RISK ASSESSMENT, LIFE HISTORY STRATEGIES, AND TURTLES: COULD DECLINES BE PREVENTED OR PREDICTED?

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The process of ecological risk assessment should involve the ability to predict adverse outcomes of particular environmental contaminants or human intrusions. Ecological risk assessment generally focuses on populations, communities, and ecosystems, rather than on individual health. We explore the importance of life history strategies of aquatic turtles to their risk from environmental contaminants and other human activities using three examples: the wood turtle Clemmys insculpta, a freshwater species; the diamondback terrapin Malaclemys terrapin, a litoral species; and marine turtles as a group. These turtles are partly herbivorous and are at low or intermediate levels on the food chain, yet are particularly vulnerable due to their life history strategies of being long-lived with relatively low survival of young. They suffer a variety of natural mortality factors that include predation, starvation, and disease, as well as inundation and destruction of nesting beaches and their eggs by storms. Yet they also face a number of anthropogenic hazards, including toxic chemicals and flotables (plastics); capture for food, other products, and pets; incidental mortality in fishing gear; disturbance while nesting or moving on land; injuries or death by collision with boats; and increased predator exposure because of humans. The three turtle species or groups of species examined have experienced these natural and anthropogenic pressures differentially, with resultant differences in the rates of population declines. Because they are lower on the food chain than other obligate carnivores, they are less vulnerable to toxics, and to date, toxics seem to have a relatively inconsequential environmental risk to turtles.

In the last decade ecological risk assessment has played an increasingly important role in decisions about potential adverse effects of exposure to chemical, physical, and other anthropogenic hazards in the environment. Ecological risk assessment, developed partly following the formalization of the environmental or human health risk assessment paradigm (NRC, 1983),

Received 7 February 1995; accepted 27 April 1995.

This research was partially funded by NIH grant ES0 3522 to the Environmental and Occupational Health Sciences Institute, Rutgers University, and DOE-funded CRESP. The authors thank M. Cochfield, K. Cooper, D. Warnberg, W. Gibbons, and two anonymous reviewers for valuable discussions of ecological risk and for comments on the manuscript; A. S. Lighthame, D. Carle, M. Kellett, J. Garner, R. Kelly, M. Setlow, and H. Setlow for advice and logistical support while working with wood turtles; and W. Morinvecchi, M. Cochfield, and C. G. Beer for advice and logistical support while working with diamondback terrapins.

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0098-4108/95 $10.00 + .00

has been slower in its formalization due in large part to its greater complexity and scope (O’Neill et al., 1982; NRC, 1986, 1993; Barnthouse, 1992; Burger, 1994a). Some of the particularly difficult questions have involved the necessity for large-scale considerations, in terms of space and time, and in number of organisms, interactions, and processes (Suter, 1990, 1993; Burger & Cochfield, 1992; NRC, 1993; Cochfield & Burger, 1993).

In general, human health and ecological risk assessment have been used to examine threats from chemical hazards, notably anthropogenic toxic chemicals (NRC, 1983, 1993; Graham et al., 1991; Gribb-Smith, 1992; Landis et al., 1993). Partly this comes from the ecotoxicology phase of ecological assessment (Butler, 1978; Bascietto et al., 1990; Okerlman et al., 1991) and partly it comes from the often severe and relatively immediate consequences of exposure to chemicals (Barnthouse, 1992). For example, pesticides provided one of the first clear examples of environmental hazards when raptoral and fish-eating birds suffered eggshell thinning, egg breakage during incubation, lowered reproductive success, and eventual population declines documented in the late 1960s and early 1970s (Hickey, 1969; Peakall, 1975; Lincer, 1975). Although the detrimental effects of DDT were known for fish and birds prior to the 1950s (Langford, 1949; Carson, 1962), the public outcry did not come until falcons, eagles, and some species of colonial bird populations produced no young for some years, and populations of these birds began to crash.

