Captive Reproduction of Sea Turtles: An Important Success Story

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Abstract

All seven extant species of sea turtles are considered endangered or threatened with extinction. Because of their commercial value for food (particularly the green turtle) and for craft materials (bekko or tortoiseshell from the hawksbill turtle) they have been heavily exploited around the world. Sea turtles are also charismatic animals to view in large aquaria and three species have proven easily reared in captivity. Initially, in the 1970s, the green sea turtle was bred in captivity by the Cayman Turtle Farm on Grand Cayman Island in the Caribbean. Subsequently, the loggerhead, Kemp's ridley and hawksbill have also been bred in captivity at several aquaria and research labs around the world. Research on captive sea turtles has proven very important in improving our understanding of the reproductive biology of sea turtles. Our group, as well as other researchers, has made key original observations on captive animals, particularly at the Cayman Turtle Farm over the last four decades. These include the first evidence of temperature dependent sex determination in sea turtles, the first understanding of the ovulation cycle in any sea turtle, the first description of the hormonal control of reproduction 2 in turtles, the first quantitative description of mating and courtship behavior in a sea turtle, and the first captive breeding of the green, hawksbill, loggerhead and Kemp's ridley sea turtles. In addition, multiple paternity has been observed in captive greens with as high as seven fathers in a single clutch. Proper nutrition in captive animals has permitted sea turtles to reach sexual maturity 2-5 times faster than they do in the wild. On the other hand, imbalanced free fatty acid ratios from the diet appear to cause a reduction in viability of captive bred embryos. Finally, unique observations of sea turtles in aquaria have improved our knowledge of physiological processes such as the occurrence and possible seasonal cycles of a softened plastron in adult males, an adaptation important in mating behavior. It can be argued that successful captive breeding of four species of sea turtles, while not favored as a current conservation strategy, has nonetheless reduced the prospect of extinction for these species. Captive breeding programs for the other three species would teach us much more about these turtles and improve the long term conservation options for these species as well.

Introduction

Sea turtles are visually spectacular when swimming, providing the appearance of underwater flight, very much like a large graceful bird on the wing. As air breathing vertebrates with their tough reptilian skin and shell, they are exciting as large and distinctive display specimens. When you combine the important "appearance factor" with the fact that sea turtles are very robust animals, having minimal disease problems, you have a combination of characters which make them very desirable for modern zoos and public aquaria. The second important factor adding to sea turtle's general desirability is their economic value. Parsons (1962) once described the green sea turtle (*Chelonia mydas*) as the most valuable reptile on the earth. Indeed the meat, shell and skin have been important commercial products for millennia (Frazier, 2003). Because of the hardy nature of turtles, they were actually important in discovery and exploration of the new world since they could be carried alive aboard ships and used as fresh food as needed without requiring fresh water (see Carr, 1967 for discussion). Similarly, for centuries in several different cultures, the keratinized shell of the hawksbill (*Eretmochelys imbricata*) turtle has been commercially valuable for carvings, jewelry and as furniture inlays (Frazier, 2003).

Considering this general interest in sea turtles, it is not surprising that they have long been maintained in captivity and that they have also been used in several attempts at captive culture and farming (Table 1) (Carr, 1967; Hendrickson, 1974; Ross, 1999). Indeed, in the 1960s the idea of sea turtle aquaculture seemed a very logical and practical extension of the popularity of these species for food and other commercial uses. Carr (1967) in his most popular book "So Excellent a Fishe" devoted part of the last chapter to evaluating options for sea turtle culture. He argued that such culture prospects could be valuable for the conservation of these species which he was becoming more and more concerned about in terms of over exploitation in the wild. Subsequently, in the 1970s, he modified his thinking and began to feel strongly that captive culture of sea turtles could work against the long term conservation strategies for sea turtles (Carr, 1967; Ehrenfeld, 1974; Fosdick and Fosdick, 1994). This change of philosophy was devastating to the commercial approach to turtle culture as it directly resulted in more restrictive changes in the US Endangered Species Act as well as in international thinking as evidenced by many CITES (Convention on International Trade in Endangered Species) policy decisions up to the present time. 4

The turtle farm at Grand Cayman Island and other places have had significant success with captive breeding and the remainder of this paper will focus on those results. The first author of this paper and three of his subsequent graduate students had the opportunity to conduct extensive reproductive biology experimentation at Mariculture, Ltd. (initial name) and the Cayman Turtle Farm, Ltd. (CTF) between 1973 and 1999 (Owens, 1976; Crowell Comuzzie, 1987; Rostal, 1991; Craven, 2001).

