussed later in this chapter, the decline of the olive ridley fishery near La Escobilla spurred Mexico's ban on sea turtle use (Aridjis 1990).

During arribadas, tens of thousands of turtles come ashore to lay eggs over a few consecutive days (from one to 30, depending on definition), several times a year, presumably as a strategy for predator saturation (Bernardo & Plotkin 2007). A,number of factors affect nest success at La Escobilla, many of which may be density-dependent. High nest density on arribada beaches can determine low hatch success due to disease, inadequate gas exchange, nest destruction (as turtles arriving later damage previously laid nests), predation by the beetle *Omorgus suberosus,* and other factors (discussed in Chapter 3).

The apparently negative effect of high nest density has led to the theory that otherwise-destroyed eggs can instead be sustainably harvested by local communities as an economic resource (Campbell 1998). A legal harvest by a local cooperative in Ostional, Costa Rica, has been built on this argument, even though the specifics regarding destruction and harvest impacts remain under-researched. In contrast, coastal communities of Oaxaca, including Escobilla, have not included legalized sustainable egg harvest in their conservation plans, owing perhaps to the fallout from their industrial harvest history.

As with many other wildlife species worldwide, the treatment of olive ridley turtles on the Oaxaca coast as a natural resource has shifted significantly over time. The various eras in the history of turtle harvest have shaped how Escobilla residents interact with the nesting population today. Moreover, the history of harvest and protection at La Escobilla holds important implications for the well-being of both humans and turtles in the future. Over the past hundred years, different aspects of the resource have been utilized, a variety of stakeholders have held control over the resource, and local and international interest in protecting the turtle population has grown. In addition, regulation and enforcement have shifted over time as the nesting population has fluctuated. This history of turtle use (and non-use) informs the current situation at La Escobilla, where local awareness of harvest as a conservation problem has become a part of the mainstream consciousness of the local population as residents struggle for economic stability within what has largely been an externally-imposed protectionist framework. This history also affects how future conservation plans will be implemented. Thus, a greater understanding of the historical context of resource use at La Escobilla can help managers and researchers move forward in their conservation goals, ideally, while supporting the community in their own goals.

Research Methods and Purpose

In this chapter, I describe the human-turtle relationship at La Escobilla, past and present. How turtles have been viewed and used by this community has important ramifications for management and conservation efforts now and in the future. In the following section, I trace the evolution of the human-turtle relationship at La Escobilla through four periods, from subsistence or small-scale commercial use through the industrial period to the implementation of a ban on harvest and ending with a snapshot of Escobilla today. In discussing that final period, I report my own findings on how community members view turtle research and pressing conservation issues and the implications of those perceptions for future research efforts. Throughout, I refer to both Escobilla, the town, and La Escobilla, the nesting beach.

To understand the history of turtle harvest and how it has shaped current dynamics at Escobilla, I conducted semi-structured informal interviews with nearly a dozen key informants in Spanish. Throughout the chapter, historical information obtained from secondary sources is interspersed with lessons and translated quotes garnered from these interviews. All references to community members' statements are from my interviews, if not otherwise cited. To provide a diversity of perspectives, I attempted to interview individuals who represent the various groups involved with turtles; I spoke with Escobilla community residents, including members and non-members of the local tourism “cooperative,” and also government researchers. Discussions with local stakeholders allowed me to shed light on how local residents view arribada nesting dynamics, conservation-oriented scientific research, and their potential involvement in it.

History of Olive Ridley Use at La Escobilla, Oaxaca

1. Subsistence/Small-scale Commercial Use (pre-Hispanic period to 1950s)

Sea turtles have been a historically important resource for numerous coastal cultural groups around the world. From pre-Hispanic times, subsistence egg consumption existed in Mexico and is believed to have been more common than adult turtle harvest for meat (Cornelius et al. 2007). There are many examples of turtle consumption by indigenous cultures, e.g., the diet of the Huaves from Oaxacan rainforests, and the harvesting of eggs during arribadas by Zapotecos, a dominant Oaxacan group (Cornelius et al. 2007; Trinidad & Wilson 2000). Small-scale egg commerce also occurred with eggs dried and sold in regional markets as a substitute for meat (Marquez 2000 in Cornelius et al. 2007). Many nesting beaches are remote, often resulting in gaps in historical data. If current poaching is any indication, harvesting likely occurred on low density beaches as well as arribada beaches, as nesting turtles are large animals (about 1m in length) and their tracks are easy to identify. It was likely more effective to harvest during arribadas, due to the large quantities of eggs available.

Population estimates from this period are lacking, but it is generally assumed that this level of harvest was not damaging to the population, as non-human predation rates on turtle eggs are high (Marquez et al. 2007). But by the early 20th century, turtle use had intensified throughout the country, leading to government intervention to prevent overharvest. The 1927 Fishery Regulation (Article 97) prohibited collection of turtle eggs and destruction of nests throughout Mexico. By 1929, closed seasons and minimum sizes were in force for several turtle species hunted for meat (Trinidad & Wilson 2000). Yet the regulations were little more than paper, as there was little enforcement in place and likely little change in local egg harvest.

Settlements alongside La Escobilla beach eventually coalesced into the current town of Escobilla sometime between 1940 and 1950 (interviews). It is generally believed that turtles mass-nested at this beach before the human community was founded, though residents apparently did not start reporting thousands of turtles until the late 1950s (Albavera pers. comm.). Houses have been built right along the beach, and turtles wander through residents' "yards'. As one community indicated, with turtles living "right in front of them," it is logical that Escobilla residents and others along the coast used to grow up eating eggs. A 2009 survey provided evidence for this idea, reporting that home egg consumption had been learned and passed on generation after generation (Gomez Padron 2009).

2. Industrial Harvest *(1950s – 1990)*

Creation of an industry

A major shift in harvest levels came in the mid-20th century with the transition from subsistence and small-scale commercial harvest to large-scale, industrial harvest of olive ridleys for international trade (Chapter 3 Figure 3.9 for map of regional nesting beaches) (Campbell 2007; Trinidad & Wilson 2000). The international turtle leather industry flourished in response to a decline in the crocodile leather industry (Marquez & Carrasco 1996). Fishing occurred off Oaxaca's coasts, targeting turtles that nested en masse at La Escobilla or individually on the many neighboring beaches. Turtle harvest in Oaxaca peaked at around 15,000 tons in 1968, with demand primarily from Europe and Japan (Trinidad & Wilson 2000). In this new, mechanized era, slaughterhouses were built to harvest turtles and process carcasses; the Oaxaca slaughterhouse was located at San Agustinillo, a beach neighboring La Escobilla. One government interviewee described the learning curve: slaughterhouse workers at first lacked the necessary skills, because turtles had traditionally been harvested for meat, not skinned for leather. Though leather was the lucrative product, wasteful practices that just marketed skins inspired a 1969 law stipulating that the entire turtle had to be used (Campbell et al. 2007). Eventually slaughterhouses developed the capacity to process meat and unlaid eggs from the carcasses that were originally thought of as "byproducts" (Cornelius et al. 2007). During the peak of harvest, even bone, blood, shell, entrails, and cartilage were utilized for medicinal purposes, consumption, and fertilizer (Campbell et al. 2007; Marquez et al. 2007; interviews).

Harvest estimates are staggering (Figure 2.1). For example, the catch reported in the Oaxaca fishery in the 5-year period up to 1969 was around 700,000 individuals, mostly females captured during the nesting season. A calculation accounting for expected underreporting estimated an actual take of 2 million turtles in that period (Cliffton et al. 1982). Most turtles were fished offshore, though females were often caught when they came ashore to nest (Cornelius et al. 2007). Egg collection remained important during this time with an estimated 150 metric tonnes (or 45,000 nests) harvested annually (Cornelius et al. 2007).

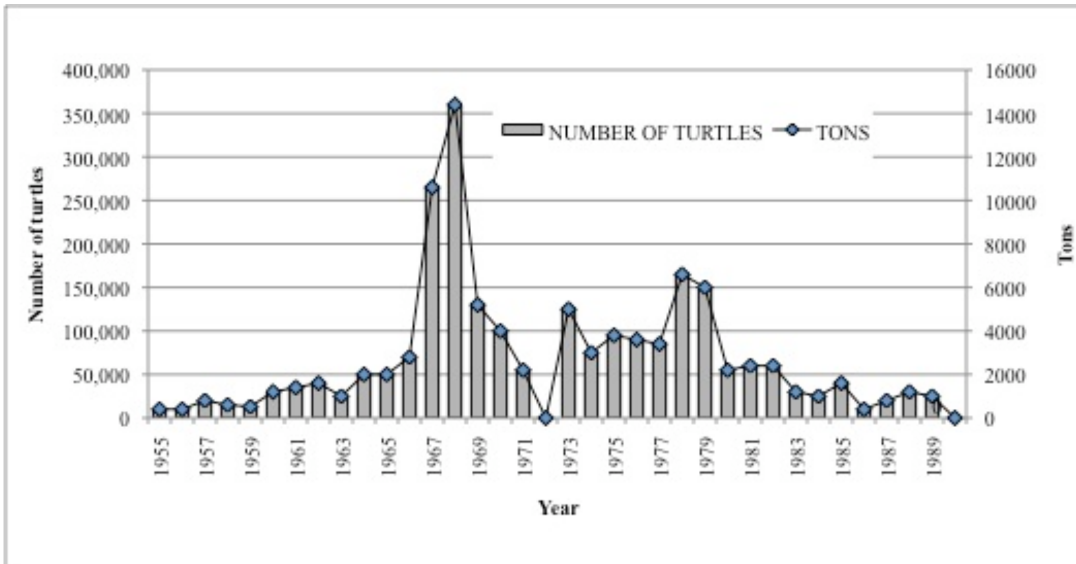

Figure 2.1. National commercial harvest levels of sea turtles between 1955 – 1990. Years are on the x-axis. Tons (line) and number of individuals (gray bars) harvested are on the y-axis. There was a harvest ban in 1971-1972. Note that this represents the reported take and therefore is an underestimation of actual numbers of turtles harvested due to poaching. Graph by Marybeth Head. Data from Instituto Nacional de la Pesca (INP) Penaflores et al. 2001.

When considering the full impact of this level of harvest, it is essential to remember that sea turtles are highly migratory animals. Olive ridleys nesting at La Escobilla are subject to threats wherever they travel; similarly, any turtles migrating from elsewhere arrived offshore Oaxaca to find an efficient fishing operation. In fact, turtles tagged in Costa Rica were captured near La Escobilla (Cornelius & Robinson, 1986). As such, a decline in the size of arribadas at Nancite, Costa Rica may have been due to the Oaxaca fisheries (Valverde 1998). It was a dangerous time to be an olive ridley; overlapping with the Oaxaca industrial period was a large-scale legal harvest at foraging areas off of Ecuador. La Escobilla nesters likely constituted part of Ecuador's harvest, as several turtles were caught with tags from Mexico (Green and Ortiz-Crespo 1982). Between 1970 -1981, meat and skins were exported from Ecuador, also mostly to Japan and Italy. Harvest levels in Ecuador were substantial; in 1978, 80,535 - 89,483 turtles were skinned from that fishery (Green and Ortiz-Crespo 1982). These levels are parallel to those in Oaxaca where 70, 000 ridleys (90% of them carrying eggs) were harvested in 1977 (Cliffton et al.1982).

Through much of the 1970s - 80s, regulations and turtle population sizes changed, which led to shifts in how the turtle resource was controlled. In light of declines in annual take, the government agency that oversees fisheries (now called the Instituto Nacional de la Pesca or INP) took strides to regulate harvest. Adult turtle fishing was banned in 1971 for 18 months and a new set of complex regulations put into place (Campbell 2007). Fishing reopened in 1972 with exclusive rights given to local cooperatives (Sociedades Cooperativas de Producción Pesquera) (Trinidad & Wilson 2000). Yet, this new era (1973-80) for the fishery was controlled in great part by a private firm, Pesqueria Industria de Oaxaca (PIOSA); PIOSA, owned by Antonio Suarez, controlled the slaughterhouses, which were the primary market for the co-ops (Campbell et al. 2007). While touting conservation and protection of nesting beaches, Suarez was exposed in 1978 for illegally importing ridley meat into the U.S. under the guise of river turtle meat (Campbell et al. 2007). As turtle numbers waned, the Oaxacan turtle industry quickly became less profitable. In 1980, the Mexican government bought the PIOSA plants to create a para-statal organization, PROPEMEX, and, in an effort to reorganize the supply chain to involve the fishermen, transferred 45% of the new organization's ownership to the fishing cooperatives (Frazier 1981; Trinidad & Wilson 2000). In another effort to stem declining harvests and protect dwindling stocks, the INP trimmed 1980 quotas to 80% of 1979 levels (Frazier 1981).

By the end of the 1970s, two of the other olive ridley arribadas in Mexico had collapsed. While the biology determining arribada beaches is not understood, this decline was attributed to heavy regional harvesting (Penaflores et al. 2001; Marquez et al. 2007). Along with declining catch, a decline in populations of nesting turtles at La Escobilla was another sign that harvest rates were unsustainable. The population is believed to have reached record low levels in the 1980s, as evidenced by infrequent arribadas and reduced numbers of nests (Penaflores et al. 2001, Figure 2.2).