The tradition of wild vertebrate populations providing an early warning of the hazards of toxic chemicals has continued with the discovery that DDT causes the feminization of male gulls, leading to their inability to breed, skewed sex ratios at breeding colonies, and female–female pairs (Fry & Toone, 1981; Fox, 1992). With this discovery came the research emphasis on endocrine disruptors (Colborn & Clement, 1992).

Recently, however, ecological risk assessors have considered hazards other than toxic chemicals to species, populations, and communities (Graham et al., 1991; Fogarty et al., 1992; NRC, 1993). Understandably, some of the initial ecological risk assessments have involved renewable resources of commercial value, such as fisheries (Fogarty et al., 1992). One of the commonalities of the ecological risk that birds have suffered when exposed to toxic chemicals and that fish have suffered when exposed to overexploitation by fisherman is that the affected species are those that are relatively long-lived and are high on the food chain. They are generally species that have low annual rates of survival to adulthood, and a relatively long prereproductive period. Such species are also vulnerable because they have a long period for bioaccumulation of toxic chemicals (Burger, 1994b).

Another commonality between the population declines of birds caused by DDT and other environmental chemicals and the declines of commercial fish species due to overexploitation is their relative importance to humans who, traditionally, care about large, showy, dramatic birds and about fish that provide a living or a food source. Humans also “care” about the six
species of sea turtles, all of which have declined dramatically in this century. The possible causes of the declines have been examined, and methods to reduce mortality have been introduced (NRC, 1990). Other less prominent species of turtles, however, have also suffered declines, yet the causes of their declines, methods of halting the declines, and overall ecological risks to these populations have not been compared.

In this article we examine three examples of aquatic turtle declines to assess the hazards to which they are exposed, the factors that make them particularly vulnerable to certain hazards, and their dose-response behavior in terms of population levels. We were particularly interested in whether the declines could have been predicted or prevented, and in the use of turtles as models for ecological risk. Examples we use include the wood turtle Clemmys insculpta, a freshwater turtle; the diamondback terrapin Malaclemys terrapin, a littoral species; and a group of seaturtles. Although we could have used a variety of species for these case studies, these three were chosen because they are at least partly aquatic species that live in coastal areas for critical life stages. Wood turtles are not exclusively coastal, but some populations are. Coastal areas are particularly impacted by humans. The risk assessment paradigm normally involves hazard identification, exposure assessment, dose-response analysis, and risk characterization; all are addressed briefly.

WOOD TURTLES

General Breeding Biology

The North American wood turtle (Clemmys insculpta) ranges from Nova Scotia south to Virginia, and west through southern Ontario and New York to Michigan, Wisconsin, eastern Minnesota, and northeastern Iowa (Ernst & Barbour, 1972). It uses a variety of habitats, including rivers and streams, wet meadows, swamps and bogs, upland fields, woods, and farmland. The habitat requirements of wood turtles vary both seasonally and geographically (Harding & Bloomer, 1979). They overwinter in streams. During warm sunny days of late winter and early spring the turtles emerge onto land where they bask. They stay in or near the streams during the spring, and mate in the water. Gravid females usually lay their eggs in dry sandy areas in June. They then travel up to 750 m from the water, to stay during much of the summer. From mid-June through July, the turtles stay on land over 85% of the time, occasionally returning to the streams for short periods. Clutches hatch in late summer and autumn and the hatchlings slowly move to the stream banks, where they stay in a relatively circumscribed area during the first several years of life. In late summer and autumn, adults return to the water where they mate and remain to overwinter (Garber & Burger, 1995).

With increased human densities and development, populations of certain turtle predators, such as skunks and raccoons, have been increasing. A rise in these predator populations has led to increased wood turtle egg and juvenile predation. Wood turtle nesting areas are usually used many years in a row, so when predators learn that turtles nest in one location, they return there each year and become more effective at finding the turtle nests. Hatchlings emerging from nests that escaped predators are found later by raccoons patrolling up and down the banks of streams.