Materials and Methods

In addition to the Cayman Island facility, mentioned above, several public aquaria have had limited success with captive breeding of sea turtles. While the breeding facilities we have seen around the world range from very large as in the Cayman Islands (Fig. 1) to very modest as at the Miami Seaquarium (Fig. 2), the minimum requirements for success in breeding have included adequate depth for movement during mating and courtship, an associated sandy nesting beach and a good nutritional diet for the breeding animals. While we do not claim this to be a complete listing, the following facilities are known to have had at least some success with captive breeding of sea turtles: Cayman Turtle Farm, Ltd., Grand Cayman Island; Miami

Seaquarium, USA; Xcaret, Mexico; Sea Life Park Hawaii, Oahu, Hawaii; Yaeyama Station, Ishigaki Island, Japan.

Figure 1. Cayman Turtle Farm breeding pond and nesting beach in 2009. Note tracks and nesting pits on the beach. (photo J. Parsons of CTF)

Figure 2. Naturalistic holding pond at the Miami Seaquarium about 1986 (photo D. Owens).

An important advantage to the use of enclosed and protected facilities such as zoos and aquaria for research on captive breeding and reproductive biology, is the improved ability to track and carefully observe the animals aver an extended period. In addition, the captive situation is a good location to test the development of new technologies not yet proven in wild populations. While we will not go into detail on the following methods themselves, which are published elsewhere, most of these technologies were first used and adapted to sea turtle work in captive/farm situations: Radioimmunoassays (RIA) on sea turtle hormones were first used to determine the sex of juveniles (Owens et al., 1978) and reproductive condition of adult sea turtles (Licht et al., 1979) in experiments done at CTF. Safe and efficient blood and cerebral spinal fluid sampling techniques were first developed at CTF as pictured in Figure 3 (Owens and Ruiz, 1980). Sea turtle laparoscopy or endoscopy was first done by Dr. James Wood and collaborators at CTF (Wood et al., 1983). In addition, Dr. Fern Wood and her collaborators made significant improvements in the anesthesiology of sea turtles at CTF (Wood et al., 1982a). The nutrition of sea turtles in captivity, improving our understanding of nutritional requirements in the wild, was first studied in captivity (Wood, 1974; Wood and Wood, 1981). The first tissue grafting for “living tags” was also tested and improved in captive conditions (Hendrickson and Hendrickson, 1983; Balazs, 1999). Finally, electroejaculation of adult male semen for use in artificial insemination was also developed at CTF (Wood et al., 1982b).

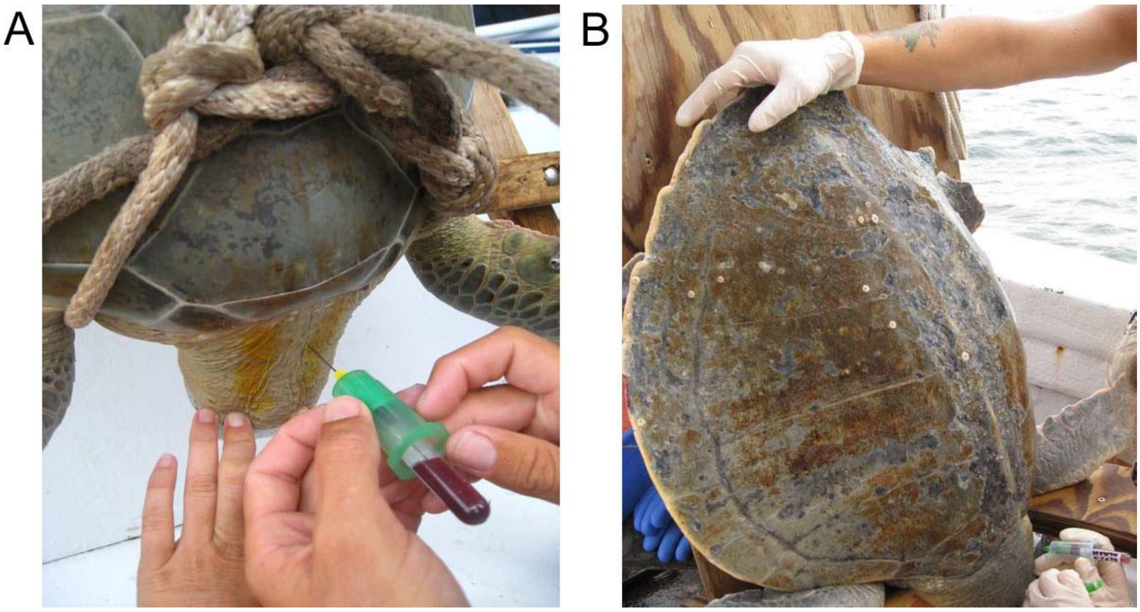

Figure 3. Bleeding a green sea turtle (a) and a kemp’s ridley (b) from the dorsocervical sinus In (b) note the use of a wooden rack to passively restrain the turtle for sampling (photos G. Blanvillain).