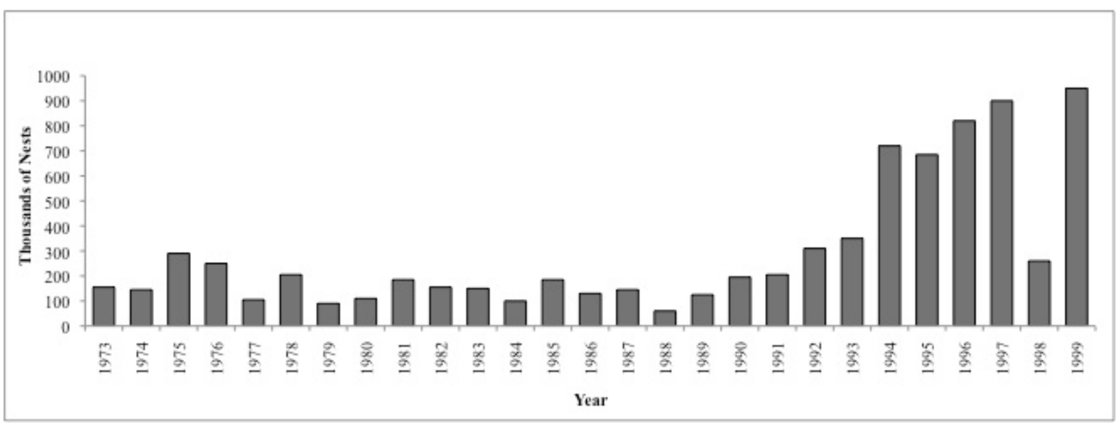

Figure 2.2*. Changes in estimated numbers of nests at La Escobilla, Oaxaca between 1973 and 1999. Years are represented on the x-axis and thousands of nests on the y-axis. It is generally accepted that the nesting population was in drastic decline by the late 1980s. Graph by Marybeth Head. Data from Instituto Nacional de la Pesca (INP) Penaflores et al. 2001.*

Conservation efforts and the Escobilla community during industrial harvest

In the 1960s, before declines in the population were noted, Mexico's sea turtle program was proclaimed by some as a conservation model (Cliffton et al. 1982). Harvest – use the resource to protect it – was the prevailing wisdom in Mexico: "a philosophy of 'rational exploitation' has emerged in Mexico, and relies on modern processing to make maximum use of natural resources" (Cliffton et al. 1982). In part, promotion of industrial harvest may have been the government's attempt to provide employment to marginalized communities. Additionally, the size of Oaxaca's coast made anti-poaching enforcement difficult (Trinidad & Wilson 2000); industrial harvest may have been implemented as a roundabout way to obtain enforcement of regulations given limited resources. One government employee I interviewed vouched for this explanation and stated that the government at that time did believe that industrial harvest was more controlled, presumably compared to the free-for-all harvest that existed previously. A representative of the INP claimed that, during the industrial period, controlled legal harvest was a necessary conservation measure. The hope was that legal cooperatives would "act as unofficial enforcement agents, ensuring that no one else would dare get in the act" (Pritchard 1978). However, not everyone agreed with this approach at the time; sea turtle researcher Peter Pritchard pointed out the danger of allowing the commercial pressure to determine harvest quotas (Pritchard 1978).

At the same time that harvest levels were increasing, scientific interest was rising. In 1967, the first research efforts at La Escobilla were led by the INP and included participation by fishing cooperatives in establishing hatcheries; careful evaluation of nesting began in 1973 (Marquez et al. 2001, Cornelius et al. 2007). Suarez (PIOSA's owner) paid for beach patrols to prevent egg poaching as well as an oviductal salvage program that placed eggs taken from butchered females into a hatchery for release (Carr 1979; Cahill 1987). Some visitors expressed doubts in the soundness of the research facilities (Cahill 1987). Scientists at the time highlighted the paradox of hatcheries: they may lull authorities into a false sense of accomplishment in protecting the population, resulting in higher harvest quotas (Pritchard 1978). The image of thousands of baby turtles being released obscures the relatively low benefits accrued to the population, due to high mortality rates and a time delay of 8-12 years to reproductive age (Heppell et al. 1996). As a result, the PIOSA-funded conservation efforts may have led to a sense of complacency about the negative impact of adult harvest.

Yet, despite potential shortcomings, "there is little doubt that Suarez's protection of the Oaxaca nesting beaches postponed the total collapse of this population" (Cliffton et al.1982). One interviewee who knew Suarez defended him, saying he was not ill-intentioned but simply a capitalist. Suarez invested in conservation measures he believed would prolong his company's ability to harvest turtles. Suarez professed his commitment to the conservation work and made clear his opinion of different conservation options, saying: "the surest way to drive a species to extinction is to give it total protection" (Cliffton et al.1982).

Despite Suarez's belief that the presence of the legal industry curbed poaching, illegal harvest remained prevalent throughout the period. Community members reported groups of leather poachers filling corrals with turtles on La Escobilla beach (inteviews). Similar corrals were used to store thousands of eggs before transport to the cities, originally done by burro and then by truck after the highway was built. While existence of the cooperatives guaranteed legitimate employment for members, the economics speak for themselves: a fisherman could legally earn only about 14% of what he could make illegally (Trinidad & Wilson 2000). An interviewee confirmed that quotas were also exceeded in the legal slaughterhouse.

For those who believed that industrial harvest was the route to conservation, illegal poaching of turtles and eggs was painted as the opposition. Poaching was believed to cultivate local corruption, despite the "spirit of cooperation" that existed among "the Mexican government, commercial interests, local people, and the international sea turtle community" in the late 1970s (Cliffton et al. 1982). PIOSA took pains to separate itself from illegal activities by refocusing attention on poaching; Suarez reported that despite well-organized protection, poachers took about 1 million eggs from La Escobilla in 1979 (Cliffton et al. 1982).

The industrial fishery had clearly transformed Oaxaca's use of turtles. The Escobilla community, right in the center of this flurry of activity, might logically have played a central role during the industrial harvest period. However, interviews suggested a different outcome. Fishing cooperatives from neighboring areas benefited from the presence of PIOSA, as did those working in the slaughterhouse itself. However, few slaughterhouse employees were from Escobilla; they had come from other areas and subsequently left after the industry's close (interviews; Marquez et al. 2007). While some interviewees said that Escobilla residents made money by assisting adult harvest on the beach, most residents at that time do not appear to have benefited from the industrial harvest. Instead, they continued to focus on egg poaching, as they had previously. As one community member put it, eggs were breakfast, dinner, and their occupation. With little control, a resident stated that Escobilla egg poachers were "living with the turtle, but in a malignant way." The most important and lasting impact of industrial harvest on Escobilla residents was likely that fewer turtles nesting meant fewer eggs: "turtles ran out because of fishing for the slaughterhouse and everyone paid for it." One government interviewee explained that conservation efforts touted by PIOSA conflicted with the Escobilla community's egg harvesting; those involved in the industrial harvest were obligated to protect the eggs that Escobilla residents relied on for income.

Who is to blame for what clearly became an unsustainable harvest? On the one hand, this is a story of locals who overharvested the resources in their backyards. On the other, it is a story of industrial-scale overexploitation by private interests, backed by the government. It can also be read as another example of the need for strict international oversight to protect global natural wealth. At best, the government appears to have thought a sustainable harvest would be possible, resulting in much-needed economic support for local communities, and thus encouraged local harvest skills and infrastructure. The difficulties of enforcement and abundant illegal activities in addition to legal harvest were likely too much for the population. Though the full story may never be known, it is evident that overexploitation of olive ridleys came from a number of pressures, both at La Escobilla and in Oaxaca more broadly.

3. Before and after the ban on sea turtle use *(1990)*

The period leading up to and directly after Mexico's 1990 ban on sea turtle use was a pivotal one that permanently changed the human-turtle relationship. Increasing global and local awareness of the decline in nesting turtles marked an emphatic beginning to a non-consumptive conservation-centered relationship. Enforcement of the ban forced changes in both adult and egg use by those inside and outside the industrial fishery.

By the end of the 1980s, adult turtles and their eggs were being harvested legally and illegally for commercial as well as subsistence use.. In 1988 only 55,730 nests were estimated over 4 arribadas at La Escobilla (Marquez et al. 1996). While interannual fluctuations are common, the nesting data indicated an overall decline (Albavera et al. 2009). Awareness of the turtles' importance as an international public resource appears to have been growing. International and domestic turtle advocates raised the alarm about the waning turtle population and led the efforts to end olive ridley harvest (Aridjis 1990).

One of the first windows for the outside world was an emotional 1978 exposé on "The Shame of Escobilla", by U.S. writer Tim Cahill, published in *Outside* magazine. Cahill described a horrific scene, using phrases such as "final evil" to describe piles of rotting eggs. Cahill argued that “despite the good intentions of the Mexican government,” the industrial harvest was motivated by sheer greed (Cahill 1987). Today, Cahill understates the influence of his article, citing the importance of TV in drawing attention to the area (Cahill pers. comm.). Visual displays did raise awareness; a “powerful and emotional documentary” on the plight of the olive ridley aired in the U.S. in 1976 and a Mexican TV special in Sept. 1980 inspired additional articles critical of harvest (Cahill 1982; Frazier 1981).

Leaders in the movement to end turtle harvest in Mexico were the NGOs Earth Island Institute, based in the U.S., and Pronatura, based in Mexico; the international marine turtle research community; and Mexican environmentalist and author Homero Aridjis. In early 1990, Aridjis’ “Group of 100” Latin American intellectuals launched a protest letter campaign with tens of thousands of individual letters addressed to the Mexican president (Aridjis 1990). A public statement from the marine turtle research community was signed by 189 turtle conservationists (*MTN* 1990). With international and domestic outcry so evident, President Salinas de Gortari banned sea turtle use throughout Mexico on May 28, 1990 (Aridjis 1990). Legal quotas and slaughterhouses were to close immediately.

The ban was a monumental step by the Mexican government along a new path to turtle conservation. Policies in the years that followed echoed this change as Mexico acceded to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), supported the Inter-American Convention for the Protection and Conservation of Sea Turtles, and required Turtle Excluder Devices for shrimp trawlers (Trinidad & Wilson 2000). Several nesting beaches were eventually federally protected, and La Escobilla became a full-fledged Sanctuary under a system of Natural Protected Areas in 2002 (Penaflores 2007).

Based on the reduction of poaching and disbandment of the processing plants, the ban appears to have been fairly effectively implemented and enforced. Yet a crucial part of the President's statement accompanying the ban was neglected: along with increased protection and support for turtle research camps, his decree also implied government-supported development of alternative sources of income for locals (Aridjis 1990). Interview responses indicate that this largely did not happen, and communities were mostly left to fend for themselves. Clandestine fishing continued for a short while, and local communities, such as San Agustinillo where the main slaughterhouse was located, struggled to find alternative income sources (Angelo 1990). Despite the President's stated intentions to help the communities following the ban , many interviewees felt that there was a serious lack of government support in the years directly after the ban. Some also pointed a finger at the government for allowing the overexploitation at La Escobilla without considering impacts on the town of Escobilla.

Some economic development effort was made for Escobilla residents through the establishment of the Mexican Sea Turtle Center (CMT) at Mazunte, a neighboring beach. The CMT (now run by the government's National Commission for Natural Protected Areas), opened in 1991 as a conservation-oriented aquarium, located on the battlegrounds of the harvest era in an area formerly used for salvaged egg incubation (Trinidad & Wilson 2000). One government representative explained that the CMT represented a way for the government and the community to work together towards turtle conservation (interviews). In part, the "museum" was to offset the local negative economic impacts associated with the ban by fomenting regional tourism. Community members currently engaged in tourism also described CMT researchers' efforts to help them explore options to legally farm or fish. The CMT's creation represented a shift away from turtles as consumptive resources and toward a movement to inspire Escobilla residents to see the conservation value of turtles.

Escobilla residents may not have benefited economically from the industrial harvest, but interviewees insist that the ban affected the community. After the ban, one community member said, Escobilla was "disheartened and desperate." With no clear plan for the future and no work, many families left for the U.S. Yet others describe a more positive change: a gradual realization that turtles had been overly depleted. When pressed for examples of the effects of the ban, residents today point to increased vigilance by Marines from Mexico's military rather than the ban on harvest itself. La Escobilla had vigilance fairly early on, with Marines visiting from 1967 (Penaflores et al. 2001). The full impact of the marines was not felt, however, until they established permanent residence and regular patrols. This act of armed surveillance transformed how people approached the beach. As one researcher describes the scene, "it doesn't matter where Marines are- they can be watching TV in hammocks- as long as they're there, there's less poaching." Indeed, when the Marines left, the poaching returned: in 1996, serious poaching occurred when Marines were called away from La Escobilla to deal with the Popular Revolutionary Army (Moore 1996). A similar spike in poaching came when Marines left after hurricane Paulina in 1997 (Albavera, 2005). In 2005, carcasses and 80 shells were found at La Escobilla (AP 2005). However, despite sporadic poaching spikes, most interviewees described an eventual lifestyle and resource use change, where fewer community members poached eggs, turning instead to other income sources, such as legal fishing, restaurants, and tourism.