The shells of juveniles are thin, rendering them vulnerable to predation; adults have considerably thicker shells, and therefore have fewer potential predators. However, some predators can bite through thinner parts of the anterior and posterior portions of the shell, and predators can reach toes, portions of the turtle's limbs, and parts of the tail. If too much of the tail is bitten off, the turtle will die. Many maimed turtles survive, but in a diminished reproductive capacity. Three-legged males, as well as males with much of their tail bitten off, usually cannot mate.

Hazards and Exposure

In the late 19th and early 20th century wood turtles were caught and sold in markets. The New York legislature was the first to recognize the species' vulnerability as evidenced by its drastic decline, and in 1905 they protected wood turtles by passing a law that forbade the sale of wood turtles. Some populations slowly recovered over the next several decades; however, by the mid 20th century wood turtles were becoming popular as pets. When Archie Carr (1952) wrote in his Handbook of Turtles that wood turtles were the most intelligent of turtles and that they make a better pet than any other turtle species, he substantially increased wood turtle popularity among generations of reptile fanciers, of which there are many. The Humane Society of the United States estimates that 1,484,000 American households have turtles as pets, with a total of 2,463,440 captive turtles (Humane Society of the United States, 1994). Most turtles come from the wild, and many of these pets die. Thus, most wild stocks have been radically depleted, especially wood turtle populations. In addition, human development of wood turtle habitat has been a major contributor to the decline of these species (Restore: The North Woods, 1994).

Habitat loss and degradation are two important threats to surviving wood turtle populations (Ernst & McBreen, 1991; Garber & Berger, 1995). In addition, fragmentation of habitat due to residential and commercial development contributes to their decline, although some wood turtle populations can survive in rural areas with large woodlots and open fields. However, when roads, driveways, or housing developments are placed near a wood turtle population, the population's decline and eventual extirpation can be predicted. Other factors that radically alter habitat, and thereby contribute to turtle declines, include dredging streams and rivers for flood control, building dams, and human recreation (Garber & Burger, 1995).

Direct removal of juveniles or adults from an area is a major threat to wood turtle populations. Recently Congdon et al. (1993) demonstrated the importance of protecting young and breeding Blanding's turtles (Emydoidea
blandingii) in order to maintain population stability. With a similar life-history strategy, wood turtles are also vulnerable to the removal of adults. In addition, destruction of adults by vehicle traffic is a major threat. Many people find it impossible to leave a wood turtle in the woods; they take it home for a pet, or carry it for a while before deciding to leave it in the woods, often in an area unfamiliar to the turtle. When wilderness is opened to hikers, when the back woods become areas of heavy use by hikers and fishermen, or when a collector finds a population, it is often just a matter of time before the population size declines to such a low point that it is no longer viable. Habitat loss and degradation are a problem for wood turtles throughout their range (Restore: The North Woods et al., 1994).

There are no data on the levels or effects of toxics on wood turtles, and few on other turtles (Stone et al., 1980). However, since they mainly eat invertebrates as well as vegetation and are long-lived in the wild (up 45 years; Garber & Burger, 1995), they might be expected to bioaccumulate toxics. The oldest wood turtle in captivity was 58 yr (Oliver, 1955).

**Dose Response**

A positive relationship exists between increases in human activities and declines in wood turtle populations. In our 20-yr wood turtle study, the size of the forest at our Connecticut study site remained the same, road building was restricted, and the quality of the air and water was constant (Garber & Burger, 1995). The wood turtle populations remained stable when people were denied access to the property. When this area was opened to human recreation (hiking, fishing), the two discrete wood turtle populations declined steadily. The total number of turtles in both populations declined by 100% in 10 yr, going extinct by 1993 (Figure 1). As wilderness areas become mixed-use recreation areas, wood turtle populations will continue to decline and may be extirpated (Garber & Burger, 1995).