Behavioral studies lend themselves to captive and enclosed systems as well. Crowell Comuzzie (1987) and Rostal (1991; 2005) studied green turtles and Kemp’s ridleys (Lepidochelys kempii), respectively, at CTF. The advantages in both sets of captive studies include long term visual tracking of individuals (both males and females), temporal/quantitative studies not feasible in the wild and multi-year and multi-clutch viability follow up analyses. Craven (2001) was also able to track paternity and fertility for marked individual green turtles over time in her captive studies.

Results

For a summary of the species of sea turtles known to have been bred in captivity, see Table 2.

1. Nesting and hatching success

Early reports of green sea turtle breeding activity occurred incidentally while keeping these large animals in captivity. Mowbray (1965) observed a mating pair of Pacific green turtles at Hawaii’s Waikiki Aquarium, as did Hendrickson (pers. comm.) at Sea Life Park, Hawaii in the 1960s. Nesting attempts were also noted in both of these aquaria, however viable hatchlings were not produced. Witham (1970) reported breeding by a pair of pen reared green turtles in Florida, however no hatchlings resulted from this event as well. Ulrich and Owens (1974) noted that females captured in the wild during their nesting season will produce viable nests and eggs when placed immediately in a functioning nesting arena (Fig. 1). Breeding of wild caught green turtles from several areas of the Caribbean and Atlantic first occurred in the summer of 1973 (Ulrich and Owens, 1974). Breeding in the 1973 season was initiated immediately after two additional wild males from Surinam were introduced to the breeding pond. When these two males started mating, several other resident males initiated mating as well. A total of 19 females nested that summer, producing 11,268 eggs in 92 clutches with an average of 593 eggs per female and 122 eggs per clutch (Simon et al., 1975). Reported hatchability was low however, compared to wild populations with 42% viable hatchlings produced. Hatchability did not improve significantly over the next several years and continues to be a general problem in captive breeding programs for sea turtles (Craven, 2001). In 1975, captive turtles raised from eggs also began to breed at CTF (Wood and Wood, 1980). This accomplishment then constituted the first closed breeding cycle for sea turtles in captivity. Green turtles have bred annually at CTF for more than 35 years. In the 1980s, the Miami Seaquarium was also able to breed green sea turtles in their naturalistic tanks with adjacent small beaches (Greg Bossart, pers. comm.). More recently, Sea Life Park, Oahu, Hawaii, has been able to produce 200-800 live hatchlings on an annual basis at their facility.

Surprisingly, at the CTF, captive green turtles produce more eggs, more clutches, and most individuals nest on a shorter re-nesting interval (1.9 yrs) than do their counterpart populations (~3-5 yrs) remaining in the wild (Wood and Wood, 1980). Regarding the later observation, many captive green turtle females nest annually in captivity which rarely occurs in the wild. Thus it is clear that overall annual biological productivity is greatly enhanced (from 2-5 times) in this captive situation. It is suspected that feeding a high protein diet is responsible for this dramatic difference (Wood and Wood, 1980). The captive hatched and farm reared green sea turtles also mature at a much younger age (8-9 years) than wild turtles, which take from 20 to 40 years to reach sexual maturity (Seminoff et al., 2002; Balazs and Chaloupka, 2004).

In 1985, the Kemp's ridley was a species in serious danger of extinction (Magnuson et al., 1990). Even today, because of its relatively limited overall distribution and very restricted nesting range in the Gulf of Mexico, this species has to be considered the most endangered of the sea turtles. By 1980, the CTF had clearly proven their ability to breed the green sea turtle in captivity. At the request of many scientists working at the time on ridleys, CTF agreed to attempt a captive breeding program for this species (Wood and Wood, 1984; 1988). We all considered this to be a critical final conservation strategy in case all other approaches failed. At this time, there were no indications that the large bi-national conservation effort (Mexico and the U.S.A.) was having any positive impacts (Heppell et al., 2007). In July of 1980, CTF accepted some yearling turtles derived from nests laid in Mexico and head-started in Galveston, Texas at the U.S. National Marine Fisheries Lab as well as some additional hatchlings directly the wild nesting beach at Rancho Nuevo, Mexico. For a full explanation of the head-starting captive rearing program see Shaver and Wibbels (2007). In 1984, some of the 5-year old captive hatched and reared turtles were already breeding in a cordoned off section of the primary breeding pond at CTF (Wood and Wood, 1984), and several turtles were nesting by 1986 (Wood and Wood, 1988). The turtles were fed commercially available modified floating trout chow produced in the U.S. by Ralston Purina. Their behavior appeared to be somewhat distinct compared to the greens in captivity (Wood and Wood, 1988) but their clutch hatchability rates were also low (0 - 45%), similar to the situation with captive green turtles. Rostal (2005) provides a more complete and instructive comparison of wild versus captive Kemp's ridley nesting.

