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Turtles and Tires: The Impact of Roadkills on Northern Diamondback Terrapin, *Malaclemys terrapin terrapin*, Populations on the Cape May Peninsula, Southern New Jersey, USA

ROGER CONANT WOOD[1,2] AND ROSALIND HERLANDS[1]

[1]*Faculty of Science and Mathematics, Richard Stockton College of New Jersey, Pomona, NJ 08240, USA*
[2]*The Wetlands Institute, 1075 Stone Harbor Boulevard, Stone Harbor, NJ 08247, USA*

ABSTRACT: A century ago overhunting of the northern diamondback terrapin, *Malaclemys terrapin terrapin*, nearly extirpated populations in many parts of its range. More recently, coastal development has led to considerable habitat destruction, especially of traditional nesting sites on barrier beach islands. Along the Atlantic coast of New Jersey, the search for alternative nesting sites on highway embankments has resulted in large numbers of roadkills every nesting season.

We have documented the annual mortality of nesting diamondback terrapins on the Cape May Peninsula of southern New Jersey from 1989 through 1995. A total of 4,020 roadkills were recorded on roads crossing or adjacent to our study area. Potentially viable eggs were recovered from carcasses and 32% were successfully incubated. Since 1991 hatchlings have been headstarted for ten months and 782 (an 81% hatchling survivorship) have been released into the salt marshes of the parents' origin. Roadkill mortality of adult females remains considerably higher than their rate of replacement, and we have noted a substantial decrease in numbers of mature female terrapins in our study area.

Diamondback terrapins, *Malaclemys terrapin*, include several subspecies within a unique genus and species of emydid turtles. The terrapin is the only one of more than 270 extant species of turtles whose habitat is confined to coastal brackish (as opposed to fresh or truly oceanic) waters. The species' range is several thousand miles long but never more than a few miles wide, extending from the north-temperate zone into the subtropics, from Cape Cod, Massachusetts, through the Florida peninsula and Keys, to the Gulf Coast of the United States. The western terminus of its range has not been precisely determined, but probably lies near Corpus Christi, Texas. *Malaclemys terrapin terrapin* (the focus of this report) is the northernmost of the seven described subspecies. It ranges from Cape Cod, Massachusetts, to Cape Hatteras, North Carolina.

Because their geographic distribution coincides with densely settled coastal areas, terrapins have long been exploited by humans. In the late 1800s and early 1900s diamondback terrapins were considered a gourmet delicacy and a valuable commodity, and by 1920 they sold for as much as $90 per dozen (Carr, 1952). As a result of this extraordinary bounty, terrapins were so heavily hunted that the mid-Atlantic population from Long Island Sound to Virginia was nearly wiped out.

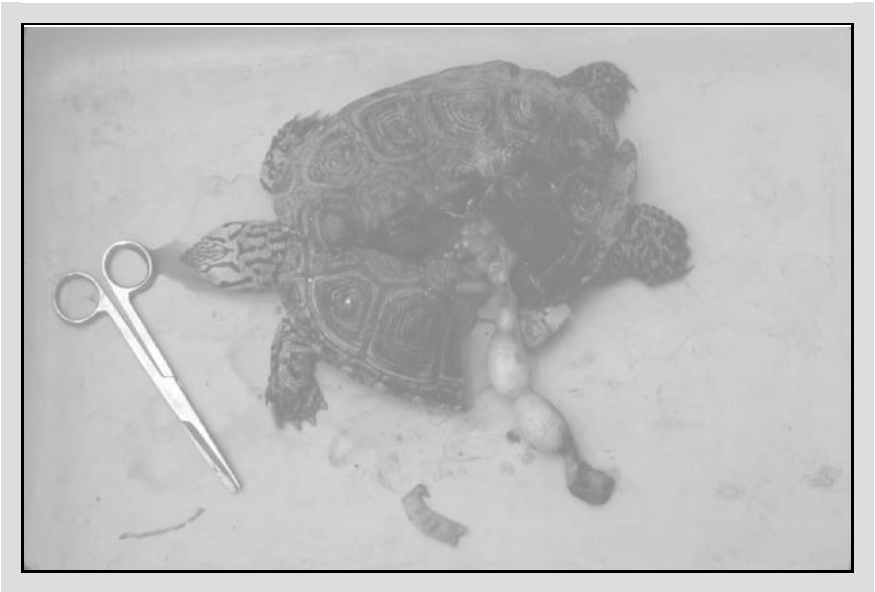

Figure 1. Roadkill of diamondback terrapin with eggs in oviduct exposed.