**Risk Characterization**

The risk to wood turtles from human activities is severe, and without intervention this species could become extinct, in our judgment. Without identification of wood turtle populations and implementation of protection and proper management procedures, human disturbance and development will eliminate populations on private lands. Further, increasing recreational use of parks, reservoirs, and wildlife reserves will continue to adversely affect the long-term survival of this species, leading to the extinction of many surviving viable populations within decades.

**Prediction and Prevention**

Data showing the radical decline of wood turtles have been available for many years. However, it was not until we analyzed the literature, contacted experts in the field, and visited the sites where populations have lived that we concluded wood turtle declines are severe throughout their range. Their decline could have been predicted two decades ago when it became apparent that these animals could not tolerate human encroachment. Yet it took another 20 yr to conduct the surveys and field studies that confirmed this hypothesis with sufficiently robust data to convince the scientific community (Garber & Burger, 1995).

**FIGURE 1. Relationship of population and mean age of wood turtles to the cumulative number of recreation permits granted to humans and the number of humans living in the two towns adjacent to our study site in Connecticut. After Garber and Burger (1996).**
There are two preventive measures that can save the wood turtle: (1) state protection, and (2) federal protection and listing. The first is to protect the species in each of the states throughout its range. Many states have declared the wood turtle a "species of special concern," a "threatened species," or a species with a take limit. States thus can pass protective laws or can declare wood turtles a game species, which makes them illegal to collect without a license. They can then regulate the period of take or the legal limit. In some states, the incidental take of one or two wood turtles is allowed with a valid fishing license.

States can list the species as threatened or endangered. However, merely listing a species as one of special concern renders no legal protection for the surviving populations. Listing often lacks sufficient protection because it is not always sufficient to provide the funds and proper attention to adequately deal with the turtle’s decline. Thus, these methods only slow the decline, rather than maintain viable populations.

The other option is to petition the U.S. Fish and Wildlife Service's Office of Endangered Species to place the wood turtle on the Endangered Species List, which is what we have done. Restore: The North Woods et al. (1994) have petitioned the Fish and Wildlife Service to designate the wood turtle as threatened or endangered, and to designate critical habitat under the Endangered Species Act, 16 U.S.C. section 1531-1543 (1982).

For the Fish and Wildlife Service to approve our petition and list the wood turtle as endangered, it must be convinced that the wood turtle is in danger of extinction throughout all or a significant portion of its range. For the wood turtle to be listed as threatened, we have to convince the Fish and Wildlife Service that wood turtles are likely to become endangered in the foreseeable future.

A species can be listed for any one or a combination of the following factors: (1) the present or threatened destruction, modification, or curtailment of habitat or range; (2) overutilization for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) the inadequacy of existing regulatory mechanisms; and (5) other natural or manmade factors affecting its continued existence. Our petition documents the need for the designation of critical habitat to provide for the conservation of the wood turtle (Restore: The North Woods et al., 1994).

When a species becomes rare and its decline is apparent, funds may become available to study the animal. Many such studies only contribute to the species decline, while delaying the time when conservation measures are enacted. We feel that taxonomic and demographic studies to determine what variation might exist among wood turtle populations with regard to their allometrics, behavior, and genetics through field studies and/or DNA fingerprinting might not help save this species. Likewise, we feel that life history, ecological, and natural history studies are valuable, but should be conducted sparingly and carefully to avoid detrimental effects on the species.

We feel that this species can be saved from extinction only by laws that protect sites where turtles currently live or used to live from unsoundable levels of human access or recreation. Possible measures to protect and increase wood turtle populations include repatriation (after Reinert, 1991) of turtles to sites where depleted populations exist or where the populations have been entirely extirpated, and the purchase and protection of lands with known healthy wood turtle populations. The latter is extremely important, at least until the drastic declines are stopped. Some of these options require extensive consideration of the advantages and disadvantages before implementation (see Dodd & Seigel, 1991; Reinert, 1991).