The first captive breeding of the Kemp's ridley in the U.S. is also an interesting story. Ila Fox Loetscher, the "Turtle Lady", well known conservationist and founder of Sea Turtle, Inc., hand raised a few Kemp's ridleys in her back yard at South Padre Island, Texas (Sizemore, 2002). Her tanks were very small and she did not have a breeding beach, so after several years of unsuccessful breeding attempts in Texas we suggested she send her favorite turtle (Little Fox) to the Miami Seaquarium where they had raised some male Kemp's ridleys from the Galveston head-start program. Mrs. Loetscher shipped her turtle off in 1984, and in 1986 she laid at least one fertile clutch on the Seaquarium's small nesting beach (Fig. 2), and two little turtles were known to have survived (Figure 4) (Barbara Schroeder and Greg Bossart, pers. comm.). Subsequently, the Clearwater Marine Aquarium in Clearwater, Florida, also had some success in captive breeding of Kemp's ridleys (Allen Foley, pers. comm.).

Figure 4. 1-year old Kemp's ridley from captive breeding at the Miami Seaquarium, 1987 (photo B. Schroeder).

The loggerhead (*Caretta caretta*) sea turtle was bred in captivity at the Miami Seaquarium in the 1980s (Greg Bossart, pers. comm.). Eggs and hatchlings were produced on a small artificial beach in one of their display tanks (pers. obs.). Similarly, in Japan at the Port of Nagoya Public Aquarium, loggerheads have been bred in captivity since the 1990s as a long term conservation program (http://www.animal-dino.com/nagoya_aquarium.html).

Regarding hawksbill sea turtles, a pair of wild captured adult females maintained for two years at the Yeayama Research Station on Ishigaki Island in Japan laid 894 eggs and produced 309 viable hatchlings in 2002 (Shimizu et al., 2007). Figure 5 shows a diagram of the facility which was developed for this purpose. Wild males were also present and mating was observed at the facility at the appropriate times when it was believed fertilizations occurred at the facility. In 2003 at the aquarium in Xcaret, Mexico, seven year old captive reared hawksbills deposited four clutches in their artificial settings, resulting in the eventual release of some 3-year old offspring (Ana Negrete, pers. comm.). If the seven year age is accurate, this would be a very rapid growth to maturity. Finally, in Darwin, Australia, a captive breeding program for hawksbills was initiated in 2003 as a 1-year trial study, but unfortunately limited success was achieved (Webb et al., 2008). However, the authors remained very optimistic in the ranching and/or captive breeding potential of this species for domestic and possible international trade of hawksbill products.

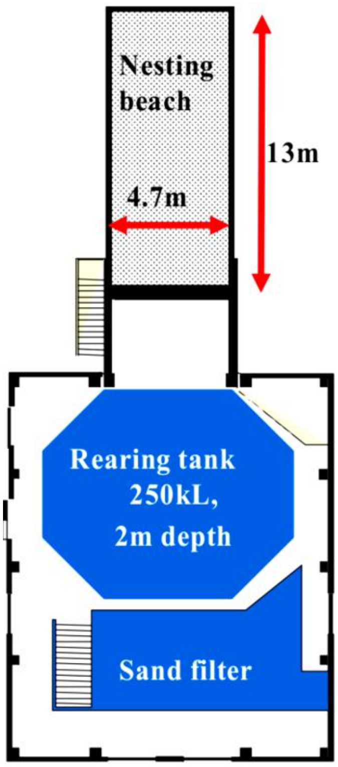

Figure 5. Diagram of the facility constructed for nesting hawksbill sea turtles at the Yeayama Research Station, Ishigaki Island, Japan. Reprinted from Shimizu et al. (2007), reprinted with permission.

2. Discovery of the soft plastron of adult males

As an example of unique research observations made at captive facility we present the following collaborative results. In 1986, as more Kemp's ridleys were reaching sexual maturity in captivity, Owens received questions from SeaArama in Galveston and the Miami Seaquarium asking about an unusual condition the aquarists had been noting in their young adult males. The central region of the plastron was softening and in some cases was even a pink color. Typically this was seen as a central patch approximately 10 cm in diameter in the

posterior medial part of the plastron but sometimes it extended anterior and medially all the way to the front edge of the plastron (Fig. 6). The aquarists also reported a loss of appetite in these males. Our field research group had also seen similar softening of the plastrons in wild males and began to realize that this was probably a natural phenomenon related to the mating season. Wibbels et al. (1991) subsequently described this phenomenon which has now been documented in most of the hard shelled sea turtles. It is believed that the softening in the male's plastron facilitates the gripping of the female during copulation. Blanvillain et al. (2008) also noticed a correlation between the extent of plastron softening and reproductive condition in adult male loggerheads (assessed by testosterone, laparoscopy and testis histology). The plastron is so soft in these reproductively active males that ultrasound can be used directly through the plastron to visualize heart function, a process not possible in juveniles or females.