4. Where are we now?

Escobilla today

The shifting dynamics of turtle use I've described all occurred within the lifetimes of many current Escobilla residents. After a turbulent history, what is the current picture at Escobilla? Escobilla is a town of around 478 residents in 93 families with a mean of 5 members per household (Trinidad & Wilson 2000). It is considered highly marginalized with a medium-low Index of Human Development (Arellano Macedo 2007). Sixty percent of residents aged 15 years and over have not finished primary school. Residents' livelihoods reflect a split among those who live closest to the beach and rely more heavily on it, and those who live "in the hills". Agriculture is the principal economic activity (Bravo Fuerte 1994). There are few options for employment (Trinidad & Wilson 2000), but some residents rely on fishing for income, participate in government temporal work projects, work in tourism with a local cooperative, or at small stores and businesses (Gomez Padron 2009).

Escobilla today is in many ways similar to its former self and still faces a number of challenges. As one community member complained, Escobilla is basically the same as it was 30 years ago with the same, insufficient school, poor health clinic, and not a single recreation park. One community member summed up the current problems: "my town is rich (wonderful), except we don't know how to work and sometimes end up destroying everything (natural resources)."

In spite of long-enduring problems, perceptions do appear to be changing, in particular: local acceptance of a conservation oriented framework for turtle use, evidenced in word by frequent reference to conservation and in action by less egg poaching by community residents. The new mantra here, as at many other turtle conservation areas, is that turtles are worth more alive than dead. Yet not all community members agree: factions exist among residents with their own viewpoints on conservation.

Of the local residents who rely heavily on the beach, there is a distinct faction associated with the "Cooperative". The Escobilla Cooperative (Coop) is a local for-profit organization led by around 16 "associates" and with a few other employees (interviews). Founded in 2000 by local residents, the Coop is both a way to communicate with other Escobilla residents about conservation and an opportunistic business venture, albeit one that reportedly has yet to reach its profit goals. The Coop effectively controls the tourism market with a restaurant, cabins, and permission to lead groups to watch nesting. It may be telling that the associates referred to the "community" as if they were a distinct group, implying that the associates view their actions as separate from other residents'. A Coop member professed the belief that other community members see their organization as prohibitive.

While ecotourism may very well be the future for Escobilla and efforts towards that goal are being pursued, it currently remains under-utilized. I believe a carefully thought out plan, that limits physical infrastructure development and defines clear regulations to protect the turtles needs to be in place before allowing an influx of tourists and solidifying for the community the perception of turtles as a lucrative non-consumptive attraction. Because the Coop is an organized entity, its voice is apparent to government researchers, whereas it can be harder to assess viewpoints from non-Coop members of the community. Government researchers recognize this and lament a lack of closeness with the community.

Discussions of the current role of the government in the local economy paint very different interpretations. Some Coop members said that as “the right hand” of the CMT, the government has a commitment to continue financial assistance to the Coop. Instead of this assistance, they see the government supporting a community that includes poachers. Government employees expressed the opposite: “they (Coop) need to find their resources and walk on their own”; “they have a paternalistic vision and not one of working together.” Aside from tourism, there is little in the way of economic influx to the area. Local community members and some researchers said that beyond current programs of temporary work, which includes nest monitoring projects, there is not much government support to the region. To most, “government support” is synonymous with job opportunities. A recent survey found that almost all respondents are dedicated to multiple activities for income (Gomez Padron 2009).

Prevalence of egg poaching

Egg poaching may represent one such activity, as egg poaching, though less severe than before, remains common despite the apparent shift towards a more conservation-based relationship with the turtles. Because it is a long-standing cultural norm, a “personal craving” as one resident described it, the persistence of egg consumption is not surprising. A recent survey found that 26 out of 31 respondents said they consume eggs, with a wide range of frequency (Gomez Padron 2009). While some do dig up eggs for home consumption, the majority of poaching is believed to be for commercial sales in the cities. "Before, most people were dedicated to taking eggs, but now they say there are few [local poachers] and [mostly] people from other towns who poach. This is partly true and partly wishful thinking," explained one researcher. Regardless, all respondents across categories believed the number of people dedicated professionally to poaching as very low, especially compared to historical activity.

Interviewees speculated about the motivations behind poaching and most agreed that lack of jobs was the primary reason for continued egg harvest. Some interviewees listed "legitimate" economic reasons, such as the expense of sending kids to school. While some appreciate the government employment opportunities, most point out the important distinction between the temporary offerings and permanent work. One frustrated community member pointed out that it's unfair to keep the community off the beach without giving them anything in return to survive. Yet this view was not universal; others expressed a common stigma: poaching is an easier way to make money than legitimate work. A government employee pointed out that complaints about lack of employment provide a nicer message than the simple fact that poaching is convenient and low effort for decent money. In addition, the definition of need has shifted: poachers have "created other needs" (for luxuries), and egg sale provides that income. Indeed, previous surveys of residents elicited similar statements that poachers like to take risks (Bravo Fuerte et al. 1994).

On the whole, most people felt the current level of egg poaching was a minimal threat, including government biologists who particularly expressed their lack of concern for home egg consumption. From the outside it is easy to assume that complete eradication of poaching activities is the ultimate goal; however, interviews revealed that the likely reality is that some level of egg poaching and consumption is both inevitable and may be acceptable.

Perceptions of science

The La Escobilla nesting population is a resource for science, but do locals see it that way? It appears that residents' perceptions have shifted in terms of understanding the role and importance of science. Researchers have become increasingly aware of the importance of the human dimensions of conservation, along with a shift in ecology fields towards including humans as part of ecosystems (Drew & Henne 2006; Berkes 2004). Mention of community involvement has become commonplace in conservation policy statements and project proposals (Campbell & Vainio 2003). In addition, the concept of Traditional Ecological Knowledge (TEK), here taken to mean "knowledge and insights acquired through extensive observation of an area of species" (Huntington 2000), is part of a growing awareness of the value of local knowledge of those who have historically lived with a resource. Consideration of this knowledge can result in more complete information than that obtained solely from scientific studies (Berkes 2000). While my project at Escobilla is not a study of TEK, there is much value to learning what is important to those living closest to the turtles, as they have had more time to observe the beach ecosystem than a visiting scientist.

There is local knowledge about the turtles that community members have accumulated from firsthand experience or from years of living in a town that has been reliant on the turtles. Researchers who have spent less time on site could greatly benefit from residents' familiarity with nesting patterns, the beach environment, and the history of turtle use. For this study, I explored insights on study-specific topics and more broadly the role of research in turtle conservation at La Escobilla. In particular, what would locals tell me about primary threats to the nesting population, the impacts of high density or nest destruction, and the scientific basis for egg harvest? What is the role of the community in research efforts? I also was interested in local researchers' perceptions as they interact with community members and lead the conservation efforts at La Escobilla.

During the height of egg removal, harvesters had to know about turtle nesting behavior and how to precisely and expeditiously pinpoint nests. One researcher reported that community members have varying levels of knowledge about turtle behavior, which is supported by the variety of responses received in the interviews. This is likely related to the amount of time interviewees spent on the beach. Some community members listed what they had learned from firsthand "viewing" or from researcher education, e.g., temperature tolerances for hatching and estimates of nest success. One community member urged me not to be concerned about the lack of hatchlings in my study area, as every few years a "change in hatchlings" happens. This implies that there are fluctuations in hatchling productivity interannually. At the least, those who have worked on research projects or with the Coop seem more familiar with the vocabulary and current scientific understanding**.**

Most community member interviewees however, were not outspoken or specific about their knowledge of turtles. Interestingly, this is a very different response than was reported by anthropologists in the early 1990s. Their Escobilla sources were very vocal about having more experiential knowledge than biologists: “no one can tell us about the turtles because we already know it all” (Bravo Fuerte et al. 1994). This discrepancy may be due to those interviewed (i.e., the previous study interviewed poachers) or interviewees’ awareness of my status as a researcher. Yet, the responses may also have differed because of a perception change. One government researcher explained that at first, Escobilla residents equated biologists with the negative impacts of the ban, “coming to deny” residents their resources. This mindset is still somewhat present today, as one community member complained that researchers keep all the biological information from community members. Harmony amongst the government and local residents also determines how effectively research can occur. Illustrative of what can happen when community members are not supportive of research efforts, several of my plot posts were vandalized early on in the research process; based on observations, this was likely done by poachers. However, based on my interviews, community members have come to learn more about the role of biologists and now see conservation favorably. Some community members echoed the importance of research to learn about the species and preserve the population. One community member expressed that Escobilla will be recognized at international levels thanks to studies.

Residents' clear recognition of La Escobilla's importance to science marks a new way of relating to the turtles; they are now an avenue for international recognition through conservation and research activities.

Biologists who work with sea turtles list incidental capture in fishing gear as the greatest threat to sea turtle populations worldwide, followed by intentional harvest and habitat loss (Lewison & Crowder 2007). Community members who live and work on sea turtle nesting beaches may have a different perception of threats to turtles, due to their proximity to the animals. Interview responses listed anthropogenic threats as the most grave, in particular development and all the infrastructure that accompanies it ("everything that generates trash and light"); purposeful taking of adult turtles and accidental trappings in nets; and trash or pollution. Other environmental stressors rounded out the list: predation by other animals and, to a lesser extent, climatic variables. Considering the warm season, temperature was not as cited as expected, owing perhaps to the propensity for distinguishing between "natural" and "unnatural" threats. A surprising number of respondents, including researchers, expressed less concern for what they termed "natural" stressors. For example, one researcher, who categorized beetles as a natural threat, was not concerned about predation because despite the prevalence of beetles throughout the most used area of the beach, "there is enough hatching to maintain the population of turtles for a long time." For the most part, however, beetle predation was a major concern for all the researchers interviewed and a couple Coop members. On a somber note, a researcher emphasized that, "the beetles are here to stay, no doubt." Researchers and community members both regretted the lack of understanding of the beetles' role in the system, emphasizing this threat as one for future investigation.

When questioned about the potential impacts of population density and nest destruction, many respondents cited the frequency of arribadas as a problem, as nests don't have time to hatch before a new wave of turtles dig them up. They indicated that arribadas have increased in frequency and size after the ban. "At the beginning of the CMT in 1994, there were 5-6 arribadas a year and they lasted 3 nights. Now they last around 15 nights and there are 8 plus per year," reported one researcher. Nesting activity has definitely increased with around 700,000 nests in 1994 and over 1 million in 2000 (Cornelius et al. 2007). Interestingly, it was a community member who spelled out the connection between arribada frequency and beetles, noting that destruction "contaminates" nests and leads to the current "plague". Similar to the way many spoke about environmental variables, a number of interviewees were not very concerned about con-specific nest destruction, calling it a natural occurrence. One researcher proposed that it may be a method of self-limitation of the population, which may support the theory that arribada beaches are ephemeral. Government researchers have spearheaded studies of La Escobilla beach since 1994 (Penaflores 2007); however, longitudinal data to investigate the "life cycle" of arribada beaches is needed (e.g., changes in sand quality).

Arribada egg harvest has been touted as a potential example of "sustainable" extraction that economically benefits the local community and has a scientific basis, owing to robustness of turtle populations to some egg loss and high levels of destruction during arribada nesting (Crouse et. al. 1987; Heppell 1998). Options for future harvest require careful study, as we need to connect management with good science. However, egg harvest was not really mentioned in interviews beyond one assessment: "it's a beautiful idea." The complex nesting dynamics indicated in my field study support that sentiment; a lack of understanding of the mechanisms that determine nest success at arribada beaches prevents definitive discussion of sustainable harvest possibilities. Yet, the truth remains that legal egg harvest is in practice. At the arribada beach in Ostional, Costa Rica, harvest has been occurring since 1987, with no indications of negative effects on the population (Campbell 1998; Ballestero et al. 2000). That said, there are many concerns, indicating that more in depth study is required (Valverde 1999). Determining the effects of harvest and various harvest schedules is an area of importance for future research.

A few interviewees were familiar with Ostional. One community member thought harvest a sound biological argument since, "at (La) Escobilla, it's constantly arribada with no time to hatch." One researcher believed that "it would be good to take advantage...but there is no mechanism of control for the market". The researcher explained that a sustainable harvest paradigm requires a community that keeps out outsiders and is not jealous. It also requires "conscientious people convinced this is a community (level) need." These conditions do not seem to hold currently. In addition, as a researcher pointed out, the government isn't interested in giving the option of legal harvest. Whereas right after the ban, there was more discussion of sustainable harvest options at La Escobilla (e.g., Marquez et al. 1996), the lack of discussion in interviews indicate that the topic may now be largely off the table.

Community members indicated interest in turning the turtles into an educational resource. Ideas for future research priorities centered on ways they could be involved, helping to collect data while benefiting from the work. Local ideas for ways to “help people to preserve turtles” included: maintain hatcheries and release hatchlings, monitor nesting females, and investigate and capture beetles. While many are personally interested in turtle conservation and some are curious about turtle behavior, a major impetus for future involvement is simply to have alternative income sources, which still places turtles squarely in the context of economic gain.