DIAMONDBACK TERRAPIN

General Breeding Biology

Diamondback terrapins occur in brackish water habitats from New England to Texas. They have been studied extensively in Florida (Seigel, 1980), South Carolina (Lovich & Gibbons, 1990), Delaware (Hurd et al., 1979), and New Jersey (Burger, 1976a, 1976b, 1977, 1989). Females lay their eggs from early June to late July on beaches and sand dunes above high tide (Burger & Montevoci, 1975), and eggs take 60–90 d to hatch, depending upon temperature (Burger, 1976a). During the rest of the year juveniles and adults live in brackish water creeks and estuaries, except for the winter months when they hibernate in the banks of creeks and bays (Hurd et al., 1979). Some populations have strongly biased sex ratios, with males predominating (Lovich & Gibbons, 1990). Young diamondback terrapins may seek the undersides of dense mats of aquatic vegetation for cover, temperature regulation, and food (Lovich et al., 1991).

In the late 19th and early 20th century populations were drastically reduced due to exploitation for food. Moreover, during this period, turtle farms transported subspecies from one part of their range to that of other subspecies, obliterating natural adaptations to local conditions. But with protection, populations recovered substantially in the 1950s and 1960s (Garber, 1988, 1989).

Overall the species has suffered nesting habitat loss due to human encroachment on preferred nesting beaches (Burger, 1989; Seigel & Gibbons, 1995). Nests and eggs are vulnerable to predators throughout development, and hatchlings are very vulnerable while they journey to the estuaries. Females and young are also vulnerable when they cross highways to reach the sea. Even the erection of turtle crossing signs does not prevent the mass slaughter of diamondback terrapins in June when they cross roads in New Jersey to reach suitable nesting sites. Further, some highways have been constructed with raised curbs that are too high for turtles to climb over, and they are trapped on highways (Burger, 1989).

Hazards and Exposure

In the bays and estuaries diamondback terrapins are vulnerable to injury or death from boat motors. While hibernating in the banks of tidal creeks
they are vulnerable to collection for food (Hurd et al., 1979; Burger, 1989; Seigel & Gibbons, 1995). Natural mortality on eggs includes predation (about 58–60%), dune erosion and tidal inundation, inappropriate incubation temperatures, and root damage (Burger, 1977). Mortality on hatchlings includes predation and failure to find the surf (Burger, 1976b). Mortality on juveniles and adults includes predation and starvation.

Anthropogenic mortality on eggs includes poaching and disruption by beachgoers, beach encroachment and nourishment, and increased rates of natural and introduced predators due to the presence of food. Anthropogenic mortality on juveniles and adults includes damage due to boat motors, entanglement in plastic, fishing gear, and other debris, and collection for food or sport (Burger, 1989; Seigel & Gibbons, 1995). Thus, diamondback terrapins are exposed to a number of hazards, both natural and human-induced.

There are few data on the effects of toxic chemicals on diamondback terrapins. However, since they are long-lived, they could bioaccumulate toxic chemicals during their lifetime. Diamondback terrapins are vulnerable to oil; an oil spill in New Jersey during the winter resulted in hibernating terrapin emerging from their burrows, soaked with oil. Oil-soaked turtles suffered appetite loss, edema, delayed righting ability, and decreased strength and movement, and only 25% survived (Burger, 1994c).

**Dose Response**

There is a positive relationship between the number of people using nesting beaches and adjacent waters, and declines in terrapin nests and nesting females. The number of females along a study transect on Little Beach Island in Barnegat Bay, New Jersey, steadily decreased from 1973 to 1990, while the human use of associated coastal habitats increased (Figure 2; Burger, 1989, unpublished data; Burger & Gochfeld, 1990). However, during this time period the habitat available for nesting did not change as Little Beach is on the protected Forsythe National Wildlife Refuge. Moreover, since the island is not inhabited and is a wilderness area devoid of people, there has been no obvious increase in natural or human-commensal predators on Little Beach Island. This suggests that the cause of population declines is not nesting habitat loss, but either loss of foraging habitat, increased anthropogenic causes, increased disease or parasites, or increased predation of juveniles and adults in the waters or marsh during the nonbreeding season, or a combination of these factors.