Eventually, the combined effects of Prohibition (sherry was an essential ingredient of terrapin stew recipes) and the economic stresses of the Great Depression in the 1930s signaled the end of significant commercial demand for terrapins

(Conant, 1955, 1964). But not until nearly a half- century later (approximately the late 1960s) did terrapin populations recover to a level approaching their former "pre-gourmet" abundance. Unfortunately, terrapins are again becoming popular as a food item in urban areas (Garber, 1988, 1990). If the current gastronomic interest in terrapins persists, populations of these beleaguered turtles may once more be severely depleted.

The unsustainable exploitation of terrapins at the turn of this century raised such concern for their well-being that protective legislation was enacted by most of the states where terrapins are found (Donnelly and Owens, 1988). These regulations vary widely from state to state, and while penalties for violating these laws may be imposing, they appear to be largely unenforceable and do not address issues of habitat degradation. At the federal level, several subspecies of terrapins (including the northern diamondback terrapin) were, until recently, listed as a "Category-2 candidates," i.e., ones that are being considered for addition to the national list of "Endangered" and "Threatened" Wildlife and Plants (Lovich, 1995), but this category was recently eliminated by the U.S. Fish and Wildlife Service (USFWS, 1996). Consequently, neither the species as a whole nor any of its component subspecies is currently afforded any special federal protection.

While terrapin populations struggled to recover through the middle decades of this century, a considerable portion of their habitat was degraded or destroyed by industrial activities and real estate development, especially in urbanized areas along the mid-Atlantic coast. Diamondback terrapins' preferred nesting sites (sand dunes) were largely obliterated when the coastal barrier beach islands became densely settled summer resorts. Because shoulders of heavily trafficked roads crossing or adjacent to the salt marshes often provide the only available nesting substrate, large numbers of nesting terrapins are killed each season by motor vehicles. Despite growing awareness of this new source of mortality, no systematic attempt had been made to quantify its impact. In early summer 1989, the Wetlands Institute initiated a long-term terrapin research and conservation project to assess the impact of roadkills and to take steps to mitigate them.

The Study Area

Fieldwork was centered around the Wetlands Institute, a coastal research and environmental education facility located on a salt marsh of the Cape May Peninsula, adjacent to Stone Harbor, New Jersey (Figure 2). This expanse of marsh extends continuously along a NE–SW axis and parallels the Atlantic Ocean coastline from Cape May north to Ocean City, a distance of approximately 35 km. The width of this salt marsh never exceeds 4–5 km. Tidal amplitude within the marsh is about 4.5 feet (1.5 m). Salinity is similar to that of nearby ocean waters (usually 30–32 ppt) as there are few freshwater streams emptying into this marsh and several large inlets connect directly to the ocean.

The salt marsh is bounded on the ocean side by barrier beach island resort communities, which are densely populated during the summer terrapin nesting season. Causeways and bridges across the marsh provide access to the resorts from the mainland and also connect neighboring islands along the coastline.