Community members had insightful comments on nesting patterns and the role of various threats on nests, including density and destruction. On the whole, the positive reception to research I encountered is likely attributable to most people’s awareness of La Escobilla’s biological importance and equating broader international interest with research activities. However, as one community member pointed out, Escobilla may be internationally famous for the importance of the turtles, but the community itself remains the same. Most people interviewed reiterated that permanent employment is required to change the community and change lives. From my experience, the benefit of engaging residents in fieldwork is obvious; community members were more familiar with the beach environment than the student volunteers. That said, research projects as currently laid out do not lend themselves to permanent employment; other opportunities are required to make up for seasonal differences.

Conclusions

It is clear that La Escobilla olive ridleys continue to be important consumptive and non-consumptive resources. A review of how resource patterns have shifted in the last hundred years provides a more complete understanding of their value. La Escobilla provides an intriguing example of how quickly wildlife resource use can change and the various factors that drive conservation decision-making. Management cannot simply respond to changing resource availability; at La Escobilla, there was the rise of an industrial infrastructure out of demand for leather, a ready workforce, and an aggregated resource. Unsustainable legal and illegal adult harvest pressures resulted in closure of the fishery and strict enforcement that changed the egg harvest practices of Escobilla residents. Now, however, the ubiquity of conservation messages and research activities has local residents' attention focused on the future potential for non-consumptive use as a route to economic stability.

Anecdotal understandings of wildlife and perceptions based on direct observations often determine what is pursued in research and management. Much of what interviewees reported was consistent with my hypotheses about the turtles, though particular details were often incorrect. The interviews highlighted areas of potential future research as well as validated my choice of research questions (Chapter 3) as being of importance to those interviewed.

Despite the complicated history of harvest, Escobilla residents seem to have had a stable focus on egg harvest. With all the reasons to poach, what is there to discourage egg harvest? Along with greater awareness of the need to conserve resources, there has also been brute enforcement by armed Marines with serious penalties. La Escobilla provides yet another example of protected-area managers grappling with the best way to conserve resources. While enforcement by Marines seems to have been mostly successful, ill will remains. Self-policing seems an effective addition, but it requires a level of motivation and commitment to a conservation ethic that may not yet exist among community members. Despite this, self-policing may be the most effective direction for moving forward, as some residents both know the few dedicated poachers and engage in egg consumption themselves.

The realities of continued egg poaching and enforcement are obvious challenges to conservation efforts, especially in light of limited resources. Another potential barrier is the continued suspicion and skepticism among the various stakeholder groups. This is an unfortunate reality when dealing with groups who have a shared turbulent history seeded with examples of corruption. A potential solution to diffuse disagreement among stakeholders is to distribute benefits from conservation efforts to the entire community, such as to local schools. Not everyone is necessarily going to be able to be employed by conservation revenue. Rewards from ecotourism, government training, or research grants must be implemented to the whole community to not exacerbate factions among community members.

The human dimensions of turtle use are more than just a backdrop at La Escobilla; they have shaped management up to the present in critical ways and will continue to do so in the foreseeable future. The relationship between Oaxaca’s olive ridleys and those humans who live closest to their nesting beaches has transformed over time with respect to subsistence, commercial, industrial, and non-consumptive practices. The foundation is already laid to equate turtle protection with research, jobs, international renown, and community prosperity; solidifying this combination would improve conservation of this nesting population.

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CHAPTER 3: FACTORS AFFECTING ARRIBADA NESTING DYNAMICS OF OLIVE RIDLEY SEA TURTLES (*LEPIDOCHELYS OLIVACEA*) AT LA ESCOBILLA, MEXICO: CONSIDERING DENSITY-DEPENDENCE

Introduction

Although intraspecific density undoubtedly affects vital rates and subsequent population dynamics in most, if not all, taxa (Brook & Bradshaw 2006), assessing the role of density-dependent factors in determining population status or cycles can be difficult (e.g., Gaillard et al. 1998). Density-dependence may operate through various pathways, one of which is the effect of aggregating behaviors of adults during reproduction on subsequent offspring production. Aggregation behavior has costs and yet also confers benefits to individuals (Allee 1931); it may enhance reproductive success through increased mating opportunities and predator satiation (Wilson 1975), but may be detrimental if offspring production is compromised at high densities through interference competition among adults or the offspring themselves (e.g., Bustard & Tognetti 1969). Understanding the mechanisms of density-dependence in wildlife populations is important for conservation and harvest management (Grant & Benton 2000), as density-dependent changes in offspring survival or reproductive success will affect adult population size and stability.

Interference of offspring production as a result of high adult density has been found for a number of taxa, including butterflies, large herbivores, and river turtles (Nowicki 2009; Bonenfant et al. 2009; Fordham 2008). The direct effects of high adult densities on offspring are acutely demonstrated in aggregations of nest building taxa, such as salmonids and sea turtles. When salmonids aggregate to lay eggs, nest superimposition (overlap) and subsequent egg damage is common; 39-60% of nests were superimposed in a population of brook trout (Curry & Noakes 1995). Salmonid nest superimposition may be driven by density through location of females' nests and habitat selection and scarcity (Blanchard & Ridgeway 2005); however, the causes and consequences of nest superimposition in sea turtles are far less studied.

Sea turtles are a challenging taxon for studies of density dependence in part because of their long life spans. Most population monitoring is based on adult females, resulting in a substantial time-lag before density effects on hatchling production and subsequent adult year classes are detectable and underscoring the need to preemptively recognize mechanisms that drive population changes (Heppell et al. 2003). Unfortunately, precise quantitative estimates of population level productivity parameters, such as offspring survival, are difficult to obtain. Inferences can be made, however, with behavioral observations that provide the first step in evaluating potentially density-dependent effects.

The most apparent negative impact of high density nesting occurs when later-arriving females dig up eggs from previously laid nests in the process of creating new nests (Figure 3.1). A number of studies have investigated effects of high density and/or destruction at "solitary" (i.e., non-aggregation) nesting beaches of sea turtles (Bustard & Tognetti 1969; Chaloupka 2002; Girondot 2002; Tiwari et al. 2006; Caut et al. 2006). Three main effects were noted: destruction was found to increase with increasing female density, nest superimposition resulted in partial destruction of both nests, and the amount of nest overlap affected hatching (Girondot et al. 2002; Caut et al. 2006). Findings from these studies of solitary nesting may have parallels to mass-nesting sea turtle dynamics, but may also be fundamentally different due to density levels or beach characteristics.

Figure 3.1. *Nest destruction: in the process of excavating her nest, a female olive ridley turtle (Lepidochelys olivacea) digs up eggs from a previously laid nest that appear to be far along in their incubation. Photo by M. Ocana.*

Olive ridley sea turtles (*Lepidochelys olivacea*) are known for their remarkable synchronized mass-nesting behavior (arribadas), which are restricted to only a handful of beaches worldwide (Figure 3.2). These events are distinct from the common "solitary" nesting behavior, where females emerge to nest individually. Arribada beaches provide an excellent case study for monitoring behavior related to density-dependence in wildlife populations given the prevalence of observable density-dependent mortality factors on nests. During an arribada event, hundreds to thousands of female turtles nest over a few consecutive days. Several arribadas occur in an approximately 7-month season, during which an individual female nests an average of 1.6-2.3 times (Penaflores et al. 2001). In large olive ridley populations, arribadas are believed to lead to high nest densities, e.g., up to 16 nests/m^2 modeled in Nicaragua (Honarvar et al. 2008). However, nest density is a dynamic value as the number of nests present in an area changes with each new nest laid.

Figure 3.2. *Map of arribada nesting beaches in Western Hemisphere, denoted by solid circles. Ring around La Escobilla beach, Oaxaca, Mexico. Dark lines represent solitary ridley nesting beaches. Other arribada beaches are present in India. From Bernardo & Plotkin 2007.*

Arribadas represent a behavior exclusive to the *Lepidochelys* genus. Scientists believe this behavior evolved as a predator satiation strategy: as millions of hatchlings emerge *en masse,* predators can not consume all the hatchlings (Bernardo & Plotkin 2007). Although mass-nesting provides some advantages to fitness compared to solitary nesting, density-dependent mortality is considered one major disadvantage (Bernardo & Plotkin 2007). High density is widely hypothesized to have a negative effect on nest success, but this hypothesis has not been empirically well-verified. Nest density can affect nest success through interrelated extrinsic factors, such as microclimate variations; likelihood of predation; and likelihood of con-specific nest destruction (Figure 3.3). In addressing the evolution of arribadas, Bernard and Plotkin (2007) hypothesized a functional relationship between the probability of nest success (here termed mortality) and nest density in which a more or less exponential increase in nest destruction occurs with increasing nest density (Figure 3.4). Further, they theorized that predation trumps the role of nest destruction in driving nest mortality until high nest densities are reached, at which point destruction becomes a dominant factor.

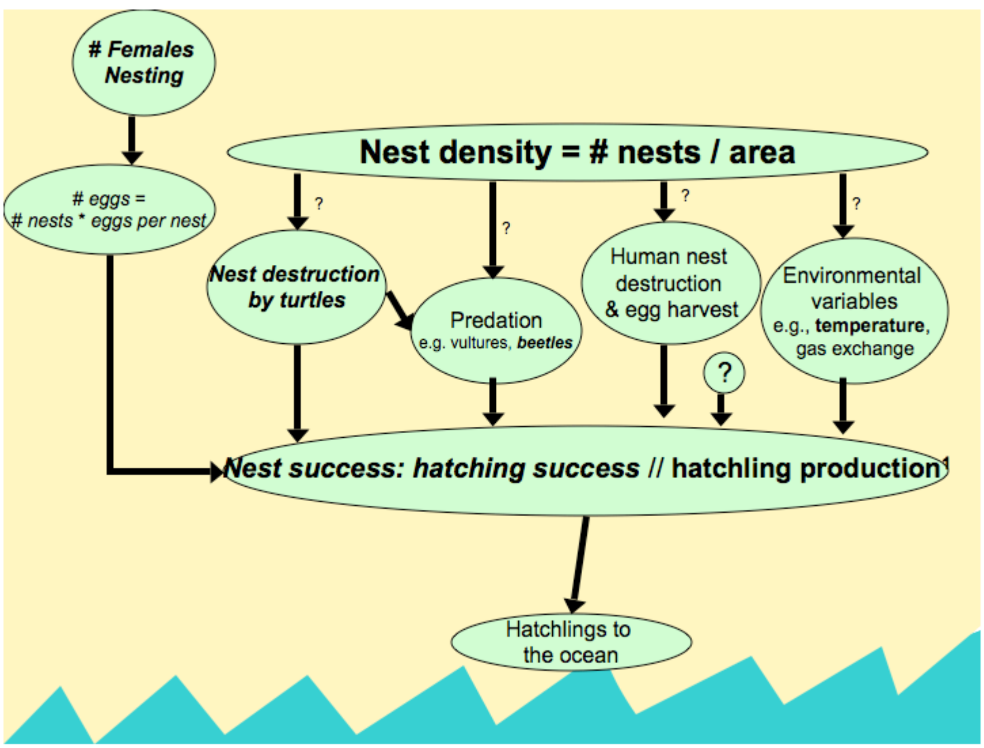


Figure 3.3. *Simplified diagram of factors affecting nests at arribada nesting beaches. At La Escobilla, current attention is focused on estimating variables in italics during arribadas. Bold indicates my study foci. Note that nest density may act on hatchling*

production via a number of potential routes, which in turn may affect each other. For example, nest destruction could increase microbial activity, which could affect oxygen levels; environmental variables, such as wave action, could affect whether beetles were present or washed away. 1. Nest success is used generally in this thesis to refer to whether a nest makes it through incubation with viable undamaged eggs. Hatching success refers to the percent of eggs that hatch in a nest, while hatchling production is the number of hatchlings that successfully emerge over a given area.