Figure 6. Soft plastron of an adult male loggerhead sea turtle during the mating season, captured at Cape Canaveral, FL, in April 2007. Note the several healing abrasions on the softened pink area presumably from recent mating events (photo G. Blanvillain).

A pair of injured reproductively active male loggerheads rehabilitated in 2007 at the South Carolina Aquarium in Charleston, SC, was also very interesting. Both males had been caught in crab trap lines in the spring near Charleston. One lost its front right flipper and the other a section of a rear flipper. When brought in to the Aquarium they were found to have extensive softened plastrons (Fig. 7a) and active testes and epididymides based on ultrasound examination (Fig. 8a). Plasma testosterone levels were not high at this point but many other studies have shown that by this time of the year it is normal for the high spring testosterone levels in males to have fallen (Wibbels et al., 1990; Blanvillain et al., in press). What is most interesting is that over the summer and fall, as the injuries healed and the males began to feed, the soft plastron was replaced by a much harder layer of bright yellow new keratin (Fig. 7b). Ultrasound revealed atrophic testicular and epidydimal structures (Fig. 8b). Plasma testosterone levels continued to be low as well. These captive observations strongly suggest that the softened plastron is a seasonal phenomenon which occurs when male turtles are maximally developed for courtship and reproduction, regressing to some degree in non-reproductive years.

3. Behavioral studies

The reproductive behavior of green and Kemp's ridley sea turtles has been studied in captivity at CTF by

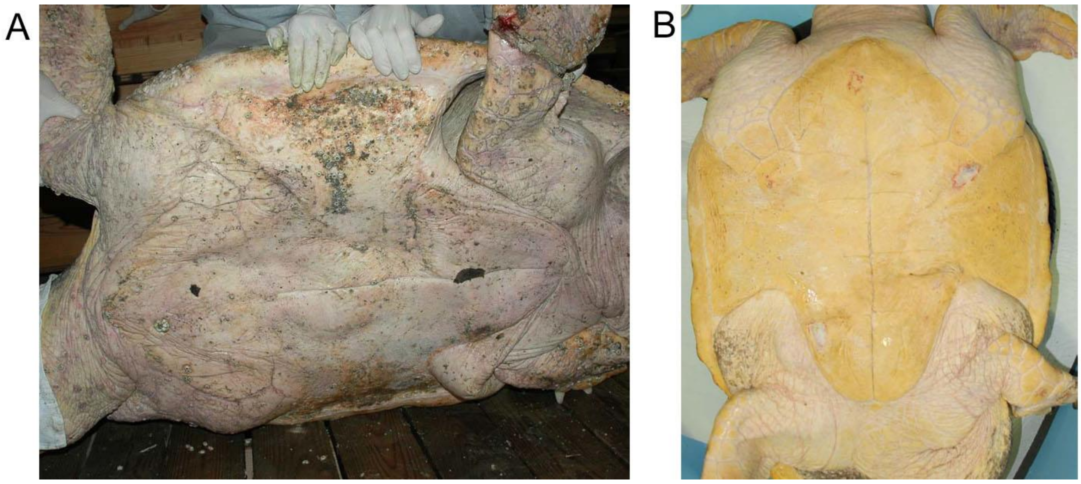

Figure 7. Plastron of an adult male loggerhead transferred to the SC Aquarium in May 2007 (a), and prior to release in October 2007 (b). Note the healed left rear flipper which had been caught in a crab trap float line (photos B. Bergwerf).

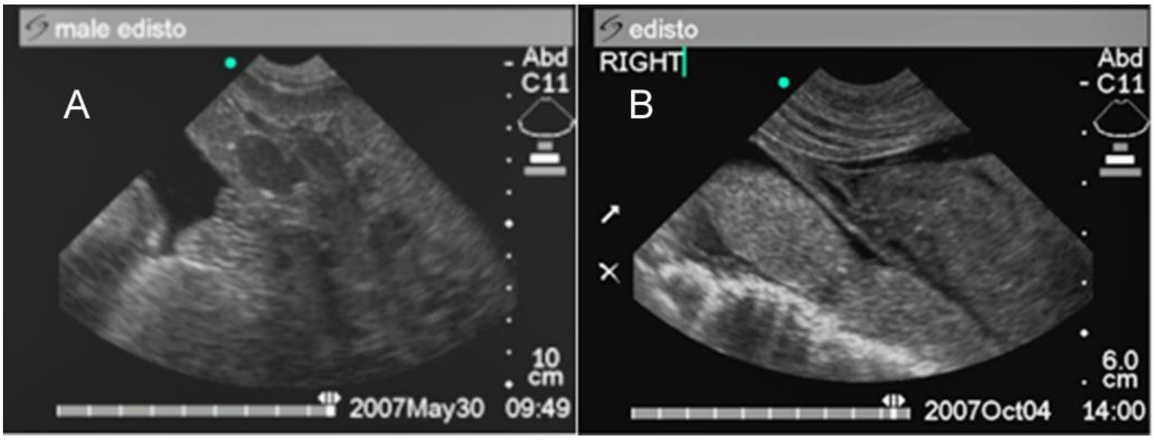

Figure 8. Testis (T) and epididymis (E) images from adult male loggerhead in May 2007 (a), and prior to release in October 2007 (b). Note different scales and thus smaller testis and no obvious epididymis in October image.