**Risk Characterization**

It seems likely that the causes of the decline relate to changes in their foraging space or food quality, to mortality due to boat motor damage or inadvertent bycatch, or to toxics. Foraging space around Little Beach Island has not changed dramatically over the course of the study, although the quality is difficult to ascertain. The number of injuries on the bodies of nesting females due to boat motors has increased over the study period (from 1–2% in the early 1970s to 12–17% in the 1990s; J. Burger, unpublished data). Some boat injuries seem minor and result in nicks to the carapace, but others result in death or serious injury.

Recent changes in crabbing and fishing gear type have increased the incidental take of diamondback terrapins in New Jersey (Burger, 1989; Garber, 1989, 1990a, 1990b), as well as elsewhere (Seigel & Gibbons, 1995). The New Jersey Endangered and NonGame Species Program is currently investigating methods of decreasing such bycatch with gear changes, and R. Wood has developed a modification for crab traps. At present, the modifications result in a substantially lowered catch of terrapins, but also a slightly lower crab catch (R. Wood, personal communication). This exclusion device has great promise for reducing diamondback terrapin loss. Moreover, unlike the case with sea turtles, the device is being developed before the overall populations decrease precipitously to threatened or endangered status. Nonetheless, the northern diamondback terrapin is now on the U.S. Fish and Wildlife Service's Candidate Species List, meaning it needs study to determine if it is threatened or endangered.

There are few data on toxics for terrapin, but because they are relatively low on the food chain, they are probably not good candidates for toxic effects. Although longevity records are not generally available, Hildebrand (1932) stated that they no doubt live 40 yr or more in the wild. Even with their low position on the food chain, however, living 40 yr might provide
sufficient time for bioaccumulation. At Little Beach Island, the average size of nesting females decreased from 1973 (mean plastron length = 15.4 ± 0.98 cm; Burger, 1989) to 1989–1990 (mean plastron length = 12.8 ± 0.55 cm; unpublished data), suggesting either restricted growth or loss of older females (which could be due to bioaccumulation of toxics). This aspect of risk assessment bears further examination.

It is clear that diamondback terrapins have decreased in New Jersey, and in some other parts of their range (Burger, 1989; Seigel & Gibbons, 1995). Overall concern for their populations has become clear enough to place them on the Candidate List of the U.S. Fish and Wildlife Service. Moreover, the exact mechanism of diamondback terrapin decline at Little Beach is unknown, even though the decline tracked increased exposure to human activities. Thus it is difficult to know how to prevent further declines of this population, and would have been difficult to predict current declines. There remains limited exploitation of this species for food, and this clearly could be prevented by regulation (Garber, 1988; Burger, 1989; Seigel & Gibbons, 1995). Moreover, devices are being developed to prevent the capture of terrapin in crab and other fisheries traps. However, for this to be effective regulations must be passed to ensure compliance.

**Prediction and Prevention**

Given the risk assessment presented earlier, the question of prevention of declines and prediction of the declines is relevant. The recent declines of diamondback terrapin were partially predicted by the decreases in overall habitat for nesting. Open, undisturbed beach and backbay dune habitats decreased markedly in New Jersey, particularly after mosquito control made beaches habitable. Similarly, population declines due to collisions with boats and motors, and capture in crabbing and fishing gear were also predictable. However, the decline of the Little Beach population was not predictable for the following reason: The nesting habitat has remained unchanged, there are not nesting sites, and a large area is not viable for the population. Public awareness of the plight of these smaller coastal turtles might also help.