During the late 1960s much of this marshland was pre-

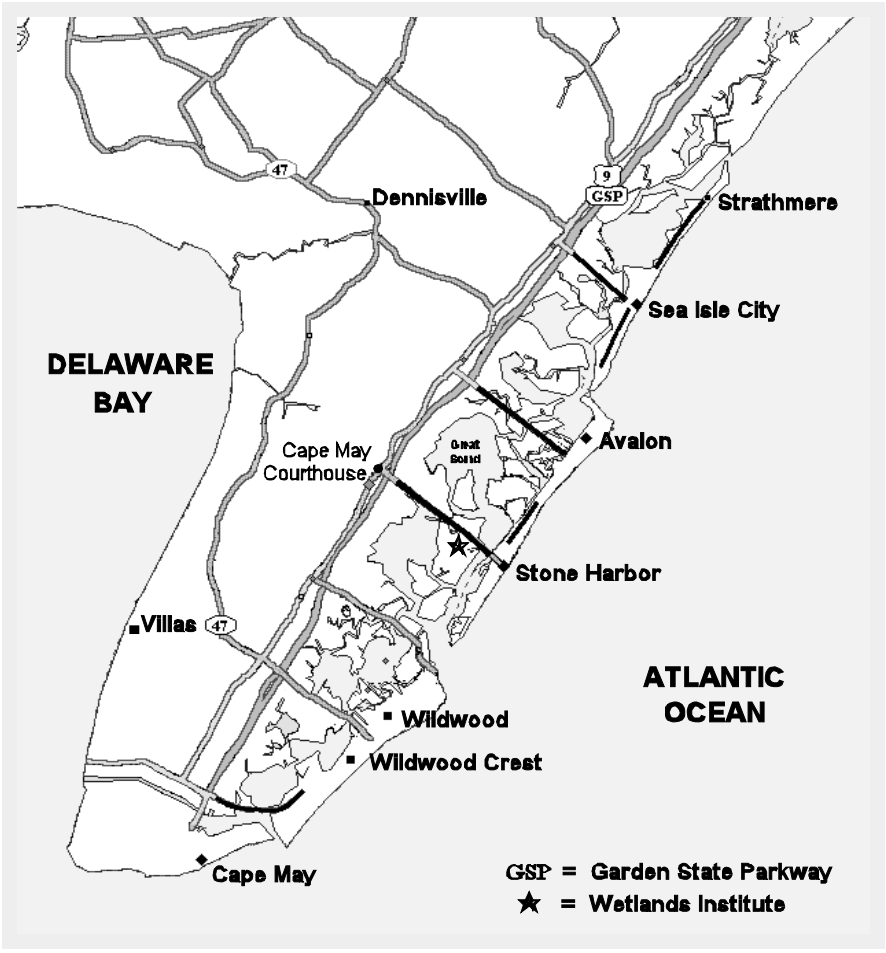

Figure 2. Map of Cape May Peninsula. Stretches marked in black indicate roads patrolled during summers of 1990–1995 (see also Appendix I, p. 53).

served from the drastic alteration that characterized many other parts of the New Jersey coast. The World Wildlife Fund, through the auspices of its then U.S. president, the late Herbert Mills, purchased approximately 6,000 acres (2,400 ha) of privately owned salt marsh extending from the vicinity of Wildwood northward to Sea Isle City. After passage of New Jersey's Coastal Wetlands Protection Act in 1971, the state acquired most of this acreage from the World Wildlife Fund, with the exception of 30 acres (approx. 12 ha) set aside near the center of the area for the Wetlands Institute, which was established at that time.

While this marshland is no longer subject to development, the waterways coursing through it are subject to heavy use, particularly during the warmer months of the year. These activities include commercial and recreational crabbing, clamming, recreational fishing, jet skiing, water skiing, pleasure boating, and swimming. Few tributaries (all only small creeks) drain into this marsh, and the only major industrial installation is a large clam cannery at the southern edge of our study area. There is also a large, ocean-going commercial fishing fleet that docks in the vicinity of the cannery.

While this salt marsh was largely spared from toxic industrial pollutants, the island resort communities' antiquated sewage treatment facilities have been regularly overwhelmed by the mushrooming human populations, especially in the decades following World War II. Consequently, untreated sewage was routinely pumped into the marshes. Regional sewage treatment plants constructed in the mid-1980s have eliminated this problem, and the marsh waters may now be cleaner than at any time since very early in this century.

The establishment of resort communities on the barrier beach islands drastically altered the eastern borders of the salt marsh. The islands' landward side was filled in, the adjacent waterways were extensively dredged, and the construction of bulkheads created a sharp demarcation between land and water. In combination, these alterations eliminated prime terrapin habitat and, more importantly, blocked access for the turtles to the islands' sand dunes, their traditional nesting sites. The dunes themselves were almost entirely eliminated by development activities. Notwithstanding these circum-stances, in some southern New Jersey island communities, terrapins still find access to former dune areas and attempt to nest in residential yards and gardens.

Considerable alteration of the mainland side of the marsh in our study area also occurred in the 1950s as the result of construction of the Garden State Parkway. This high-speed, limited-access highway borders the marsh and frequently crosses branches of it that extend westward towards the higher ground of the Cape May Peninsula. Thus, while much of the marsh proper has been preserved in a relatively pristine state, both its eastern and western edges have undergone considerable alteration, which has substantially restricted terrapin access to natural nesting sites. Terrapins are therefore left with little alternative than to nest on the shoulders of the roads crossing and adjacent to the marshes.