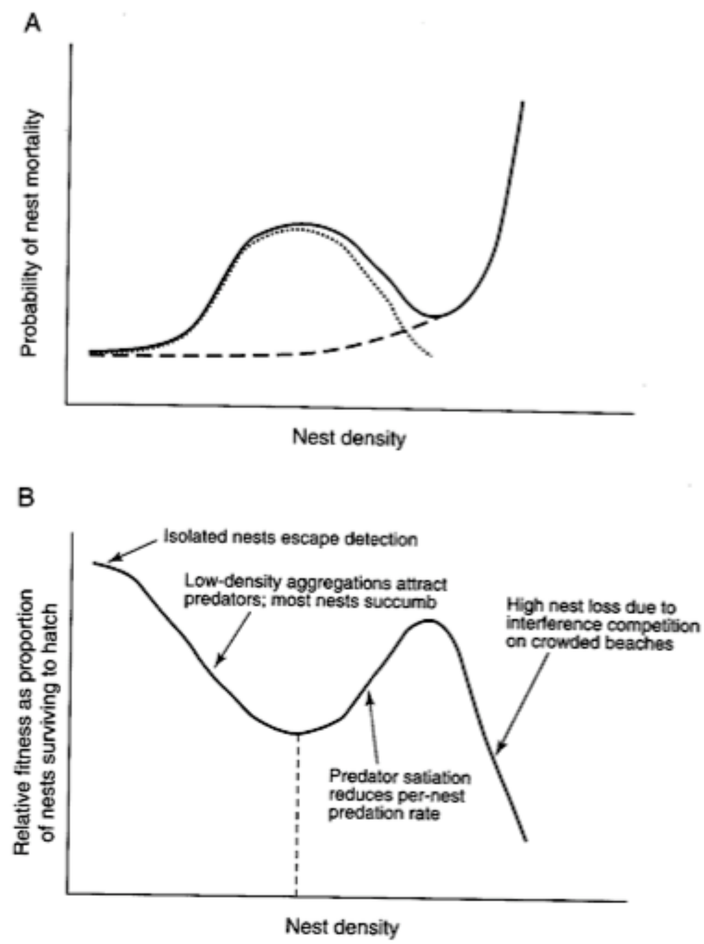


***Figure 3.4a and 3.4b**. a) Hypothetical functional relationship between nest mortality and nest density. The dashed line represents mortality from nest destruction and the dotted line represents mortality from predation. Note that destruction rates are hypothesized to be relatively low through moderately high densities and increase sharply at high densities. The solid line represents the aggregated curve. b) Hypothetical relationship between nest density and fitness. Note that nest destruction (interference competition) is hypothesized to be important only at very high densities. From Bernardo & Plotkin 2007.*

As home to one of the largest nesting populations of olive ridleys in the world, La Escobilla, Mexico, is a critical location at which to investigate nesting dynamics. Olive ridleys are listed as vulnerable or threatened (IUCN 2007; NMFS &USFWS 2007). The La Escobilla population declined during industrial harvest in the 1960s-80s, leading to a ban on sea turtle use and harvest in Mexico (Marquez & Carrasco 1996; Chapter 2). The population has since rebounded to over one million nests in 2000 (IUCN 2007; Marquez et al. 1996). This recovery is allowing researchers to study arribada nesting behavior and its effects on population productivity.

Regional arribada studies have raised interesting questions regarding density-dependent mechanisms, including destruction, predation and microclimate. For example, a mounting concern at La Escobilla is predation by the beetle *Omorgus suberosus*. Beetles are found elsewhere in low densities but their population is thriving on the large quantity of viable incubating eggs and broken eggs from nest destruction (Halffter et al. 2009). The underlying factors determining beetle predation are not well understood but may involve both microclimate and nest density (Halffter et al. 2009). Microclimate is also believed to have a large impact on nest success and has been directly linked to nest density (Honarvar et al 2008). A Costa Rican study using manipulated densities found significantly lower hatching success in high density plots (9 nests/m^2) than in low density ones (2 nests/m^2), likely due to interactions with temperature, CO_2, and O_2 (Honarvar et al. 2008). Clustering of nests may also result in higher nest temperatures, which is important given that sea turtles exhibit temperature-dependent sex determination. Additionally, a recent arribada study proposed a maximum (lethal) temperature of 35°C for olive ridleys (Tordoir *in press*); higher nest-density areas may thus be more susceptible to negative microclimatic effects of temperature on egg survival.

At La Escobilla, census of nesting females is the top research priority, though estimates of hatching success, nest destruction, and hatchling production have been made. Nest destruction is a concern in part because of the frequency of arribadas; between 2001-2005, only eight (23.5%) arribadas had incubation periods uninterrupted by a subsequent arribada (Albavera 2005). One classic study in Costa Rica found that a higher percent of marked nests were destroyed in larger arribadas; percent nest destruction by females increased each successive night of an arribada and with each subsequent arribada in the season (Cornelius et al., 1991).

The objectives of this project build on previous work by utilizing natural nesting situations, with their inherent complexity (e.g., impacts of multiple arribadas on incubation, variable beach use by females), to gather information on factors (i.e, nest destruction, temperature, underground predation) believed to affect hatchling production, an essential variable for assessment of population status. Tying together density and destruction at arribada beaches would help fill in the large gaps remaining in our understanding of density-dependent productivity in olive ridley sea turtles. I examined the pattern of nesting activity over time to empirically investigate the relationship between nest density and destruction at La Escobilla. Specifically, I hypothesized that nest destruction is positively related to nest density and increases over the course of an arribada and subsequent arribadas. As part of this work, I also investigated methods to evaluate offspring productivity variables.

Methods

Study area

La Escobilla is a 7km beach primarily utilized by nesting olive ridleys. It is part of a national sanctuary located on the Pacific coast of Oaxaca, Mexico, and has been monitored by the Mexican government since 1967. The most frequently used area of beach is divided laterally into 100m wide stations with markers every 50m (Figure 3.5). Despite the remoteness of the beach, there is a considerable daily flow of human visitors: biologists and volunteers with the Mexican Sea Turtle Center (CMT) conduct research, armed marines patrol the area in conjunction with government law enforcers, community members fish and have beachfront property, and egg poachers raid nests. Aside from poaching, other potential causes of nest or hatchling mortality at this site include predation (e.g., dogs, vultures, beetles, crabs), water inundation (estuaries occasionally feed into the ocean), extreme environmental conditions (e.g., high temperature, low humidity), and con-specific nest destruction.

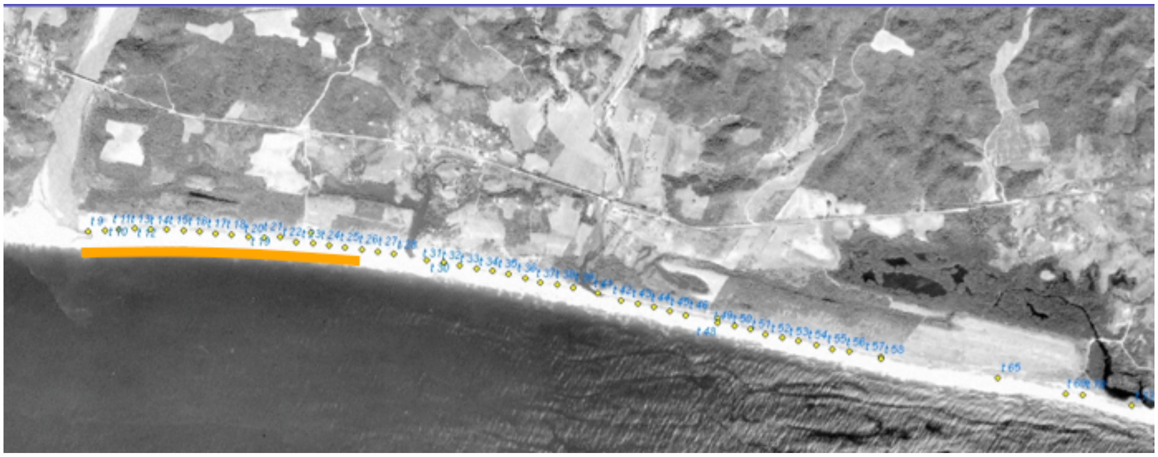


Figure 3.5. *Image of La Escobilla beach, Oaxaca with every 100m "station" noted. The study area is marked by a line. Note the estuaries that feed into the ocean. Map from El Centro Mexicano de la Tortuga.*

Field data collection

I conducted a field study between August and November 2009, when arribadas are fairly frequent and nesting density is high at La Escobilla (Albavera et al. 2009). The study commenced on the 1st night of the 1st study arribada and concluded at the end of incubation period of the 2nd arribada. Because our monitoring occurred fairly regularly between 10pm and 6am, I refer to each 24-hour period in which turtles nested as a "night," though some researchers prefer "session" (Valverde et al. 1998). Nesting activities were monitored within 9 m^2 plots (3x3m) that had selective metal fencing to control access by nesting females. My field research team constructed 40 plots in pairs along the most frequently used area of beach to increase the probability that turtles would arrive within each of the plots (ultimately 26 plots were utilized) (Figure 3.6). Plots consisted of four corner wood posts with partially buried metal fencing that could be rolled open or close to block subsequent nesting after the arribadas (Figure 3.7). I discouraged nest laying along the perimeters with netting anchored underground to inhibit females' digging.

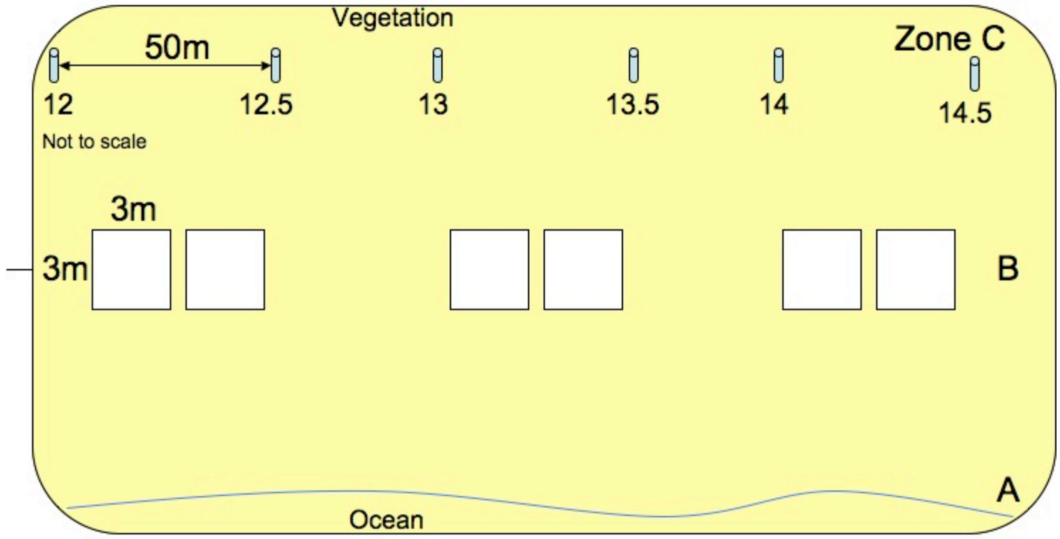


Figure 3.6. *Example of study plots set-up on the beach. The beach is divided into zones A-C from the ocean to the vegetation. Plots were located in pairs to allow for comparison and ease of monitoring. Plots ultimately utilized for the study (n = 26) were located in five groups of three pairs between stations 8-10.5, 12-14.5, 16-18.5, 20-22.5, and 24-26.5. Each plot was separated from its pair by 10m.*

Figure 3.7. *Study plots were constructed mid-beach at La Escobilla. Here, a pair of plots surrounded by fencing effectively block out subsequent olive ridley turtles after the study arribadas.*

This study was designed to encompass a “natural” range of nest densities in study plots controlled for female access. Following arribada-research conventions, the research team began recording data once 1000 females were present (anywhere) on the beach (Peralta et al. 2009). At the first visit to plots, the team noted any previously laid nests. Plot observation stopped when there was a marked drop in the number of females (observed during beach-wide surveys on ATVs), which signaled the end for that night. The team monitored turtle behavior every half hour and categorized the following behaviors: digging, laying eggs, covering nests, and evidence of nest destruction. Nest destruction was defined as observing a female unearthing eggs, or laying or covering her nest amidst freshly broken eggs. Because the entire nesting process takes about 45 minutes, the team observed every turtle present within study plots. Females were marked with chalk and diagrams of female locations were drawn to avoid double-counting the same nesting activity.

The 1st arribada lasted five nights, after which plots were fenced to hinder solitary females from nesting unobserved. Large-linked fencing allowed hatchlings from prior nesting to exit; however, there were effectively no nests in the plots at the start of the study. Plots were re-opened during the 2nd arribada, which began nine nights after the 1st arribada, and then re-blocked at its end, eight nights later.

To catch hatchlings from the study arribadas, the team secured netting barriers of impermeable plastic fencing around the perimeter of each plot towards the end of the incubation period (~ 45 days). After the shortest potential incubation period, plots were checked regularly for sand indentation or hatchlings (Eckert et al. 1999). However, no hatchlings emerged from any of the plots in this study.

Data analysis

I extrapolated nest density from the observations of females' behavior using methods similar to those in Cornelius and Robinson (1985). Females commonly abort partially dug nests due to external disruption, discovery of site unsuitability, or other unknown reasons (E. Albavera, pers. comm.). A previous exercise conducted at La Escobilla in which volunteers followed turtles to observe the nesting outcome (n = 791, over 3 separate arribadas and years) found that ~25% of females who began digging did not complete nesting (Albavera & Karam 1999; unpublished data). The study had similar levels of turtle-observer interaction and occurred during a similar time of year as my study. This probability of incomplete nesting has therefore been incorporated into my estimate of nest density.

I calculated density as the cumulative value of all the nests in the ground in a plot at the end of any given night. Thus, for the 2nd arribada studied, nest density is the total number of nests present at the end of the 1st arribada (in a given plot) plus the number of new nests added each night. This provides a more realistic picture of the quantity of nests in the ground, especially given the short time period (nine days) between the two arribadas. It also takes into account the fact that both inter- and intra-arribada destruction can occur. In addition, to facilitate comparison across studies, I report nest densities (measured per 9 m^2) in the more meaningful nests/m^2 metric.