Crowell Comuzzie (1987) and Rostal (1991), respectively. Captivity provided several advantages to the investigator over work with wild populations. Long term marking, tracking and recapture of specific individuals allowed detailed studies of individual males and females that would not be practical in the ocean. Crowell Comuzzie and Owens (1990), following the pioneering studies of Booth and Peters (1972), were able to document the duration of courtship and mating, duration of mating receptivity in the females, individual variation in aggressiveness, the timing of the cycle and chronology of the individual's reproductive interests. Interestingly, Crowell Comuzzie and Owens (1990) saw females involved in the aggressive biting and dislodging attempts on mounted males—typically seen in the wild and attributed primarily to males of the "escort group"-- trying to mate with receptive females. Curiously, the females who became involved were only those who had not yet gone through their own receptive period of 3 to 5 days. This observation was later confirmed in wild green sea turtles at Heron Island in Australia (pers. obs.). Crowell Comuzzie and Owens (1990) speculated that this female behavior was an example of sexual selection in that the aggressive female would be improving her own chances of finding a fertile mate at a later date by her pre-ovulatory aggressive behavior.

Low hatching success, as discussed above, has been characteristic of captive breeding programs for sea turtles (Wood and Wood, 1980; 1984). Initially, this was thought to be due to behavioral limitations with too few males in the captive setting, however in the Ph.D. thesis by Craven (2001) conducted at CTF, she found that the clutches actually had high fertility but had suffered from high early embryonic mortality. She also noted a high degree of multiple paternity with as many as seven fathers per female. In a series of nutritional studies that she conducted at the CTF, she found that there were important differences in the free fatty acid composition between captive generated and wild eggs from green turtles in Florida. She hypothesized that this nutritional difference might explain the high early embryonic mortality often seen in captive produced clutches (Craven et al., 2008). As it turns out, similar observations have been made in captive alligators and ostriches where egg development had also been impacted by free fatty acid ratios (Noble et al. 1993; 1996).

4. Reproductive endocrinology

Blood sampling from the dorsal cervical sinus of sea turtles was first developed at CTF in the late 1960s (G. Ulrich, pers. comm.). Owens and Ruiz (1980) described this very useful technique in addition to a method for taking cerebral spinal fluid from sea turtles that was also developed at the CTF (see Fig. 3).

Owens (1976) and others (Licht et al., 1979; Lance et al., 1979) studied the reproductive physiology of green sea turtles at the CTF. By observing and re-sampling nesting individuals over several months and years they were able to construct a useful chronology of the reproductive pattern of the green sea turtle (see Figure 9 for general model). For reviews of these studies see Owens and Morris (1985) and Owens (1997).

Rostal (1991; 1998) also did extensive studies of captive Kemp's ridleys at the CTF. These data on the captive reproductive biology of the species are compared with similar experiments done in the wild (Rostal, 2005). A thorough review of the reproductive biology of the genus Lepidochelys, the ridleys, including discussions of the captive studies of L. kempii, is presented by Rostal (2007).

5. Sex determination

Researchers collaborating with the CTF between 1973-1976 first noted surprisingly skewed sex ratios in the green sea turtles the farm had obtained from various nesting beaches in the Atlantic (Owens and Hendrickson, 1978). Some clutches would be more than 90% one sex while other clutches from similar origins might produce skewed sex rations in the opposite direction. Based on these captive observations the authors suggested that the green sea turtle might have temperature driven sex determination as had been shown for other turtles (Pieau, 1972). Even cohorts from the same nesting beaches but different years showed wide ranges in their sex ratios. This observation led other workers to undertake the critical studies both in the lab and in the wild, which proved that sea turtles exhibit temperature dependent sex determination (Yntema and Mrosovsky, 1980; Mrosovsky, 1980).