METHODS

Road Patrols

In June 1989, the Wetlands Institute conducted a pilot project to assess the extent of terrapin mortality from motor vehicle traffic during the nesting season. Two heavily used roads that cross salt marshes in the vicinity of the Wetlands Institute (totaling approx. 7 mi or 11.5 km in length) were regularly patrolled day and night throughout the entire nesting season (early June to mid-July) to tabulate both numbers and locations of terrapin roadkills. Because terrapins are known to nest both by day and night, nocturnal patrols were also necessary (Figure 3).

Since 1989 we have also retrieved outwardly undamaged eggs from fresh terrapin carcasses, and subsequent incubation of the eggs has produced a significant number of hatchlings (Table 1). Each dead terrapin found during a patrol is removed from the road to prevent overcounting. Data such

TABLE 1

Data summary from the Wetlands Institute's diamondback terrapin conservation project (1989–1995). NR = not recorded.

Year	No. roadkills	No. eggs salvaged	Resultant hatchlings	% hatching success	No. juveniles released	% surviving headstarting
1989	273	180	77	43	NR	NR
1990	1,077	933	85	9	NR	NR
1991	712	746	286	38	80	80
1992	586	734	235	32	230	61
1993	535	448	222	50	143	94
1994	419	399	157	39	210	76
1995	418	250	113	45	119	78
Totals	4,020	3,690	1,175	32	782	81