**SEA TURTLES**

**General Breeding Biology**

The five species of sea turtles that spend some time in U.S. waters include the green turtle (Chelonia mydas), leatherback (Dermochelys coriacea), log-gerhead (Caretta caretta), hawksbill (Eretmochelys imbricata), and Kemp's ridley (Lepidochelys kempi). Although sea turtle females return to their natal beaches to lay their eggs, they spend the rest of their life cycle in estuaries, bays, and the open ocean. Moreover, they migrate many thousands of miles from breeding to feeding grounds to nesting beaches to deposit their eggs. Males make the same migrations as females, although they do not come onto land as adults. Some species may not reach sexual maturity until 20 or 30 yr of age (Frazer, 1983; NRC, 1990). In general females lay about 100 eggs in a nest they dig in the sand. Incubation requires at least 2 mo, and hatchlings must traverse the sand to reach the surf. Once in the surf, they go to sea and feed on a variety of invertebrates and algae throughout their life. Their vulnerability relates to their foraging and migratory behavior and to their habitat usage.

The five species of sea turtles that spend part of their life cycle in the U.S. coastal waters are all endangered or threatened, in part because they were used for food, ornaments, or leather (NRC, 1990). All species of sea turtles and their eggs were eaten for food in the past, and continue to be exploited in some other countries. At present, there is little direct killing or harassment by humans of sea turtles while on land in the United States (Garber, 1988).

**Hazards and Exposure**

Natural hazards to sea turtles include predators, diseases, parasites, other nesting turtles, heavy rain and thermal stress, and erosion and tidal inundation (the latter four hazards act on nests and eggs; NRC, 1990). Predation can occur on eggs and hatchlings on land; hatchlings, juveniles, and adults in the sea; and adults on the nesting beaches (Hirth, 1971; Witzell, 1983; Dodd, 1982). The hazards just listed are all natural hazards that occur in the absence of humans and have exerted selection pressures on sea turtle populations throughout their evolution. Such pressures, however, are not without anthropogenic influence. Because of the presence of food provided by humans, predator numbers have increased dramatically on barrier islands where sea turtles nest (see Burger & Gochfeld, 1990, for a review of the problem).

There is also a high mortality associated with human activities that include shrimp trawling and other fisheries, beach development, dredging, entanglement (fishing lines, boats, power plants), oil-related activities, collisions with boats, beach activities (lighting, replenishment, vehicles), ingestion of plastics and debris, and toxics (NRC, 1990). There are almost no data on the effects of toxic chemicals in sea turtles, although plastics and other floating objects pose problems. These items, which the turtles view as food, clog their digestive tracts (Platkin & Amos, 1989). Sea turtles will also ingest oil droplets and tar, but there is very little data on the effects of such ingestion (Lutz & Lutcavage, 1989). Nonetheless, the adverse effects of toxics on sea turtles and the resultant risks to populations are largely unknown.
In a recent review of mortality in sea turtles, the National Research Council (1990) concluded that the highest relative cause of mortality on juveniles, subadults, and adults was shrimp trawling, while the highest cause of mortality on eggs and hatchlings was nonhuman predators. Recent population analyses by Crouse et al. (1987) with loggerhead sea turtles indicated that the greatest increase in growth rate of a population could be achieved by increasing the survivorship of large juveniles and subadults, and not by increasing survivorship of eggs or hatchlings. Thus it follows that shrimp trawling is a major cause of the sea turtle decline or continued low population levels (NRC, 1990).

**Dose Response**

The National Research Council committee demonstrated a clear dose-response relationship between the number of dead or comatose sea turtles and the mean tow time for shrimp trawls, and between the number of stranded turtle carcasses and the shrimp fishery (NRC, 1990). Further evidence includes increases in turtle mortality when the shrimp fishery is active in a given coastal region, and declines in turtle mortality when the fishing ceases.

**Risk Characterization**

Unlike the other two cases discussed, the risks to sea turtle populations worldwide have been examined extensively. Causes of declines relate directly to the incidental mortality due to shrimp trawling and other fishing techniques, mortality or weakening due to toxics and plastics, nesting habitat loss, poaching of eggs and laying females on nesting beaches, and predation of eggs and hatchlings (often increased by increases in human commensal predators such as fox and raccoon).