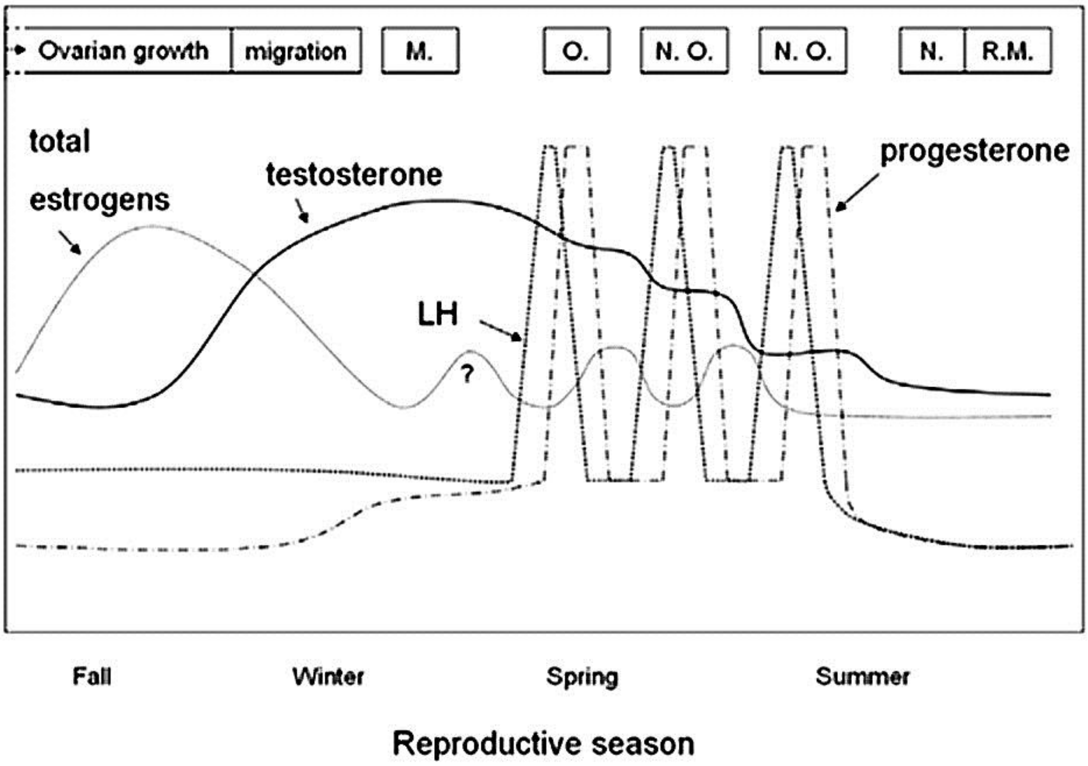

Figure 9. General model for endocrine fluctuations in adult female sea turtles, in relation to their reproductive behavior. In this example, the female would ovulate and nest three times. M = mating, O = ovulation, N = nesting, RM = return migration. Model adapted from Owens (1997), with permission.

Conclusions and Discussion

The green, loggerhead, hawksbill and Kemp's ridley sea turtles have all been bred in captivity at multiple locations. We believe that this is a good result in that learning this practical technology has provided sea turtle conservationists and resource managers a functional "back up plan" should anything disastrous happen to the existing wild populations (Owens, 1981). In 1985, when the most endangered of the sea turtles, the Kemp's ridley, was down to approximately 350 nesting females and probably far fewer males, all reproducing at one site in a remote area of Mexico, the fact that we had been able to breed them in captivity was an important milestone providing a modicum of assurance the species would not disappear despite reservations about population genetics (Magnuson et al., 1990). Most conservationists now recognize that breeding sea turtles and almost any wildlife in captivity is a lower priority than seeing the populations maintaining healthy numbers in their natural habitats. Thus natural habitat conservation is the primary goal of most modern conservation programs. During the 1980s it was realized that one of the most serious conservation threats to sea turtle survival was benthic trawling, a worldwide fishing practice (Magnuson et al., 1990). At that time, fishermen were routinely suggesting that the way to solve the sea turtle conservation problem was to breed them in captivity and just replace all the dead turtles that were being killed in the fishery. Clearly, this short sighted strategy was vehemently rejected by the conservation community (Woody, 1990), but, unfortunately, it also gave a very negative association to any sea turtle captive breeding experimentation. Captive reintroduction programs (often called head-starting) have actually proven somewhat successful (Shaver and Wibbels, 2007; Bell et al., 2005), although they are still discouraged due to concerns of misuse and high cost (Ross, 1999). In addition, while not documented to our knowledge for any sea turtle species, the risk of propagating infectious diseases from sick, otherwise healthy appearing turtles released in the wild can not be ignored (Jacobson, 1993; 1996).