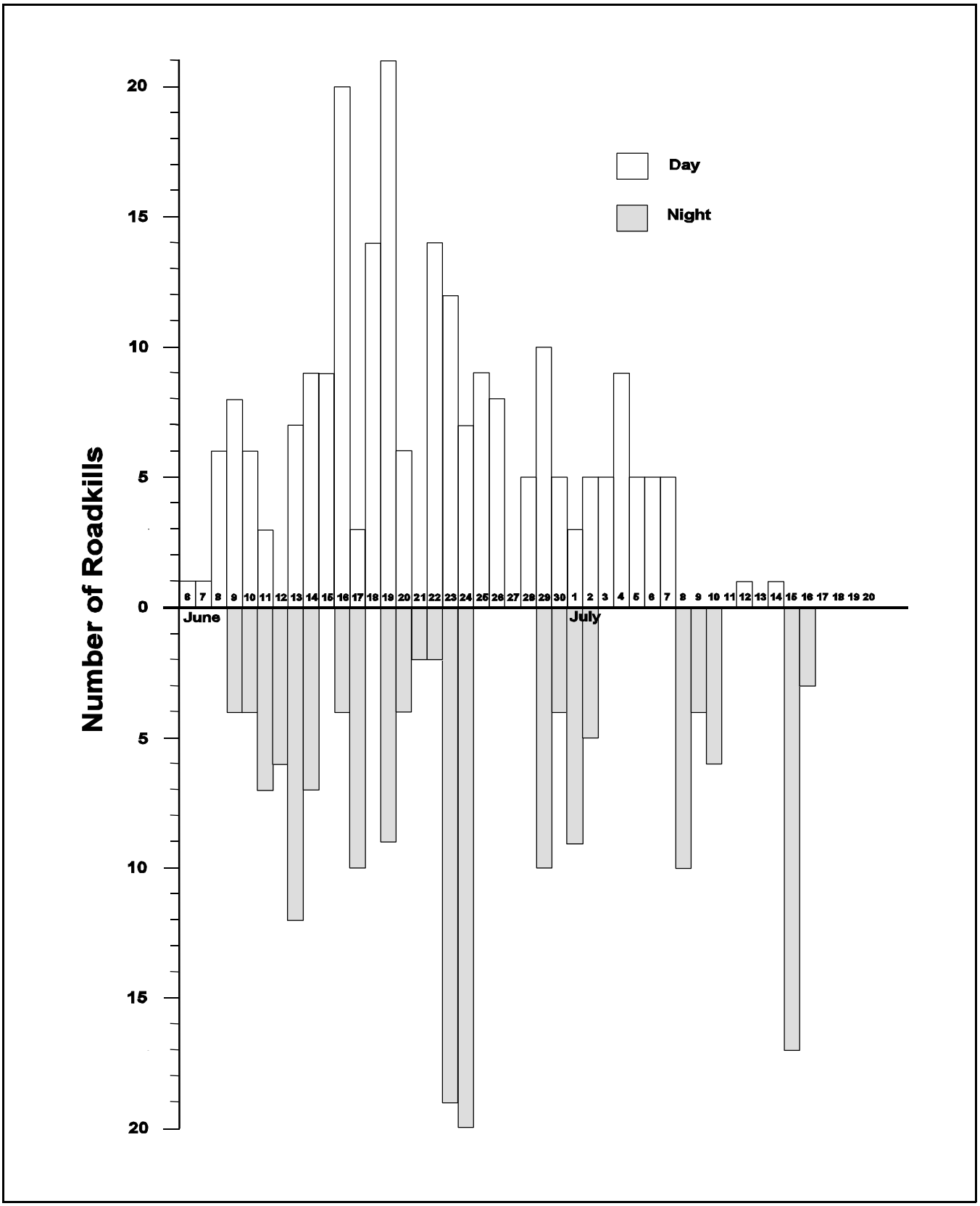

Figure 3. Diamondback terrapin roadkills during day and night hours in June and July 1994. Each shaded bar represents the period from sunset to dawn of the next day (e.g., the four nocturnal roadkills recorded under 9 June occurred between nightfall on 9 June and dawn on 10 June).

as date, time, weather conditions, tide, location, and number of potentially viable eggs retrieved are recorded on standardized forms.

Encouraged by our successful efforts to quantify terrapin roadkills as well as to recover and hatch eggs during our 1989 pilot study, we expanded the project in 1990. Since the 1990 nesting season, at least a half-dozen student interns and community volunteers have annually participated in the monitoring of terrapin roadkills. The survey was considerably enlarged in 1990 with the addition of approximately 10.5 mi (16 km) of roads and has remained essentially unchanged since that time.

Retrieval and Incubation of Eggs

Because adult females were being selectively killed on roads during the nesting season, we wanted to return a high proportion of female hatchlings to the salt marshes. In many turtle species sex determination is temperature dependent (Bull et al., 1982). Typically, only females are produced at higher incubation temperatures while eggs developing at lower temperatures generally yield only males. We have confirmed experimentally that this is the case for diamondback terrapins. Eggs retrieved during the 1989 nesting season were therefore incubated at relatively high temperatures (approx. 30–31°C).

Eggs retrieved from roadkills are placed on a bed of coarse, slightly moistened vermiculite inside plastic containers that each hold approximately 25 eggs. The containers are covered to retain moisture, and condensation generated inside the containers makes it necessary to remove the covers periodically to check the con-dition of the eggs. Freshly laid eggs are a pale, pinkish color. Viable eggs will turn chalky white within approximately one week; eggs that retain their original color are inviable.

In 1989 and 1990 our makeshift incubators were placed in the attic of a garage, which was chosen to provide an appropriate high temperature environment. Unfortunately, a prolonged heat wave in summer 1990 overheated most of the eggs, which resulted in a very low percentage of hatchlings. In subsequent years, all retrieved eggs have been incubated under temperature-controlled laboratory conditions, resulting in markedly higher hatching success (Table 1).