**Prediction and Prevention**

Given the risk assessment presented briefly for sea turtles, it seems likely that population declines due to adverse human effects (both fishing and direct take for food) could have been predicted. Indeed, many authors noted the importance of human effects on sea turtle populations well before actions were taken to reduce human take directly or to prevent losses during shrimp trawling (Bullis & Drummond, 1978; Henwood & Stutz, 1987). In the latter case, however, regulations to prevent mortality by the use of turtle excluder devices were slow in enactment and enforcement because of potential monetary costs and catch losses to the shrimp fisherman. The data presented by the NRC (1990) make a persuasive case that losses due to shrimp trawling can be reduced or prevented with the use of turtle excluder devices. This will not prevent all losses due to fisheries, or to other natural causes, but will go a long way toward reversing the declining population trends of some sea turtles. Within U.S. coastal waters, turtle excluder devices are now required for shrimp trawling.

**COMPARISON AMONG THE THREE CASE STUDIES**

There are some commonalities among the three cases: population declines are evident, natural causes of mortality are known, anthropogenic causes of mortality are known and are important causes of population declines, and turtles are vulnerable during all life stages. Adults are primarily vulnerable to anthropogenic rather than natural causes of premature mortality. Moreover, there is currently no evidence that toxic chemicals have played a key role in the decline of any of these turtle species, although plastics and oil have been demonstrated as a cause of injury and mortality in sea turtles. Moreover, given their relative longevity, it is not unreasonable to assume that the potential exists for toxic bioaccumulation, although their low position on the food chain lessens the risk.

The relationship between habitat, life cycle, and some hazards common in all three case studies is shown in Figure 3. The hazards are very similar for diamondback terrapins and sea turtles. However, for wood turtles, habitat loss and human disturbance extend throughout the life cycle, and may indeed be the overriding causal factor in their decline. In addition, bycatch has been a much more severe hazard for sea turtles than for diamondback terrapins, although the new crab traps may take their toll if excluder modifications are not made. Lastly, predators are less of a threat to adult sea turtles than to adults of the other species. As all three species are relatively long-lived, the emphasis on protection should be concentrated on older juveniles and breeding females (Crouse et al., 1987).

There are, however, some notable differences among the cases. Because of their high visibility, large size, and obvious source of anthropogenic mortality, sea turtles have received much more attention in terms of documentation of the hazards and dose-response relationships, and in terms of preventative measures. Dose-response data are clearly available for shrimp fishing activities and sea turtle mortality, but are less available for the other species. In the wood turtle and diamondback terrapin examples, there was a clear dose-response relationship between increasing human activities and decreasing turtle populations, but the mechanism is not documented. We believe that the ecological risk assessment paradigm, whereby one examines hazard identification, exposure assessment, dose-response relationships, and risk characterization for a species, can provide a useful framework for examining population changes in turtles, as well as other reptiles. We also suggest that considering whether the population changes could have been predicted and prevented is a useful exercise that will help understand, monitor, and conserve other populations of reptiles.

Finally, we note that ecological risk assessment is usually conducted within the confines of the environmental decision-making process, and it has a clear role in strategic planning (NRC, 1993). The definition of risk assessment does not include preservation or restoration goals. Ecological risk assessments often cannot compute a quantitative estimate equivalent to the lifetime cancer-
risk estimates used in health risk assessments (NRC, 1993). Nonetheless, the importance of examining ecological problems in a risk assessment paradigm cannot be underestimated. Not only does it provide consistency, but it ensures that the assessment is science-based, rather than management- or value-judgment-based. Further, it will help identify the hazards that affect populations, allowing for reasonable protection and management.

REFERENCES

RISK ASSESSMENT FOR DECLINING TURTLE POPULATIONS