Nest destruction was evaluated at both the turtle and plot levels, but not at the nest or egg level, due to an inability to accurately count destroyed eggs and identify which nest they came from. “Percent destruction” was calculated by dividing the number of turtles that destroyed eggs by the total number of turtles observed per plot, multiplied by 100. Nest destruction can be thought of as the proportion of females excavating eggs from a previously laid incubating nest (Girondot et al. 2002). Presence of eggs on the beach surface was interpreted to mean that at least one nest was negatively impacted, though it is possible that the eggs unearthed belonged to more than one nest. Other studies have stated the difficulty in empirically obtaining more specific egg level destruction estimates (Girondot et al. 2002). Although a study was conducted in a controlled hatchery with artificial destruction (Caut et al. 2006), estimating destruction at the egg level remains a difficult and imprecise undertaking in a natural setting. Because individual eggs from nests are destroyed rather than entire nests (generally), we did not interpret destruction as a net loss of an entire nest and therefore did not change our estimates of nest density as a function of observed (partial) destruction.

I focused on comparisons of density and destruction in the 2nd arribada, where destruction occurred on nests accumulated from both arribadas. I focused on the 2nd arribada because there is greater variability in both destruction and densities. To consider the overall relationship, I ran a correlation on percent destruction (all turtles over all nights) and total cumulative nest density[1]. To determine the effect of nest density on the probability of nest destruction, I ran a mixed-model logistic regression with plot entered as a random factor. I had observed spatially clustered nesting behavior suggesting location differences and a mixed-model approach allowed me to account for variability in the probability of destruction attributable to random effects of plot selection by turtles. This model assumes that the relationship between density and destruction is constant among plots. This analysis reflects an individual turtle-level, as opposed to plot-level approach.

Excavation methods and temperature monitoring

After the 1st arribada, ibutton temperature data loggers (Maxim Integrated Products, CA) were placed at nest depth alongside each plot. Loggers monitored

[1]I originally ran a conservative correlation on all the data points, recognizing that they are serially dependent, using a df based on the number of plots (the true minimum # of independent observations) to determine statistical significance. It was not significant and illustrated how difficult it would be to see an effect given all the noise created by intraplot variability.

ambient sand temperature every two hours. The values obtained represent estimates for the 45-day incubation period, as loggers were buried and nests were laid over a period of few days. Loggers were excavated upon completion of the study, after the 45 days incubation period of 2nd arribada nests.

The team also excavated areas in order to evaluate the outcomes of nests from the 2nd arribada (methodologies developed by CMT; Miller 1999). Nests were located by probing the sand with a pole every 10 cm to find air pockets. The team categorized the presence of embryo development in intact eggs and predation by beetles, which is clearly distinguishable by shell mastication. The team excavated five entire 9 m^2 plots as well as 1 m^2 sample areas in the remaining study plots. Volunteers and CMT researchers excavated an additional 30 1 m^2 samples outside of the study area, encompassing all three zones of the beach.

Results

Turtles nested in 26 plots over two study arribadas, one from August 14-18 (1st Arribada) and another from August 27 - September 4, 2009 (2nd Arribada). Plots were between stations 8 and 25.5 on the beach (lateral distance of roughly 1.75 km) (Figure 3.5). Unexpectedly, no hatchlings emerged from nests within study plots.

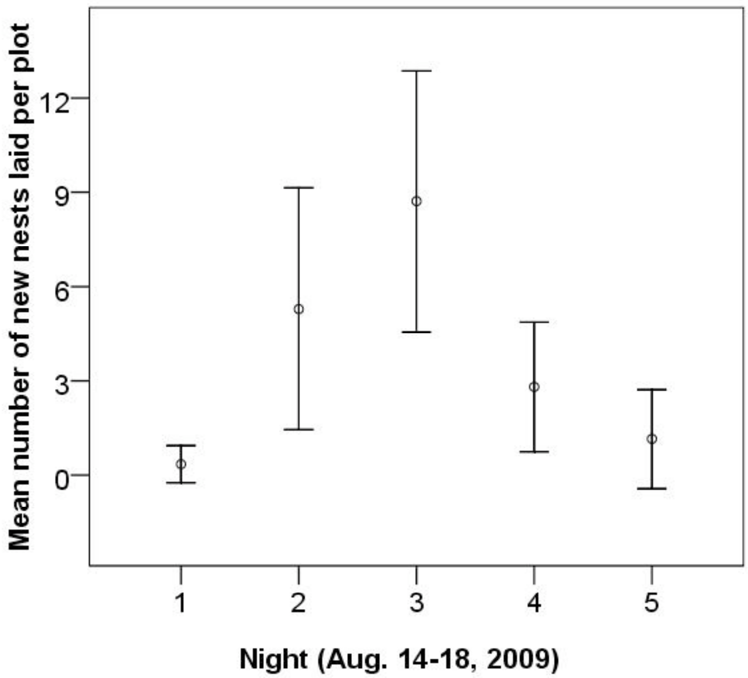
Changes in nest density over the course of two arribadas

A wide range of nest densities were observed, representing differential spatial use of the beach (Table 3.1). There were slightly more turtles observed than nests laid, as some turtles do not complete nest construction. The 2nd arribada was slightly larger than the first, as is usually the case at that time of year. Nesting is not random during the arribada; a repeated-measures ANOVA revealed significant differences in the number of new nests laid among different nights during the 2nd arribada, $F(7, 175) = 10.53$, $p < .001$. Visual inspection of means indicated that more turtles arrive and nest during the middle nights (Figures 3.8a and 3.8b).

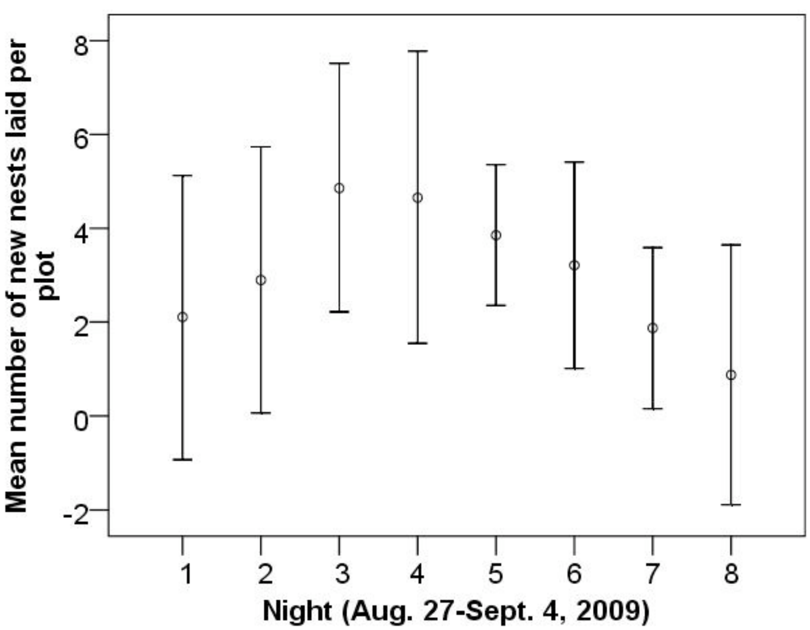
Table 3.1. *Total estimated nest densities and turtles present per plot (n = 26 plots) during two arribadas Aug.-Sept. 2009. Mexican government researchers estimate the total number of nests during each arribada by inputting results from the Gates-Valverde transect count method (Gates et al. 1996) into a population model that accounts for numbers of females nesting over the area of beach used.*

Nest density/ plot	**1st Arribada**	**2nd Arribada**
Mean (SD)	18 (6.76)	24 (9.67)
Range	6-32	5-46
Total # Turtles/ plot		
Mean (SD)	21 (8)	28 (11)
Range	7-41	8-53
Total # nests estimated during the arribada (95% confidence intervals)	186,268 (146,165; 226,362)	198,594 (136,107; 261,082)

a)



b)



Figures 3.8a and 3.8b *Mean number of new nests laid per plot per night of each arribada +/- 1 SD. Temporal distribution of nesting appears to follow a pattern whereby more turtles nested during the middle nights of each arribada.*

For the 2^{nd} arribada, density values were calculated to include nests from the 1^{st} arribada to account for destruction occurring on nests from either event (Figures 3.9a and 3.9b). These cumulative densities ranged from 14 to 73 nests/9 m^2 plot (1.6 to 8.1 nests/m^2) and had a mean of 42 nests/plot (4.67 nests/m^2).

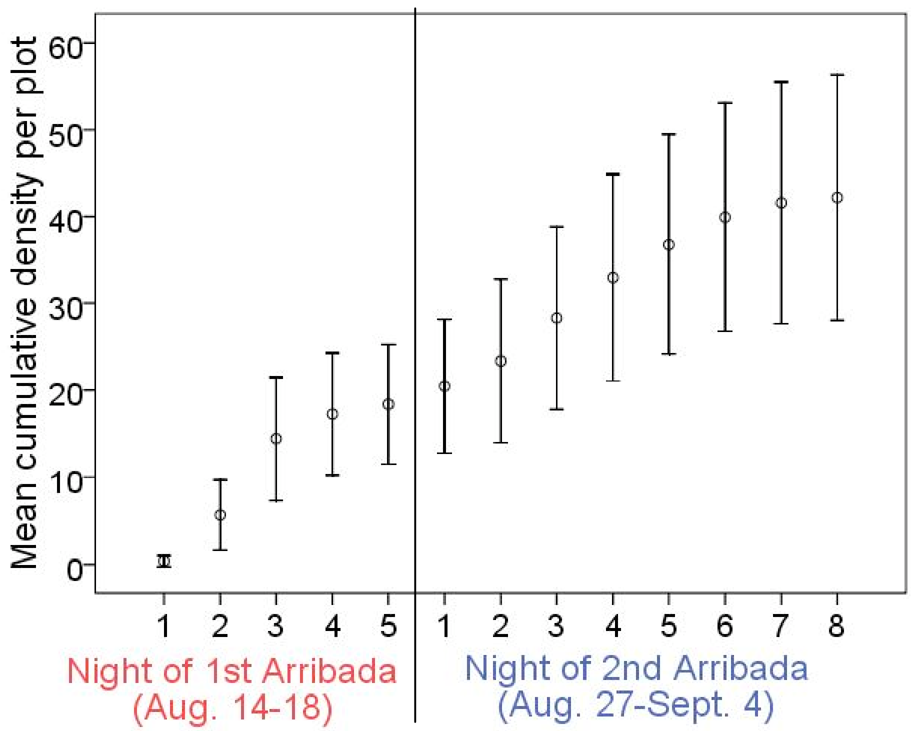
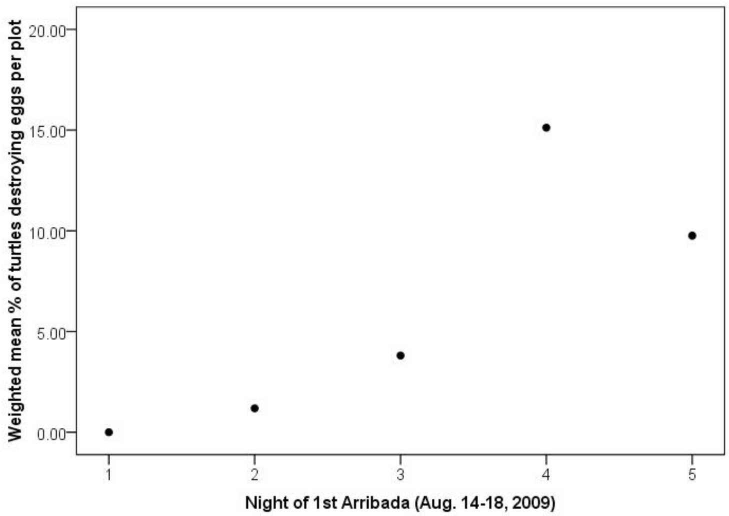


Figure 3.9. *Mean cumulative nest density +/- 1 SD per 9m² plot per night over both arribadas. For the 2nd arribada, density values include nests from the 1st arribada (to account for destruction occurring on nests from either event). N (nests) = 476 (1st arribada), 621 (2nd arribada).*

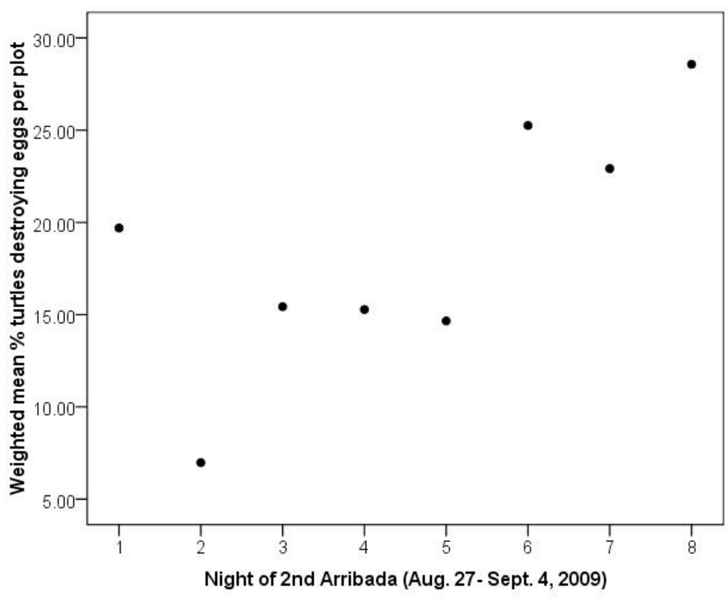
Nest destruction and nest density relationships