On the positive side, keeping sea turtles in captivity and even captive breeding programs have provided many useful although indirect ecosystem services. The relative ease of keeping sea turtles in captivity (with the exception of the leatherback, *Dermochelys coriacea*) has meant that there has been a tremendous proliferation of captive sea turtles at almost every large marine aquarium in the world. Sea turtles are virtually a required display animal at most aquaria. The education value of seeing and appreciating how these animals move and live in an aquatic world, both for students and for laymen who need to understand ecosystem conflicts in a human dominated world, are profound. For example, when the first author moved to Texas in 1978, almost no Texan even knew there were sea turtles normally off the Texas coast. In just 20 years, with sea turtles displayed at all three major and several smaller aquaria in the state, nearly every citizen not only knew about “their sea turtles” but had also shown overwhelming support for conservation measures such as Turtle Excluder Device (TEDs) use in trawl nets. In addition, the broader, citizen driven respect for coastal marine habitats was an important new ethic that was emerging. Sea turtles were only a part of this emerging conservation culture, but we maintain their use and display in captivity was a very important positive contributor (Owens and Evans, 1999).

Additional positives and ecosystem services attributable to the captive breeding and captive maintenance of sea turtles is the importance of many pioneering research approaches and insights that were developed (Owens, 1980; Fosdick and Fosdick, 1994; Owens, 1995; Ross, 1999). Specifically, as discussed above with reference to reproduction, important scientific contributions were made regarding body fluid sampling, temperature based sex determination, hormonal control of behavior, endocrine cycling, mating chronologies, egg incubation techniques, laparoscopy/endoscopy, ultrasound techniques, breeding requirements and nutrition. In addition, many captive culture techniques which have become valuable include important veterinary care procedures, disease diagnoses, essential nutritional requirements for all ages of turtles and many more esoteric “basic” research findings.

Finally, another positive outcome from the captive breeding of sea turtles has been that marine aquarium leaders, particularly at the Grand Cayman facilities have not only supported conservation and research but have also encouraged the publication of the data and insights gained from the use of captive sea turtles (for example this symposium held at the Churaumi Aquarium; Fosdick and Fosdick, 1994; http://turtle.ky/scientific_papers.htm).

Projecting into the future, we do not recommend the proliferation of captive breeding programs, especially where success has already been achieved. However, one consistent observation from captive breeding programs is that captive bred females do not produce clutches of high viability. While fertility could be a problem at times, it has been suggested that this viability problem may be a nutritional imbalance in the female's captive diet where the fatty acid ratios are not the same as from usual wild food sources (Craven et al., 2008). A careful study of this hypothesis could provide an important new understanding of sea turtle diets as well as improve the nutrition of turtles being held in captivity.

Leatherback sea turtles are particularly difficult to keep in captivity since they are not well adapted for enclosed systems and hard surfaces. Their softer skin is often abraded by tank walls which soon lead to sores and infections. By careful study, a few labs have been able to raise leatherbacks in captivity for up to a few years (see review in Jones et al., 2000) however no one has been able to raise a leatherback to sexual maturity. Considering the many new very large aquarium facilities now in operation around the world it might be an excellent time to attempt keeping adults in captivity and even rearing them from eggs to adults with the purpose of a research project to study their poorly know reproductive behavior.

The hawksbill sea turtle is distributed in tropical and sub-tropical seas around the world, usually associated with coral and sponge rich reefs. While it is found in high densities on certain reefs such as in Yucatan, Mexico (Meylan, 1999), their populations are greatly diminished in other reef areas such as the Ryukyu Islands in southern Japan. In this area, the Churaumi Aquarium on the island of Okinawa, Japan, has gathered a few clutches of hawksbills from rare local nestings and is raising them at the aquarium. If proper diet, genetic and health issues can be addressed, these animals could become the nucleus of a captive breeding program that may be used to help replenish the depleted hawksbill turtles of this part of the world. Since another lab nearby has already had good success with breeding of wild adults maintained in captivity (Shimizu et al., 2007) this proposal seems practical. Many controversies surround the use and conservation of this beautiful species (Mrosovsky, 2000), however it is believed that a localized breeding program for this species could be of great conservation, research and education value in this specialized case.

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Table 1. Key sites of green sea turtle captive culture Location

	Time period	Source
Cayman Turtle Farm, Grand Cayman Island, U.K.	1969-present	Hendrickson, 1974
Union Creek, Great Inagua, Bahamas	Historical and 1960s	Carr, 1967 (pp. 234-237, Fig 45)
Torres Straight, Australia	1970-1980	Carr and Main, 1973
Corail Farm, Reunion Island	1972-1995	Lebrun, 1975

Table 2. Sea turtle species known to have been bred in captivity

Species	Approach	Purpose	Location
Green	Active	Commercial/Conservation & Research Conservation	Cayman Islands, UK; Miami Seaquarium, FL, USA Sea Life Park, Hawaii, USA
Kemp's ridley	Active	Conservation	Cayman Islands, UK; Miami Seaquarium, FL, USA Xcaret, Mexico Clearwater, FL, USA
Loggerhead	Passive	Conservation	Miami Seaquarium, FL, USA Nagoya, Japan
Hawksbill	Attempted Passive Active	Conservation Conservation Conservation/Research	Darwin, Australia Xcaret, Mexico Ishigaki, Japan