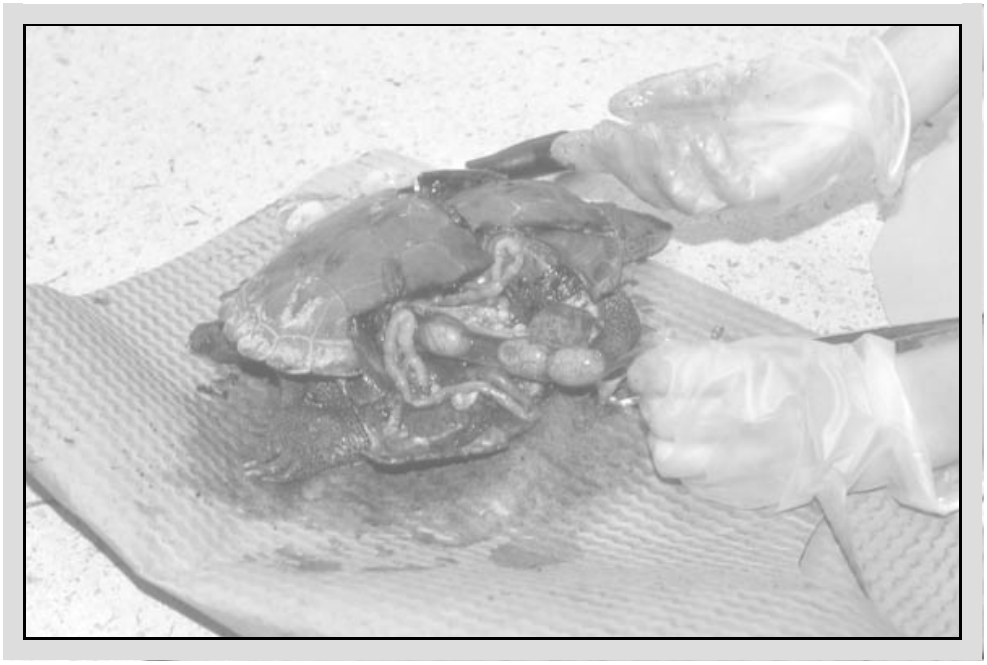

Figure 4. Potentially viable eggs are retrieved from a roadkill carcass.

Headstarting

Freshly hatched terrapins, with soft, largely unossified shells approximately 25 mm (1 in) in length, are preyed upon by a variety of birds, mammals, fish, and crabs. The natural survival rate of hatchlings is undoubtedly very low. Once a terrapin has grown to a shell length of 75–100 mm (3–4 in), or approximately half adult female size, its shell has fully ossified and provides effective protection against most predators.

To maximize the chances of survival for our roadkill hatchlings, we undertook a headstart program modeled on procedures originally developed for marine turtle hatchlings. In 1991 we constructed a rearing facility at Stockton College, equipped with saltwater tanks and heat lamps that maintain room temperature at or near 27°C (80°F). The warm temperature inhibits normal winter hibernation, and hatchlings are fed constantly to promote rapid growth. After ten months of this husbandry, the hatchlings reach approximately half their expected adult size and are ready for release. This facility can comfortably house 200 hatchlings. Some of our hatchlings have been headstarted at the Cape May County Zoo Reptile House, thus dividing the work load and reducing the risk of accidental loss or disease.

In view of the possibility that hatchling terrapins imprint on their release point and subsequently return as adults to nest at the same site, the head-started juvenile terrapins have been released at nine different localities throughout our study area. This may prevent an unnatural future clustering of nesting adults at a single former release point.

RESULTS

Roadkill Mortality

Data for the first seven years (1989–1995) of this project are summarized in Table 1. Over this period of time 4,020 roadkills have been recorded within our study area. From these dead terrapins, 3,690 eggs have been salvaged and incubated, nearly a third of which (1,175) produced hatchlings, resulting in a cumulative overall hatching success of 32%. With improved incubation techniques, hatching success now approaches 39%.

Only two roads were patrolled in 1989, while six roads of our study area were patrolled in subsequent years. Thus, only the annual data since 1990 are directly comparable.

The total number of roadkills recorded for 1991 (712) is less than expected for two reasons: (1) one of the routinely patrolled roads in our study area was repaved during the nesting season and was blocked to traffic, and (2) the 1991 nesting season started unusually early (in late May rather than early June) before road patrols had been organized, and the first big surge of nesting activity (and therefore terrapin roadkills) was missed.

Figure 5. Hatchling terrapins produced by eggs retrieved from roadkills.

Figure 3 shows the pattern of terrapin roadkills (which also reflects relative levels of nesting activity) in our study area during summer 1994. The pattern depicted is typical of every nesting season we have so far monitored. Nesting started in early June and continued almost without interruption for 41 days through mid-July.

After nightfall terrapins on a road are almost impossible to detect and cannot be avoided, even by conscientious motorists. Thus, despite the fact that the hours of darkness during the nesting season are from roughly 9:30 P.M. to 5:00 A.M., or only about one-third of a 24-hour day, nearly half (43%) of all roadkills (180 of 419) occurred at night in 1994.

As indicated in Figure 3, the number of roadkills varied greatly throughout the nesting season. Daily fluctuations in mortality are not correlated with increased weekend traffic, variations in weather conditions, tidal cycles, or any other perceivable factor. Peak numbers of roadkills were recorded on 16 June (24), 19 June (30), 23 June (31), and 24 June (27). Occasionally, other days in the midst of the nesting season featured little or no nesting activity and hence few, if any, roadkills (only 2, for example, on 21 June and none on 27 June). After 10 July nesting activity was desultory except for a major spike on 15 July, which we suspect may represent terrapins emerging to lay their second clutches of the nesting season.