As hypothesized, mean percent destruction (total number of turtles destroying eggs divided by the total number turtles in plot), weighted by sample size (to account for differing numbers of turtles/plot), increased over the course of both arribadas (Figure 3.10a and 3.10b). I evaluated the difference in destruction between the two arribadas; the 2nd arribada had a significantly larger proportion of destruction than the 1st (z = 8.928, $p < .0002$).

a)



b)



Figures 3.10a and 3.10b. *Mean percent destruction per plot per night of the 1st (a) and 2nd (b) arribada. N (turtles) = a) 566, b) 727. Means weighted by sample size to account for different numbers of turtles (total number of turtles destroying divided by total number of turtles in plot).*

I found a significant positive correlation between percent destruction (total number of turtles over all nights) and total cumulative nest density (Figure 3.11; r = .441, *p* = .024). A mixed-model logistic regression with plot entered as a random factor showed little variability in probability of destruction among plots (intercept = 2.9×10^{-6}). This value implies that the observed differences in nesting among plots did not impact overall destruction probabilities. The model revealed a positive and statistically significant effect of nest density in predicting the odds of destruction (ß = .191, *p* = .005)[2]. The change in odds of destruction predicted by a one nest increase in density (per m^2) can be calculated by exponentiating the beta coefficient for density (.191); doing so reveals that the odds that an individual turtle destroys eggs increases by a factor of 1.21, or 21%, for every additional nest in the ground per m^2 (95% confidence interval: 6-38%). A curve of this positive relationship was modeled from the logistic regression for densities up to 15 nests/m^2 (Figure 3.12)

[2] The odds of destruction are calculated as the probability that a given turtle destroys eggs divided by the probability that a turtle does not destroy eggs; changes in the odds of destruction are directionally but not perfectly related to the probability of destruction.

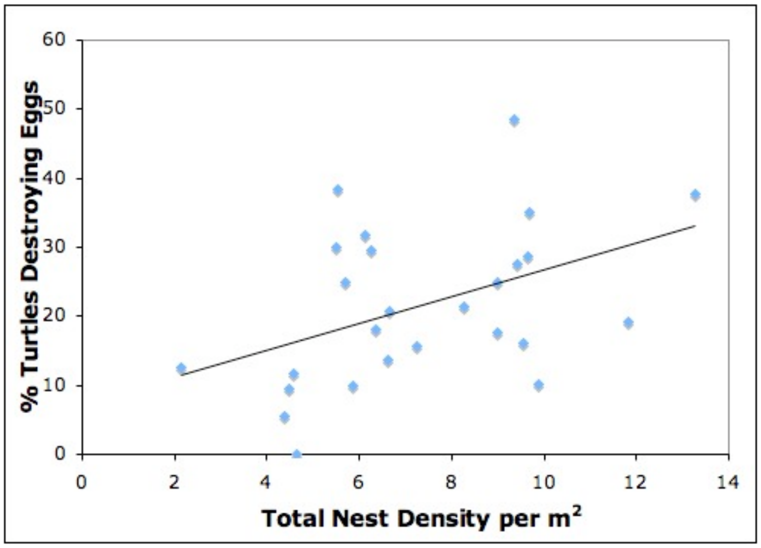


Figure 3.11. *Cumulative nest density per m^2 versus percent destruction for the 2nd Arribada (linear trend line). Each point represents one 9 m^2 plot's nest density after both arribadas, divided by nine (n = 26 plots), r = .441, p = .024.*

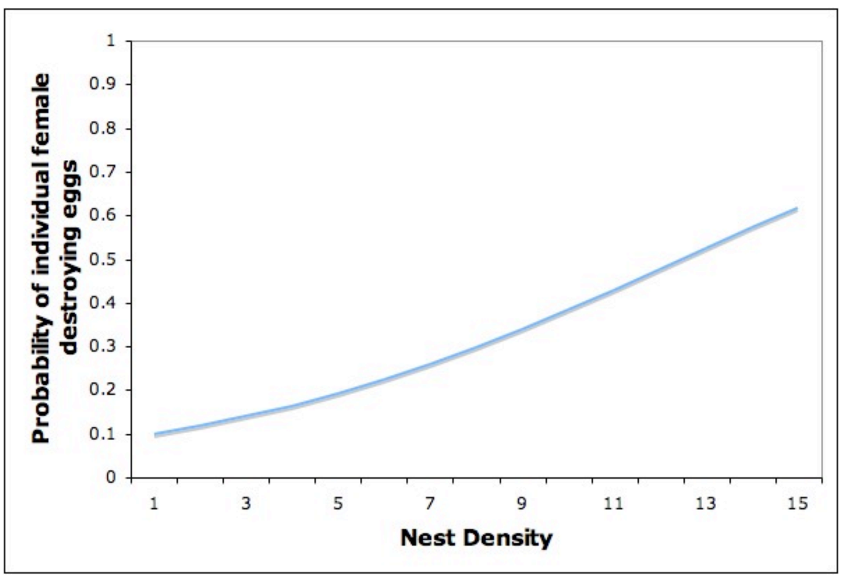


Figure 3.12*. Probability that any given turtle destroys a nest for hypothetical densities (per square meter) between 1 and 15. Probabilities are given by the formula: P(destruction) = 1/ (1+exp[-(-2.389+ .191x)])*

Other factors contributing to nest success in study plots

Sand temperatures at nest depth at my scale of reference were consistently high across the study area with mean maximums well above the proposed 35°C lethal threshold (n=22) (Tordoir et al. in press) (Table 3.2). Beetle predation was also high, with all nests experiencing some predation (Table 3.3). No hatching from the two arribadas was observed in the entire middle beach zone (B, stations 8-25.5) in which plots were located (Table 3.2). Some hatching occurred outside the study area, especially where the rivers occasionally overflow into the ocean and in areas near high tide. Very rough estimates from nest excavation from those areas indicated mean hatching success rates of 7.8% (n=30, weighted by estimated total number of eggs). It was difficult to determine numbers of eggshells because of fragmentation from predation.

Table 3.2. *Temperature at nest depth measured with ibutton loggers (n = 22), one per plot. Range and mean of plots' mean temperatures during incubation is reported. Mean number of days over 35°C indicated as this temperature is the potential olive ridley lethal threshold (Tordoir et al. in press). These values represent estimates for the 45-day incubation period, as nests were laid over a period of a few days. For the 1st arribada, sensors were not put in until a few days after the start of the incubation period.*

Temperature per plot during incubation period	**1st Arr.**	**2nd Arr.**
Mean (SD)	34.6°C (.68)	35.0°C (.69)
Mean Range	33.7-35.8°C	34.0-36.2°C
Mean Minimum (SD)	31°C (1.2)	31.5°C (1.4)
Mean Maximum (SD)	37°C (.92)	37.1°C (.1.0)
Mean # days reaching 35°C	23	30

Table 3.3. Results of excavation to determine potential causes of nest failure. No hatching was observed in the most used portion of the mid-beach (zone B), which is where study plots were located. Nests were excavated in study plots as well as in areas

away from the most used part of the mid-beach. All nests in the study plots had evidence of beetle predation. Very rough estimates provided for % nests with over 50% beetle predation; the number of eggshells in nests was difficult to determine because of fragmentation from predation.

Nest Excavation	**Inside study plots (n=215)**	**Outside plot area (n=30)**
% Nests with beetle predation (% Nests with over 50% eggs depredated)	100 (87.5)	69.8 (48.3)
% Nests with hatching	0	63.3
% Unhatched eggs without embryonic development (#eggs)	87.7 (3247)	43.8 (1048)
% Unhatched eggs with embryonic development (#eggs)	12.3 (455)	56.2 (1342)

Discussion

Field study results

One novel goal of this project was to consider density and destruction in a relatively simple way for naturally occurring densities on arribada beaches. My study results support the hypothesis that nest density is an important factor contributing to nest success due to its positive association with destruction. It is logical that destruction (percent of turtles destroying eggs) would increase over time, since density increases over time (Figure 3.9) and destruction increases with increasing density (Figure 3.11). I found that total nest density and destruction per plot were positively correlated; more notable is the significant predictive effect of density, wherein nest density was positively related to the odds of a given turtle destroying eggs. In the complex interplay among potential density-related factors that affect nest success, this study empirically shows that the odds of a turtle destroying nests are clearly and significantly density-dependent (i.e., odds of destruction increase 21% for each additional nest in a 1 m^2 area surrounding a nesting turtle).

Study results also emphasize the complexity of arribada nesting dynamics whereby overlapping arribadas and incubation periods preclude simple comparisons of impacts of nests (and turtles) on each other. True estimates of nest success and population projections must take into account the fact that incubating eggs are impacted by multiple arribadas. Arribadas at La Escobilla are frequent: between 2001-2005, twenty-six arribadas (76.5%) had incubation periods that overlapped with one subsequent arribada and four overlapped with two arribadas (Albavera 2005). In this study, nests from the 1^{st} arribada would have interacted with turtles and nests from two subsequent arribadas, if not for the subsequent fencing that ensured observation of all nesting behavior. As it was, the accumulation of nests in the ground from just two arribadas corresponded with higher destruction levels, as both intra- and inter-arribada destruction became possible during the 2^{nd} arribada. Destruction levels varied both within and between arribadas, indicating the inadequacy of using any single value to represent destruction levels at a beach. The relative importance of various factors may also depend in part on arribada timing, most obviously in terms of destruction impacts. Thus, placing values on Bernardo and Plotkin's (2007) graph is not as straightforward as it seems because of the complicated relationship among factors, both spatially and temporally.

Regardless of the importance of destruction, it is clear that environmental variables can trump density impacts with respect to hatchling production. For example, unsuitably dry warm weather and El Niño conditions likely explain the lack of hatchlings in the mid-beach study area. Mean sand temperatures in study plots were around 35ºC, the proposed lethal maximum for olive ridley nests, and the literature indicates that corresponding nest temperatures would have been even higher due to metabolic warming (Tordoir et al. *in press*; Broderick et al. 2001; Godfrey et al. 1997). The majority of unhatched, unpredated eggs in study plots also did not have evidence of embryo development, a finding that likely means mortality occurred early in incubation.

I hypothesize that beetle predation is the other main cause of lack of hatchlings in this study. With all study nests experiencing some level of predation, beetles are likely becoming a major cause for nest failure. While unusual, similar plague-like behavior has been documented elsewhere (Allgower 1979). Beetles have historically had the largest presence in the most used area of the beach, and in the last few years the beetles' range appears to have expanded at La Escobilla (Halffter et al. 2009; Harfush & Lopez 2007). While presence of beetles does not preclude hatching, the potential impacts of an increasing beetle population do not favor hatchling productivity. The high invariable level of predation, however, prohibited investigating a relationship of predation to density, despite what is indicated by the literature; a recent study found that lower density areas had fewer nests with beetles present (Halffter et al. 2009). Ultimately, it was impossible to discern whether temperature or predation was more influential owing to the lack of variability in hatchling production. The fact that hatching did occur outside the study area could indicate the importance of these variables, as the successful area has historically less beetles present and was likely cooled and cleansed by waves and river flows.

Much previous attention to nest destruction came out of interest in use of aggregated wildlife. Highly visible nest destruction is the primary fuel for pressure to consider harvest of eggs based on compensatory arguments that eggs otherwise destroyed should be utilized as a resource for human consumption (Campbell 1998). This concept of destruction has translated into management action, although the scientific basis is still being investigated (Campbell et al. 2007). To date, significantly higher mortality rate of nests has been found in double clutch nests after superimposition compared to single clutch nests (Von Mutius 2000). A Nicaragua arribada study assessed nest extraction by removing superimposed “double clutches”. Significantly lower hatchling production occurred in the removal plots versus the controls, after accounting for differences in numbers of nests. This suggests that other factors may be influential and that removal itself may be detrimental (Honarvar 2007**).** My study results do solidify the relationship between density and destruction, but they also indicate that the effectiveness of harvest will be difficult to assess given that arribada nesting dynamics are a multi-faceted phenomenon.

Future directions

The dynamic nature of nest density is yet another factor that complicates our evaluation of its effects on hatching success and population dynamics. The present study demonstrates the utility of possessing reliable estimates of nest destruction and density. The concept of low or high densities is by definition comparative and not precisely defined. The densities in this study fall within the “low to high density” range reported in a Costa Rica arribada study and the mean density is near the “medium density” value obtained in the same study (Honarvar et al. 2008). Given that densities up to 8 nests/ m^2 were obtained over the course of just two arribadas, density should be quantified during the largest arribada of the season to see how high La Escobilla densities may be. Future studies of arribada beaches should report the range of nest densities, cumulatively to account for overlap of incubation periods, in a comparable unit (m^2). Researchers should determine and report upfront the most meaningful temporal and spatial scales for interpreting densities, and try not to stumble over the fact that the number of nests in the ground is constantly changing, with some partially destroyed and at different incubation stages. The decision of how to report density would be more exact if there was research at the individual egg level determining destruction, predation, and survival.

As indicated above, the relative importance of different factors on nest success is difficult to tease apart and almost certainly varies by season and arribada. As such, it is important to regularly measure some of the factors highlighted here, in particular temperature and beetle predation. Future studies should obtain a temperature profile for different areas of the beach. In this study, average temperatures recorded showed little variability. However, this could be an artifact of the plot level scale of density used. At Nancite, Costa Rica, the highest temperatures were recorded in high density plots (Honarvar et al. 2008). Thus, a study designed to differentiate among nest temperatures at a localized microclimate scale (multiple sensors within each plot) at lower ambient sand temperatures might have found a strong temperature-density relationship. My results also highlight the need to investigate a beetle control program. Traditional trapping will be challenging given that nesting turtles regularly disrupt the ground, but the widespread beetle predation is worth the resources to develop an alternative mode of abatement.

With up to 28.5% of turtles destroying nests per night, nest destruction was a frequent occurrence. Future studies should try to estimate nest destruction either as a fraction of nesting activity or as a probability of destruction, instead of relying on current methods at La Escobilla that simply estimate the absolute number of turtles destroying nests. This would allow for more accurate future projections of destruction rates based on numbers of turtles or nest density. This could lead to a useful and potentially effective multi-purpose strategy, as nest density is likely related to a suite of other factors as well. In addition, past attempts to incorporate destruction into models have raised relevant concerns regarding the challenges to fully understand nest destruction processes, including the need for specific estimates of destruction levels and of how much of a nest is damaged (Caut et al. 2006). These solitary nesting models that examine spatial use by incorporating nest density, destruction, and other factors could be a useful foundation for arribada beaches to determine nest success and carrying capacity for population estimates. This project provided empirical data on nesting beach factors that could be used for such future modeling.

Understanding what determines offspring production is particularly important when there is pressure to utilize wildlife as resources because of aggregation behavior. In the past, large numbers of turtles nesting at arribadas created a false positive perception of their conservation status (Cornelius et al. 2007). The reality is more complicated as their great abundance may negatively inhibit productivity through complex density-dependent mechanisms. Understanding nesting dynamics over the course of an arribada is important for conservation efforts because timing of nesting activity plays into both behavioral (e.g., is it more advantageous to nest in the middle of an arribada) and management (e.g., when to bring tourists, relocate or harvest nests, or intensify patrols) discussions. Continued efforts to monitor the La Escobilla population will help ensure their rebound from industrial harvest as well as provide insights into the web of factors driving this unusual reproductive strategy.

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CHAPTER 4: RESEARCH RECOMMENDATIONS AND CONCLUSIONS

This thesis explored arribada dynamics at La Escobilla, Oaxaca through a historical review of the human-turtle relationship brought into present context through interviews with key informants and through a field study of nesting behavior and nest success. Research projects such as this one provide valuable information on a phenomenon that, while unique to the *Lepidochelys* genus, illustrates important factors that are relevant to the study of conservation of wildlife aggregations utilized as community resources.

Field Study: Findings and Recommendations

The present field study was novel in its evaluation of the relationship between density and destruction for naturally occurring nests at an arribada beach, and by providing updated estimates of productivity variables for La Escobilla. Timing of nesting activity, and in particular destruction of nests by con-specifics (hereto referred to simply as nest destruction), is relevant to understanding arribada behavior and making management decisions about where to focus research energies, when to allow tourism, and if or how to manage nests. The findings demonstrated a clear pattern in nesting intensity throughout the course of an arribada event, whereby nesting peaked during the middle nights. Nest destruction was prevalent and variable throughout the study area, with averages of between 0-28.5% of females destroying eggs per plot per night. The percent destruction increased over the course of both arribadas, and also between the 1st and 2nd studied arribadas. A major finding was that destruction and "medium to high" levels of density were positively and significantly related; nest density was positively and significantly predictive of the odds of any given turtle destroying eggs, providing support for the theory that density-dependent mechanisms drive nesting outcomes. Overall, one of the most important implications of this study is the need to take into account multiple arribadas when attempting to estimate and manage nesting turtles.

A key methodological challenge addressed in this study was the quantification of density in time and space. Because density changes constantly as new nests are laid, I chose to represent density cumulatively as all the nests incubating in a localized area at the end of a night of arribada activity. Overlapping incubation periods, due to short inter-arribada periods, lead to destruction of nests from previous arribadas, as well as potential impacts on eggs from neighboring nests in various stages of development. Thus, I recommend using cumulative nest density, accounting for all nests incubating.

When considering factors determining nest success, do we need to look over a larger time scale? It may be best to consider nesting factors over an entire season to account for the many potential points of interaction since incubation periods are difficult to separate, e.g., hatchlings emerging from a nest climbing through the partially destroyed eggs of a superimposed nest that a female turtle is currently digging up. Given that density can be measured at any point in time, I recommend that researchers clarify their working definition and decide on a standard way of describing density. Given that density may operate very locally on microclimate, it is logical to consider the area immediately around nests with the per m^2 metric.

Directions for Future Research

Evaluating hatchling production

In order to more accurately evaluate the status of the present and future nesting population, an up-to-date estimation of hatchling production is needed at the beach level. Estimating hatchling production, however, is not as straightforward as simply multiplying the number of nests laid by an average success rate. The spatial and temporal variability of nesting activity affects nest success by changing interactions among a suite of factors, such as density-dependent con-specific nest destruction and microclimate. The relationships among factors that influence nest success are widely believed to be significant but remain poorly quantified in the peer-reviewed literature, in part because their interplay is challenging to tease apart in natural settings. Nest success may not be determined by any one factor: "It is possible that individual sea turtle nests are small ecosystems, with each being characterized by numerous, multidimensional, interacting parameters" (Madden 2008). Quantifying female behavior and factors that may affect nest success *in situ* are a first step to understanding the potentially density-dependent mechanisms that ultimately determine hatchling production.

Quantifying hatchling production

Two recommended studies would elucidate how to measure hatchling production and its relationship to nest density. In order to estimate the effects of nest density directly on hatchling production, one could utilize a field study that builds on this thesis. Given inter-seasonal variation, the study should be conducted over a number of arribadas. Given spatial variation, the study should provide hatchling production estimates in plots of known nest density in all three zones of the beach. This would fill in holes by quantifying hatchling production at La Escobilla, categorizing production by area of the beach, and associating production with nest densities.

My field study has shown that, while it is not impossible to successfully conduct the studies above, it would require a concerted effort and greater input of human resources than currently exists at the beach. Given this knowledge, more realistic methods to accurately evaluate hatchling production are required. Currently, excavation of nests provides critical information on mortality causes and estimates of hatchling production; at its simplest, excavation entails eggshell counts to categorize successful hatching and numbers of dead hatchlings found (e.g., Miller 1999). During excavation of nests in study plots, interpretation was made difficult because of beetle predation that appeared to have reduced shells to shredded pieces and because of insufficient training in eggshell interpretation. What is needed to make shell counts work? Future research should compare known hatchling production from capture to that estimated from the current excavation methodology. This would require a large sample size (in case of lost or hard to count depredated nests), nests with known numbers of eggs laid, and reliable nest covers monitored for direct observation of hatchlings. In light of limited resources, the above two studies could be combined to provide empirical estimates of current levels of hatchling production as a function of nest density.

Modeling hatchling production

Previous studies modeling the interplay between density and hatchling production at solitary nesting beaches (see Chapter 3) provide a baseline for models to estimate hatchling production at the beach level from arribadas. While there are a number of challenges to creating such a model, it would provide a more accurate estimate of the number of hatchlings produced. Currently, a model is used to estimate the number of nests laid during arribadas, with data collected from transect counts of nesting females projected over the entire area; this provides the foundation on which to build estimates of nest success.

What are the parameters or factors that affect nest success that need to be taken into account? The present study emphasized the importance of accounting for: density; destruction; temperature; and, beetle predation. Observational results indicate that other environmental variables, such as moisture and gas exchange, should also be included. Further research is also needed to better understand the impacts of partial destruction and subsequent survival at the egg and nest level (building on work of Caut et al. 2006) as well as factors that influence the beetle population. Other sources of predation, such as dogs and vultures, also need to be estimated, while effects of poaching during arribadas may be of less importance due to heightened research and tourist activity (which tends to discourage poachers). Finally, study results suggest that some of these factors can serve as proxies for others, e.g., density could be used to estimate nest destruction.

The key to simplicity and accuracy in predicting hatchling production across the beach lies in accounting for spatial variation. In the present study, nesting was observed to be clustered, so it is important to consider non-uniform use of the beach when estimating density-dependent effects. Estimates for temperature and moisture could largely be accounted for by location. A temperature and moisture profile of the beach would reveal areas that are warmest or reached by wave action; this, combined with events during the arribada such as flooding from the estuary, could predict the relative influence of those environmental variables. While I observed relatively little variability in beetle predation at the plot level, general patterns are evident over a larger area of beach. Previous studies have found that the most beetle-affected area is where our study plots were located, which is associated with higher use and therefore higher nest densities, than in outside areas where there is less nesting (Harfush & Lopez 2007).

Given the challenges faced in creating the model to estimate numbers of nests, an even more complex model to estimate hatchling production would be an ambitious undertaking. However, future improvements to the nest model, which purportedly are in the works to increase precision, could provide a better baseline for estimating hatchling production. The sticking point for estimating hatchling production will be in determining the relative significance of various causes of mortality, e.g., how to definitively determine if eggs in our study died from microclimatic conditions before predation.

Human Dimensions: Recommendations for community involvement

The realization that another layer of complexity, i.e., human dimensions, must be added to an already complex system is daunting. However, exploration of the historical harvest at La Escobilla and firsthand experience of local use of the beach during the field study emphasized that humans are an essential part of arribada conservation. During any given field season, researchers only experience a snapshot of human-wildlife interactions, missing much that can be learned from the historical context in which current management activities occur. I strongly urge other biologists to immerse themselves in the context of their field site and the human dimensions of the wildlife they study.

Mexico has a long history of turtle use and past harvest is an important part of La Escobilla's story. Local residents continue to seek economic stability and are still in the process of becoming familiar with a conservation-driven framework. What happens to the nesting population is of concern not only to government researchers but also to local community members. La Escobilla's turtles would benefit from their human neighbors being more engaged in research and conservation efforts; involvement serves double duty by educating residents about scientific investigation of turtles as well as by getting them invested in the success of conservation activities. Simple principles could be employed to initiate these efforts. For instance, there are certain data collection activities that people are more likely to feel positively about being involved in, e.g., counting hatchlings, than others, e.g., excavating predated nests. Additionally, more school programs could bring local children to the beach to assist with such activities. Both of these “interventions” would likely foment the ongoing changes towards less consumptive behavior that were reported in interviews.

Giving community members a greater voice in future research would likely motivate them to move beyond seeing research as just an employment opportunity. In interviewing and working with local residents, it was readily apparent that Escobilla needs longer term employment opportunities that provide rewards to the entire community as a result of turtle protection. If there were a way to indicate to local residents that these job opportunities were mutually exclusive with egg poaching, I believe that more locally driven self-policing would occur. Egg harvest has a long history within the local community and continues to be a reality at Escobilla. While this project did not evaluate impacts of poaching explicitly, it was clear that egg consumption is part of the local lifestyle and some level of illegal harvest is to be expected. If a goal of future management and conservation strategies is keeping poaching to a minimum, local residents need to be engaged in these efforts.

Most of the potential factors determining population status described in this project are arribada and even beach-specific drivers of hatchling production. However, conservation efforts at La Escobilla share similarities with other wildlife resource conservation stories. One key stressor of many populations is also relevant in this case: development. With the ongoing construction of a faster highway to Oaxaca’s coast, some are worried about ramifications for nesting beaches. The loss of nesting habitat to tourism infrastructure is a real concern that could trump other factors if development is not pursued wisely. Ecotourism is just starting and, if poorly devised, these activities could also negatively affect nesting turtles. It is imperative that a well thought-out regulatory plan is put into place to shape future tourism activities in a way that results in positive outcomes both for the turtles and for local residents.

Conclusion

Olive ridley conservation efforts in Oaxaca are touted by some as a success story. The rebound in La Escobilla's nesting population is definitive evidence of the power of sound management decisions, in this case, an end to difficult to regulate adult harvest. However, the full story illustrates that the lead up and aftermath of the ban were not ideal. Focused research can continue to fill in gaps in our understanding of arribada nesting dynamics and how various factors interact to determine hatchling production; continuing to flesh out the population model based on empirical values gathered at La Escobilla can lead the way in honing similar estimation methods for other arribada beaches; integrating community members into research efforts will solidify local investment in conservation efforts. Similarly, providing assistance in helping community members find permanent employment related to protecting turtles will foster community pride in their resources and hopefully provide for positive incentive-based, as opposed to fear-based, enforcement of conservation efforts. Finally, carefully regulating both future development in the area and burgeoning ecotourism ventures will be essential to maintaining a healthy nesting habitat. If La Escobilla can live up to these priorities, then the beach will represent a wildlife recovery success story that other areas can use as a model.

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