There is more nesting activity in the earlier part of the nesting season than in its latter part. In 1994, for example, there were 264 roadkills (156 during the day, 108 at night) over the course of the first 20 days, while during the remaining 21 days of the nesting season there were 136 roadkills almost evenly distributed between daylight (67) and darkness (69). Thus, almost twice as many terrapins were killed by motor vehicles in the first half of the 1994 nesting season compared to the last half.

Eggs and Hatchlings

As many as 14 potentially viable eggs have been recovered from a single roadkill, but such is exceptional, the usual number of salvageable eggs being from one to five. Undisturbed nesting terrapins in our study area typically lay 8–12 eggs per clutch.

Temperature-dependent sex determination (TSD) in terrapins was experimentally verified. Eggs maintained at relatively high temperatures (30–31°C) hatch in the least time (usually 6–8 weeks) and produce only females. These hatchlings have a relatively high proportion of scute anomalies (particularly on the carapace), which is consistent with our observations of female scute abnormalities in natural populations. Eggs incubated at lower temperatures (25–28°C) take 2–3 weeks longer to hatch and usually produce males. At even lower temperatures (<25°C),

a mixture of males and females results, with males more numerous. These latter eggs may incubate for as long as 12–15 weeks before hatching. Eggs never hatch below 23°C, although embryos may develop to an advanced stage.

Post-natal mortality among hatchlings from the retrieved eggs varies unpredictably from year to year. From 6 to 39% of the hatchlings die while being headstarted (Table 1) for unknown reasons. Most of these deaths occur relatively soon after hatching.

After seven seasons of rescue efforts, as of June 1995 we have repatriated 782 headstarted juvenile terrapins (Table 1).

DISCUSSION

Over a period of four years, we maintained reasonably accurate records of the total number of miles driven each year on road patrols. From 1990 through 1992, the total annual road patrol mileage increased substantially from approximately 9,000 to more than 12,000 mi. During this same period of time, the number of terrapin roadkills fell to almost half (from 1,077 to 586).

We suspected that some of this decreased mortality was attributable to the removal of a higher proportion of terrapins from harm's way as a result of more frequent road patrols. If this were the case, the number of roadkills during the 1993 nesting season should have noticeably increased, when road patrol mileage decreased by approximately 25%. However, roadkills continued to decline in 1993 (by approx. 10%). An even greater decrease in roadkills between the 1993 and 1994 nesting seasons were recorded (from 535 to 419, a drop of approx. 22%).

Thus, increased vigilance in the form of more frequent road patrols during a given nesting season does not account for the steadily decreasing numbers of roadkills over the course of the last six years of our study. During this period of time, roadkill mortality has dropped from 1,077 to 418, a nearly 62% reduction. Superficially, this appears encouraging, suggesting that our conservation efforts are increasingly successful at saving nesting terrapins. However, roadkills account for only a fraction of the overall annual terrapin mortality in our study area (see Wood, this volume, on the drowning of terrapins in commercial crab traps). We fear that our local terrapin population is, in fact, undergoing a severe collapse not unlike the dramatic decline in terrapin populations associated with the terrapin stew fad of the late 1800s. We intend to continue monitoring terrapin nesting activities in coming years to determine whether roadkill numbers continue to decrease.

We have established the feasibility of large-scale incubation of eggs retrieved from roadkills. We can now hatch 40–50% of the eggs removed from fresh terrapin carcasses. Because newly hatched terrapins are easy targets for a host of predators, we have also developed a headstart program that promotes the rapid growth of hatchlings in captivity for the first nine to ten months. By the time we release our headstarted juvenile terrapins (in June following their late summer or early fall hatching of the preceding year), they have attained a size sufficient to substantially increase their probability of reaching adulthood.

Our experiments with incubation of eggs retrieved from roadkills show that diamondback terrapins, like most other turtle species so far investigated, are characterized by temperature-dependent sex determination. Our observations have shown that hatching size is not correlated with incubation temperature (Herlands and Wood, in prep.). Hatchling size is, however, (and not surprisingly) correlated with egg size. Our data confirm a similar study of a terrapin population in the Chesapeake Bay (Jeyasuria et al., 1994).

Our results clearly show that our terrapin conservation efforts, however well-intentioned and well-publicized, are the equivalent of waging a losing battle. We simply lack the capacity to replace adult road-killed terrapins with headstarted juveniles as fast as the adults are killed by vehicles. After seven years of extremely labor-intensive efforts, we will have released nearly 800 head-started terrapins. Unfortunately, during these same seven years, 4,020 adult female roadkills have been documented. Thus, even in the unlikely event that every head-started juvenile we released actually survived to reproductive age, we would at best be replacing one adult for every five killed by motor traffic. Under current circumstances, therefore, we can neither reverse nor even stabilize the precipitous population decline now taking place. At best, we are merely slowing the rate of the local terrapin population crash.

Finally, we are continuing to strongly publicize the current plight of terrapins. While it is unknown whether these activities have actually benefited the terrapins in our study area by reducing roadkill mortality during the nesting season, public awareness and concern has substantially increased since we started our project seven years ago. We have created both temporary and permanent public exhibits about terrapins for the New Jersey State Aquarium, Sesame Place Amusement Park in Langhorne, Pennsylvania, and the Diller Coastal Education Building at the Wetlands Institute. We also routinely set up short-term terrapin displays for public events, such as the annual New Jersey Wings 'n Water Festival, the Avalon Seafood Festival, and Sea Isle City's annual Terrapin Day. Our conservation efforts have been featured in the Emmy Award-winning TV documentary *Terrapin*, produced by New Jersey Network (a PBS affiliate), and terrapins were also featured in the award-winning film *Secrets of the Salt Marsh*, produced by the Wetlands Institute. Numerous newspaper and magazine articles (some with national distribution) have been published, and stories about our terrapin project have also been carried on local, regional, and national TV.

The public has also participated in our conservation efforts. School and scouting groups (most notably the Avalon/Stone Harbor kindergarten) have raised money in a variety of creative ways to help support the costs of our program, and hundreds of people have taken part in the Wetlands Institute "Adopt An Egg" program, which has provided funding for some of the expenses associated with our project.

ACKNOWLEDGMENTS

The data presented in this report, accumulated over seven years (1989–1995), were made possible only by the dedicated efforts of large numbers of volunteers. Especially deserving of recognition are the nearly 30 college and university students, two high school students, and one high school teacher, who have served as summer-long participants in the diamondback terrapin research and conservation project since its inception at the Wetlands Institute. Others who have contributed significantly to the success of the project include Lisa Roselli, Joe Grottola, Tom McFarland, Townsend Dickinson, and last but by no means least, Gary and Nat Wood. To all of these associates we are enormously indebted.

Meriting special thanks are John Rokita and his several student assistants who, over the years, have nurtured our terrapin hatchlings with outstanding success at the Stockton College science laboratory complex. We are also most grateful to the staff of the Reptile House at the Cape May County Zoo for providing care for some of our terrapin hatchlings.

Financial support has come from a wide and, in some cases, improbable variety of donors. Sustained and substantial sources of long-term support have been the Wetlands Institute and Stockton State College. Much-appreciated contributions have also been provided by the teachers and children of the Avalon/Stone Harbor combined kindergarten as well as the fourth and fifth grade Science Club of the Port Republic Elementary School, the Cape May County Zoological Society, the Lehigh Valley Herpetological Society, Sturdy Savings Bank, and the hundreds of visitors and contributors to the Wetlands Institute whose $10 donations for the "adopted" or "orphaned" terrapin eggs have supported our headstarting operations.

Considerable thanks are also due to New Jersey Network, and especially to producer Leandra Little, for the production and broadcasting of the television documentary *Terrapin*. This has been a wonderful and continuing source of information about our project for the general public.

We wish to express our appreciation to the New Jersey Division of Fish, Game, and Wildlife for issuing us annual scientific research permits.

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Appendix I. Stretches of roads patrolled in Cape May County, New Jersey during summers of 1990–1995.

- Ocean Drive between 29th Street in Sea Isle City and Strathmore, and Ocean Drive between 74th and 53rd streets in Avalon (Cape May County Highway 619).
- Central Avenue between 82nd and 49th streets on the bay side of Sea Isle City.
- Sea Isle Boulevard (Cape May County Highway 625).
- Avalon Boulevard (Cape May County Highway 601).
- Stone Harbor Boulevard (Cape May County Highway 657).
- East Railroad Avenue in Wildwood Crest.
- Ocean Drive (Cape May County Highway 621) between Cold Spring Harbor and Wildwood Crest.